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Rakas, Marija

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MODES OF INNOVATION IN FIRMS AND NATIONAL SYSTEMS OF INNOVATION

BY
MARIJA RAKAS

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MODES OF INNOVATION IN FIRMS AND NATIONAL SYSTEMS OF INNOVATION

By

Marija Rakas

Department of Business and Management

Aalborg University, Denmark

AALBORG UNIVERSITY
DENMARK

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PhD supervisor: Associate Professor Ina Drejer
Aalborg University

PhD committee: Associate Professor Jesper Lindgaard Christensen (chair.)
Aalborg Universitet

Professor Stephen Roper
The University of Warwick

Professor Helena Lenihan
University of Limerick

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CURRICULUM VITAE

Marija Rakas

Marija Rakas is a PhD Fellow at the Department of Business and Management, Aalborg University, Denmark, and is associated with the Innovation, Knowledge, and Economic Dynamics (IKE) research group, and the Danish Research Unit for Industrial Dynamics (DRUID) society. She currently holds a M.Sc. in Innovation Economics from Aalborg University (Denmark) and M.Sc. in Economics from the University of Novi Sad (Serbia). Her research interests are in the broad field of innovation studies with the particular focus on the nature and the dynamics of modes of innovation in firms, the nature and the evolution of innovation systems, and the nature and the evolution of the knowledge bases in interdisciplinary research fields.

The papers written during her PhD have been presented at several international conferences and workshops. One of the co-authored papers is published in *Research Policy*.

From October 2017 until January 2018, as part of her PhD program, she was a guest researcher at INGENIO (CSIC-UPV), a joint research centre of the Spanish National Research Council (CSIC) and the Polytechnic University of Valencia (UPV). There, she presented her work at the INGENIO's internal seminar series, and participated in various visiting scholar seminars.

During her PhD time, she lectured on group work and project management, and text analysis and sources management, and supervised projects on bachelor and master level. She has also assisted in the organization of the IKE group seminar series.

SUMMARY

This thesis examines innovative firms' behaviour – including their modes of innovation, the broader environment in which firms are embedded in the context of national economies and the national or temporal differences therein – from an innovation systems perspective. The main argument from systems approaches to innovation in the innovation studies field of research is that innovative firms' behaviour and performance can be understood only in relation to the environment in which innovation processes take place. The environment comprises the internal organisation of firms, as well as linkages between firms and between firms and the knowledge infrastructure, which shape learning and knowledge creation and, thus, innovation. This environment also includes the broader setting, such as socioeconomic and political factors, institutional and organisational set-ups and the processes that shape firms' behaviour. Taken together, the broader environment is viewed as having a decisive impact on firms' organisation and innovation modes. This overall environment, in turn, is perceived to be specific to the regional or national context, but also dynamic in terms of being amenable to change over time. This thesis sets out to explore the following broad questions: i) How innovation takes place inside firms and between firms and organisations, across countries or over time; ii) how different elements or features of the wider setting (nation-specific institutions and/or government policies and generic processes), in which firms' innovation activities take place, are related to each other in a systemic way; and iii) how alternative (nation-specific institutional and policy-related) set-ups support (or hinder) and are related to innovation and competence building in firms and a nation's technological performances. In addition, this thesis explores the boundaries, current state and the direction taken over time within the innovation system (IS) field of research in terms of distinct research areas, knowledge bases and the underlying processes of knowledge integration.

In this thesis, firms' innovation modes and the wider setting in the context of national economies are studied in and of themselves, or they are brought together in a unifying framework. Differences in innovation modes used by firms during the 2002-2015 period and different innovation modes'

temporal dynamics are analysed in a single country, Denmark. Furthermore, firms' innovation modes and the wider setting are examined in the contexts of six small European countries (Bulgaria, Estonia, Lithuania, Hungary, Portugal and Norway), where country(s) groups based on national institutional profiles are identified and related to the most dominant innovation modes to assess proposed relationships between institutional setups and innovation modes. Finally, the wider setting in the national context in this thesis also is defined as environmental conditions – or processes – for firms' abilities to generate technological dynamics, i.e., innovation, diffusion and use of technology, and for a nation's technological dynamics. Here, the problems or hindering factors related to knowledge generation, skills, demand, finance and institutional processes are identified, and broad mapping of countries at the EU level in terms of patterns of perceived problems or weaknesses in systems' activities, and how these patterns have changed during the 2002-2010 period, are pursued.

The findings from three chapters show that heterogeneity in the way that firms innovate and differences in modes across countries are present, as well as cross-country differences in institutional patterns, including a broader set of both formal and informal institutions, and in terms of broad patterns of identified system problems. This thesis also provides some support for the idea that countries' differences in the prevalence of dominant innovation modes are reflected in specific institutional profiles of countries. Finally, the country-specific patterns as to which innovation modes are prominent, and the cross-country patterns of environmental conditions for innovation in terms of weaknesses, can and do change when looking at different points in time, albeit rather slowly and following country-specific paths. These insights suggest that national innovation systems, especially their broader national settings, are an important context for explaining differences in firms and countries' predominant innovation modes – and potentially countries' innovation and economic performance – that need to be taken into account when analysing national innovation systems and their innovation performances, as well as when designing and implementing innovation policy.

RESUME

Denne afhandling undersøger innovative virksomheders adfærd – herunder virksomhedernes innovationsmåder, og betydningen af den nationale kontekst, som virksomhederne opererer i. Der sættes også fokus på nationale forskelle og ændringer over tid i virksomhedernes innovationsadfærd. Afhandlingen tager afsæt i et innovationssystem-perspektiv. Inden for innovationsstudier er det ud fra system-tilgangen et hovedargument, at innovative virksomheders adfærd og performance kun kan forstås ud fra den kontekst, som innovationsprocesserne foregår inden for. Konteksten består af virksomhedens interne organisation, samt af forbindelser mellem virksomheder og mellem virksomheder og den vidensinfrastruktur, som påvirker den måde hvorpå læring og vidensopbygning - og dermed innovation - foregår. Konteksten omfatter også de bredere rammer, såsom socio-økonomiske og politiske faktorer, institutionelle og organisatoriske set-ups, og de processer, som påvirker virksomhedernes adfærd. Samlet set anses den bredere kontekst for at have en betydelig indflydelse på virksomhedernes organisering og innovationsmåder. Den bredere kontekst anses for at være specifik for den enkelte region eller nation, men også for at være dynamisk i den forstand, at den kan tilpasse sig til ændringer over tid.

Med afsæt i ovenstående undersøger nærværende afhandling følgende overordnede spørgsmål: i) Hvordan foregår innovation internt i virksomheder, mellem virksomheder og organisationer, enten på tværs af lande eller over tid, ii) hvordan er forskellige elementer eller karakteristika ved de bredere omgivelser (nationalt-specifikke institutioner og/eller offentlige politikker og generiske processer), inden for hvilke virksomhedens innovationsaktiviteter finder sted, systemisk relateret til hinanden, og iii) hvordan understøtter (eller modvirker) forskellige (nationalt-specifikke institutionelle og policy-relaterede) rammer innovation og kompetence-opbygning i virksomheder, og hvordan er de relaterede til en nations teknologiske performance. Herudover undersøger afhandlingen innovationssystemer (IS) som forskningsfelt, med fokus på feltets aktuelle status, hvordan det har udviklet sig over tid i forhold til distinkte forskningsområder, vidensbaser, og underliggende processer i relation til vidensintegrering.

I afhandlingen undersøges virksomheders innovationsmåder og den bredere kontekst i form af nationale økonomier både isoleret og i en bredere ramme, som rummer flere nationale økonomier. Afhandlingen undersøger forskelle i virksomheders innovationsmåder over perioden 2002-2015, og samt forskellige innovationsmåders tidsmæssige dynamik i et enkelt land, Danmark. Herudover undersøges virksomheders innovationsmåder og den bredere kontekst for seks små europæiske lande (Bulgarien, Letland, Litauen, Ungarn, Portugal og Norge), hvor landegrupper identificeres på baggrund af det nationale institutionelle set-up, og efterfølgende kobles til dominerende innovationsmåder med det formålet at vurdere mulige relationer mellem institutionelle set-ups og innovationsmåder. Endelig defineres den bredere nationale kontekst i denne afhandling også som de betingelser – eller processer – som påvirker både de teknologiske dynamikker i virksomheder i relation til innovation, spredning og anvendelse af teknologi, og de teknologiske dynamikker på nationalt niveau. I den forbindelse identificeres udfordringer eller barrierer relateret til vidensgenerering, adgang til og udvikling af kompetencer, efterspørgsel, finansiering og institutionelt setup, med det formål at foretage en overordnet kortlægning af EU-lande i relation til mønstre for oplevede udfordringer og svagheder i innovationssystemet, og hvordan disse har ændret sig over perioden 2002-2010.

De tre kapitler i afhandlingen, der er baseret på innovationsdata, illustrerer heterogeniteten i den måde, hvorpå virksomheder innoverer, forskelle i innovationsmåder tværs af lande, nationale forskelle i institutionelle set-ups (med fokus på både formelle og uformelle institutioner), samt overordnede mønstre i systemudfordringer. Afhandlingen underbygger også den opfattelse, at nationale forskelle i den dominerende innovationsmåde afspejler landenes specifikke institutionelle set-up. Endelig påvises det, at de landespecifikke innovations-mønstre kan ændre sig over tid, selv om udviklingen er langsom og følger lande-specifikke spor. Disse resultater indikerer, at nationale innovationssystemer, i særdeleshed den bredere nationale kontekst, spiller en vigtig rolle for at forklare forskelle i virksomheder og nationers dominerende innovationsmåder – og potentielt også landes innovations- og økonomiske performance – og dette skal tages i betragtning, både i forbindelse med analyser af nationale innovationssystemer og deres innovationsperformance, samt når der skal designes og implementeres innovationspolicy.

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I also had great pleasure of co-authoring one of the papers in this thesis with Daniel Hain (IKE, Aalborg University). Thank you for your excellent contribution, cooperation, and tireless effort extended during the various stages of processing of the manuscript for publication. I hope that the cooperation with authors will continue in the future.

The work that comprise this thesis has been presented at various international conferences and seminars. I very much appreciate all the time and effort that has been put into helping me improve my work. For their suggestions and constructive criticisms, I thank the discussants and other participants at the DRUID Winter Conference 2016 in Bordeaux, and 2017 and 2018 in Odense, the DRUID Summer Conference 2016 in Copenhagen, the Schumpeter Conference 2016 in Montreal, and finally, the participants at the KID (Knowledge Dynamics, Industry Evolution, Economic Development) Summer School in Nice in 2017.

As part of the PhD program, I spent two months at INGENIO (CSIC-UPV), a joint research centre of the Spanish National Research Council (CSIC) and the Polytechnic University of Valencia (UPV), Valencia, Spain. I am very grateful for the opportunity to present my work and to interact with both senior and junior researchers working in a broad area of innovation related fields. Thank you for all your comments and suggestions. Special thanks goes to my two former office colleagues, Irene Ramos Vielba and François Perruchas, for the input to my project and for the great time I have had in Valencia, and to Pablo D' Este, for hosting me at INGENIO, and for taking time to meet with me and to discuss my research.

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Many thanks to all the fellow PhD students of the IKE group and those that have already finished, that I had most of my lunches (and the countless number of coffees) with over the years. During these lunch talks we discussed almost everything ranging from our in-progress research work and ideas to life issues and advices. My years as a PhD student would have been less inspiring and joyful without you. Many thanks to Daniel Hain, EunKyung Park, Roman Jurowetzki, Jesper Eriksen, David Fernández Guerrero, Gerwin Evers, Leticia Antunes Nogueira, Nazanin Eftekhari, Juan Martin Carriquiry, and Primoz Konda. I would also like to extend my gratitude to my friends outside academia who have shown interest in my research, and supported me during this journey.

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Marija Rakas
Aalborg, February 2020

LIST OF INCLUDED PUBLICATIONS

Chapter 1 **Synopsis**

Chapter 2 **The State of Innovation System Research: What Happens Beneath the Surface**

Marija Rakas, Daniel S. Hain
Research Policy, 2019; 48(9): 103787

Chapter 3 **Assessing Weaknesses in National Innovation Systems**

Marija Rakas
Manuscript

Chapter 4 **Institutional Context and Modes of Innovation in National Systems of Innovation: A Study of Six Small European Countries**

Marija Rakas, Ina Drejer
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Chapter 5 **Continuity and Changes in Modes of Innovation**

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CHAPTER 1

I Synopsis

1. Introduction

This thesis explores the behaviour of innovative firms, including the modes of learning and innovation, the wider setting in which firms are embedded in the context of national economies and the national or temporal differences therein from a systemic perspective. National Innovation Systems (NIS) literature is mainly concerned about understanding the socio-economic, institutional and infrastructural conditions within countries (national context) and how these shape processes of learning and innovation at the micro-level as well as the technological dynamics of a nation, and how countries differ according to national context as well as how different modes of innovation are combined. With the objective of making a contribution to parts of the NIS literature and debates where certain gaps still exist, this thesis sets out to explore the following broad questions: i) how innovation and competence building takes place inside firms and between firms and organisations, and across countries or over time (nation-specific modes of learning and innovation), ii) how different elements or features of the wider national contexts (nation-specific institutions and/or government policies and generic processes) in which innovation activities of firms take place, are related to each other in a systemic way, and iii) how alternative (nation-specific institutional and policy-related) set-ups support (or hamper) and are related to innovation and competence building in firms and the technological performances of a nation.

The above questions are of great relevance for policy makers who wish to analyse and influence the innovation process. Today, there is a general consensus that the capability of firms and countries to innovate and to bring innovations successfully to market is the main driver of the competitiveness of firms as well as the economic progress and social welfare of countries, both advanced and emerging (OECD, 2015a). For instance, at the national level, innovation is seen as a major source of new enterprises, new jobs, and productivity growth, and thus an important driver of economic growth and development. In addition, innovation is increasingly seen by both policy makers and scholars as a potential main factor that can help address global and social challenges such as the environment, immigration and health (Fagerberg et al., 2016; Lundvall, 2016; OECD, 2015). For all these reasons, strengthening innovation in firms as well as fostering environmental conditions that are conducive for innovation, and harnessing innovation for meeting current challenges, is a high priority for both national governments and in the broader context of European Union and OECD countries. This view is also reflected in the central role as well as broader understanding of policy for innovation in the recent Organization for Economic Organization and Development Innovation Strategy report (2015). From a political and economic perspective, improving the knowledge on how firms innovate and about how the national condition shapes these processes as well as the innovation performance, and whether there are important national systemic differences across countries is of crucial importance.

The emergence of NIS literature and the main issues it addresses

When it comes to the academic work on the processes and roles of innovation in the economy, how these might be studied, and how institutions and policies might influence these at the national level, the NIS literature plays a prominent role. The important work on the specific subject of NIS appeared at the end of the 1980s and the beginning of the 1990s and is associated with three approaches to an understanding of the innovation and economic performance at the national level (Christopher Freeman, 1987; B.-A. Lundvall, 1992; Nelson, 1993). At that time, the background of the discussion on national innovation systems can be traced back to the empirical observation that patterns of innovative activities[1] display systematic differences and relatively high degrees of persistence over time (Cefis & Orsenigo, 2001; Dosi, 1999). These findings suggested

[1] As defined by the indicators of corporate capabilities, organizational forms, strategies and revealed performances (innovation and economic), and measured at the level of sectors and countries.

that country-specific institutions and economic histories matter are influential in terms of explaining the observed patterns of innovative activities. Relatedly, the very beginnings of comparative empirical work on NIS is associated with assessing differences and similarities between 15 countries in terms of the institutions and mechanisms (elements of the NIS) that support technological innovation and how they came to be (Nelson, 1993). This work also included a preliminary discussion on the extent and manner in which these differences matter in explaining variation in the rate and the direction of the technological changes, and ultimately of countries' economic performance. The example of this early work includes explaining differences in patterns of innovation activities between Denmark and Sweden, such as input (R&D) and output (patents) measures by qualitative differences in national innovation systems (socio-institutional setting and economic structure), which in turn stem from the historical processes of industrialisation as well as more contemporary factors such as the degree of economic concentration and the role of multinational capital (Edquist and Lundvall, 1993).

The main finding from the collection of comparative work on NIS was that countries that are effective in terms of innovative performance have several features in common, of which the highly competent firms are the key. All other features refer to the environment in which firms operate that positively affects their ability and incentives to innovate and compete. Among these features are the responsive educational and training system, demanding set of home market customers, strong upstream-downstream linkages, strong competition, and the package of the fiscal, trade and monetary policies. Overall, the early approach to studying innovation systems can be characterised as historical in terms of explaining what made an innovation system and the firms within it effective in the sense that it contributed positively to the economic performance, as put by Nelson (1993). Cirillo et al. (2018) provides a recent quantitative analysis of a variety of successful NIS in terms of its innovation capabilities (and science and technology dynamics at the country level on a historical perspective), including a bigger number and variety of countries.

The approach followed by Freeman (1987) in the qualitative analysis of the single national innovation system of Japan can be characterised as mainly focusing on the network of public and private institutions whose activities and interactions are intended to initiate, import, modify, and diffuse new technologies and the ways in which the resources are organised and managed at the enterprise, the industry, and the country level, including the organization of R&D and production in firms, the relationships between firms and the role of the government. Finally, Lundvall's (1992) theoretical or conceptual contribution on the subject is best characterized as focusing on user-producer linkages rooted in the industrial structure of the national economies and interactive learning as a basis of innovation. What is common to all three early approaches to NIS is an understanding of innovation as an interactive process and that national context has a major impact on shaping the conducts and performances of the firms and countries.

These contributions have been highly influential among both policy makers and the academic community, setting the direction for the subsequent work constituting the innovation system (IS) field of research as of today, as well as influencing scholars working in different subject areas from a broad range of disciplines such as management and economics, including cross-disciplinary fields such as planning and development, among others (J. Fagerberg, Fosaas, & Sapprasert, 2012). As a consequence, understanding the boundaries, the current state and the direction taken over time within the IS field of research in terms of distinct research areas and the underlying processes of knowledge integration is a task that deserves research in itself. I have taken up this work in Chapter 2 of this thesis.

The rest of this introductory section contextualises and outlines the two main directions in the development of the NIS approach, mainly connected to the Aalborg version (B.-A. Lundvall, 1992) since the 1990s, and focuses more narrowly on the exemplary contributions of scholars working on the specific subject of national systems of innovation, since these have been given a great deal of attention in NIS and related literature, and in this thesis. The first direction concerns the extension of the Aalborg version of the approach to studying NIS(s), but especially based on contributions from the mid-1990s and the period 2000-2010, as part of a long-term research program for advancing the understanding of the importance of knowledge and learning for innovation and economic performances of countries, and in particular to the role of a broader set of institutions (B.-A. Lundvall, 2016)[2]. The second direction includes the work by scholars that have

[2] Lundvall (2016) presents three broad groups of work that in his opinion over the period of 30 years (1985-2015) have contributed to further advances in the understanding of the learning economy as a phenomena, where knowledge and

developed a novel approach to studying NIS, known as the "activities" approach that emerged in the 2000s, with the view to make the approach more useful for policy purpose and for advancing the understanding of the (in)effectiveness of activities or processes in innovation systems (Edquist, 2005; Furman, Porter, & Stern, 2002; Liu & White, 2001). I discuss each in turn with the view to point to areas where further research is needed.

First direction

In the mid-1990s, the importance of innovation for economic performance has been reinforced with the discussion on the emergence of the so-called "knowledge-based" economy[3]. Within this discussion the literature on national systems of innovation has introduced an alternative term, "learning economy", arguing that what is new about the phenomena has less to do with the growing quantity of the economically useful knowledge and the significance of the codified and scientific knowledge than with the rapidity of change in the process of the creation and destruction of knowledge (B. Lundvall & Johnson, 1994; OECD, 2000). Some of the early evidence put forward to account for these phenomena at the firm level includes the development and widespread use of information and communication technology (ICT), growing flexible specialisation of the

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learning are recognized as crucial for innovation and economic performance of countries. These three broad thematic groups of work are about: i) innovation as an interactive process and national innovation systems (from the period 1985-1995); ii) knowledge creation and the characteristics of the learning economy (2000-2010); and iii) the innovation system in the context of the learning economy.

[3] The terms "knowledge-based" or "knowledge-intensive" economy have entered the political and academic discourses as a way of describing the "new" economy in which knowledge is the most important economic resource in terms of increasing in importance in aggregate investment as compared to capital and labour (Smith, 2000). Besides this view, there were three other approaches to the "knowledge-based" economy, as pointed out by Smith (2000). One alternative view was that knowledge is most important as a product, pointing towards the new forms of activities specialized in trading knowledge products such as knowledge-intensive business services. Another perspective emphasised the significance of the codified knowledge in the composition of economically useful knowledge as exemplified with the increase in reliance on this type of knowledge as a basis of economic activities and its contribution to economic growth. Finally, the phenomena "knowledge-based" economy has been related to the technological changes in information and communication technology (ICT).

production and the accelerating rate of the processes of innovation (B. Lundvall & Johnson, 1994). The increasing rate of the innovation and change has been related to both technological and market opportunities opened up by the new scientific and technological advances and the intensification of the international competition (Lundvall & Borrás, 1997; OCED, 2000).

Several analytical concepts in relation to distinct kinds of knowledge and learning processes in the economy such as the “learning by searching” and “learning by doing, using and interacting” have been further developed, the distinction of which was considered important in the context of the learning economy (Lundvall and Borrás, 1997). The importance of the distinction in the context of the learning economy refers to the understanding that all kinds of knowledge are combined in the innovation process and that learning potential is present in all economic activities and is not limited to the high-technology sectors and firms (B. Lundvall & Johnson, 1994). In this perspective, the opportunity and the capacity of firms and people for interactive learning are seen as a necessary precondition for both adapting to changes in markets and technologies and achieving innovation. Based on the further understanding of different kinds of knowledge and learning, the original concept of NIS has been revised.

One of the core arguments from the early contributions to the NIS conceptualisation (the Aalborg version) is that firms’ innovation behaviours (conduct or strategies) and performances cannot be explained without the reference to the environment that influences its conduct and performances. Moreover, it is suggested that this environment can be broken down into user-producer relationships which in turn follow from the idea that innovation is an interactive process. The main function of these relationships in relation to innovation is access to information and knowledge about the technological opportunities and market needs as inputs to the learning and innovation process. From this follows those important aspects of firms’ innovation strategies that are related to user-producer relationships. Initially, the user-producer relationships referred to forward and backward linkages between users and producers (firms) in the production system of the national economy. The concept of user-producer relationships was broadened in the later theoretical and empirical work to include other interactions such as those between industry and science and technology infrastructure, as well as those between industry and final or end users such as workers, customers and the public sector. Finally, internal user-producer relationships referring to different organisational arrangements and practices adopted by firms were also added. The major role of these relationships in relation to innovation is interaction and communication between departments and workers' access to learning. Moreover, greater attention is given to a set of institutions and organisations outside the enterprise that influence knowledge generation and use as well as competence building in areas such as the labour market, education and working life, compared to original conceptualisation.

The examples of empirical work in the NIS literature that expand on the original approach to studying NIS(s) as presented above are reflected in the two empirical contributions from the period 2000-2010. More specifically, the authors have investigated how different forms of work organisation adopted by firms are related to the distribution of innovation modes in a nation, within the context of 15 EU countries (Arundel, Lorenz, Lundvall, & Valeyre, 2007). They show that the distribution of different modes of work organization and innovation is highly specific to individual nations. This work indicates that the systemic features distinguishing taxonomic categories reside in organisational structures. Another seminal contribution has emphasised the importance of various factors, grouped into two modes of learning (STI and DUI mode) for a better understanding of differences in innovative performance between firms and countries. These factors include interactions with suppliers and customers, cooperation with researchers, forms of "open innovation" and feedback mechanisms from the market, including R&D and skilled scientists and engineers (Arundel et al., 2007; Jensen, Johnson, Lorenz, & Lundvall, 2007). This study shows that the distinction between the two modes of learning is important for explaining differences in the innovation performance of firms, at least in the Danish context.

Second direction

In relation to the second direction, scholars in the NIS literature have developed a new approach to studying NIS mainly focusing on identifying factors that shape the technological dynamics of the whole system. The novelty of the approach consists in broadening the analysis from the institutions, organisations and the interactions to the set of activities or processes that are important for the development and diffusion of innovation at the system level. The approach is usually labelled as activities or a process perspective in NIS (Bergek, Jacobsson, Carlsson, Lindmark, & Rickne, 2008; Edquist, 2005; Liu & White, 2001). The central focus is on the relationship between the processes and the outputs of the national system of innovation, as the policy has a greater say in comparison to the original approaches.

A wealth of scholarly publications in NIS and related areas of research and the developments of the NIS approach as reflected in theoretical, empirical, and policy-based contributions, have contributed to a better understanding of the behaviours of innovative firms within countries and the aspects of national framework conditions that affect the innovation activities of firms. However, a number of questions remain unresolved. First, most studies analyse firms' modes of innovation from a static perspective, while questions such as whether and how firms' modes of innovation change over time are largely missing. In addition, most of the existing studies on firms' modes of innovation are conducted at the level of a single country, thus limiting an understanding of whether the firms' modes of innovation differ in various national contexts. The taxonomic work on differences in the modes of innovation of firms, on its own right, is important on both positive and normative grounds. In relation to enhancing the academic knowledge, a better understanding of the firms' modes of innovation at the country level helps in understanding and answering some comparative empirical questions, such as how different modes are represented in the same innovation system at different points in time, and how different modes are combined in different national innovation systems, and whether national context matters in explaining these differences. In respect to the policy matters, the more nuanced understanding of the varieties of the mode of innovation of firms in the national contexts in which firms operate and innovate at different points in time directs attention to questions of importance to innovation policy. I have taken up these issues in Chapters 4 and 5 of this thesis.

Second, the broader set of national institutions or “the rules of the innovation game” that are fixed at the national level in areas such as the labour market, and the variety of institutional set-ups within different countries and their relation to firms' modes of innovation is not sufficiently investigated in the NIS literature. The NIS literature suggests that national specific labour market institutions will shape how firms located in a country generate, disseminate and use knowledge. However, it remains open to further empirical investigation whether and how differences in the national institutional settings reflect differences in countries' specific modes of innovation. For example, are there differences in the prevalence of different modes of innovation across countries? Are different institutional profiles of countries related to differences in the prevalence of different modes of innovation? Are specific variables reflecting institutional differences among the countries associated with the prevalence of more interactive modes of innovation? To the extent that the differences in the prevalent modes of innovation are present and reflected in the specific institutional profiles of countries, would suggest that national innovation systems, but especially its broader institutional setting[4], are an important context for explaining differences in firms' and countries' predominant modes of innovation, and potentially the innovation and economic performance of countries that need to be taken into account in research as well as when designing and implementing innovation policies. I have taken up these questions in Chapter 4 of this thesis.

Finally, there is limited understanding at the empirical level about the differences between countries and varieties in the framework conditions - institutional and policy related - that hamper (or support) technological performances of the whole system, as understood from the activities perspective on NIS. This understanding of the environment in which innovation takes place is needed in order to obtain a better understanding of the systems' specific problems or weaknesses. While indicators based on aggregate data from innovation surveys as well as other data sources on the innovation performance of countries (e.g., European Innovation Scoreboard) in areas such as education, research system and finance, are informative in regards to the relative strengths and weaknesses of countries in comparison to other countries, they are not well suited to capture the relevance of the environmental conditions for firms that operate and innovate within, which is of great importance for policy purposes. The need for a better understanding of the context in which firms operate is also emphasised in the new edition of the Oslo Manual (OECD, 2019). The aspects of this issue are explored in more detail in Chapter 3 of this thesis.

Brief overview of the thesis

The papers contained in this thesis investigate various aspects of a broader set of issues mentioned above, with the view to help fill the above presented gaps. It starts with Chapter 2 that investigates the topic of the

[4] Institutions refer to norms and habits that shape modes of interaction and innovation outcomes.

evolution of IS as a field of research. Chapter 2 of this thesis can be seen relevantly to all other papers in this thesis as it can provide an illustration of how the papers presented in this thesis overlap with and embrace other streams of literature contributing to a better understanding of innovation processes from a systemic perspective. In the remaining three chapters, I have analysed the characteristics and the dynamics of the innovation activities of firms in a particular country (Chapter 5) as well as cross-country differences in the prevalence of particular innovation activities of firms (Chapter 4). In Chapter 5, the idea is to try to link the identification of national modes of innovation in a static sense with the study of the consistency and evolution in the national innovation system over time. On the other hand, in Chapters 3 and 4 the role of the differences in the national context for the innovation activities and business strategies of firms are explicitly considered. These contexts are: the countries' general characteristics (e.g., population size, economic wealth, etc.), the structural characteristics and the infrastructural features of NIS related to innovation performance (e.g., R&D and other innovation expenditures and the populations' education levels), as well as the institutional character of NIS (e.g., labour market organisation, level of trust) and the generic processes in NIS (e.g., provision of skills).

The following section introduces the IS concept which is the common point of departure of the four empirical papers in this thesis where it serves as an object of the study itself (Chapter 2) or as a broad approach for empirical analysis of the behaviours of innovative firms – the firms' modes of learning and innovation and/or the environmental conditions in the context of national economies (Chapters 3, 4 and 5).

2. Theoretical considerations

This section starts with a brief overview of the initial conceptualisations of the National Innovation System (NIS), followed with the presentation of the basics of the broad approach to innovation system analysis as adopted in this thesis. I then discuss how the broad IS approach to innovation is reflected in the separate papers of this thesis and how it is used for the analysis. The rest of this section provides the definitions, theoretical background concerning the key elements of this thesis (i.e., innovation modes) and the environmental conditions in the national contexts and relates them to the more recent advances in innovation systems research.

2.1. NIS

Initial conceptualization of NIS

While several available definitions of the innovation system (IS) concept exist in the current innovation studies literature, I start with the initial conceptualisations of NIS commonly attributed to Christopher Freeman, Richard Nelson, and Bengt-Åke Lundvall (J. Fagerberg & Sapprasert, 2011). This is due to the fact that these are the points of the research's departure on national innovation systems. In addition, these works hold a central position in the broader context of innovation system research (Fagerberg and Sapprasert, 2011). The following brief comparison between the original versions of the NIS concept in Table 1 is taken from Chapter 2 of this thesis, where the comprehensive bibliographic overview of the current state of IS as a field of research is given (Rakas & Hain, 2019).

In a nutshell, Table 1 shows the differences between the approaches with respect to the definitions of the NIS concept itself as well as accompanying terms such as "systems" and "innovation". Moreover, it can be seen that a main focus of the analysis, as well as the elements of the system included in studying NIS, differ between the approaches. These differences partly stem from the variations in the theoretical foundations and empirical backgrounds that inspired the development of the concepts.

Table 1. Comparison between the original versions of the NIS concept

	Freeman, C. (1987)	Nelson, R. R. (1993)	Lundvall, B. Å. (1992)
Concept definition	*"The network of institutions in the public and private sectors which activities and interactions initiate, import, modify and diffuse new technologies may be described as 'the national system of innovation'.* (p. 1)	*"[...] a set of institutions whose interactions determine the innovative performance, in the sense above, of national firms.* (p. 4)	*"[...] all parts and aspects of the economic structure and the institutional set up affecting learning as well as searching and exploring - the production system, the marketing system and the system of finance present themselves as sub-systems in which learning takes place."*(p. 13)
Term "System"	Not explicitly defined	*"[...] a set of*	*"[...] a system of innovation*

		institutional actors that, together, plays the major role in influencing innovative performance."(p. 4-5)	*is constituted by elements and relationships which interact in the production, diffusion and use of new and economically useful, knowledge and that a national system encompasses elements and relationships, either located within or rooted inside the boarders of a nation state."*(p. 2)
Term "Innovation"	*"[...] continuing process of technical change, involving the introduction of new and improved products and novel ways of organizing production, distribution and marketing."* (p. 1)	*"[...] the processes by which firms master and get into practice product designs and manufacturing processes that are new to them, if not to the universe or even to the nation."* (p. 4)	*"[...] on-going process of learning, searching and exploring, which result in new products, new techniques, new forms of organization and new markets."*(p. 8)
Analytical framework	•Relationship between technology, socioeconomic structures, and institutions.	•Linking institutional arrangements to technological and economic performances.	• Interactive learning anchored in the production structure (including " demand conditions" and "supporting industries") • Institutional set-up including "firm strategy" • Modes of cooperation and competition
Type of analysis	• Single case study (Japan)	•Comparative case study (15 countries divided into large high-income, small high-income, and low income countries)	• Conceptual/Theoretical

Source: Rakas and Hain (2019).

What all three approaches have in common is the idea that national context in terms of institutions and organisations and the interaction matters in shaping the innovation of firms and the impact it carries on the innovation and economic performance of whole countries. The idea that national context is important because of differences across countries in terms of some general characteristics, industrial structures, institutional infrastructures, institutions, policies, as well as knowledge conditions, demand conditions, and the possibilities for obtaining finance or skills, which all influence processes of innovation, is also the common point of departure in three chapters of this thesis (Chapters 3, 4 and 5).

While acknowledging the differences between the initial NIS conceptualisations, my understanding of NIS spans elements and relationships common to all three approaches, while putting greater emphasis on a broad understanding of an innovation system – most similar to the Alborg version of the concept (B.-A. Lundvall, 1992; Bengt-Åke Lundvall, 2010) as well as the recent advances in innovation systems research (Chaminade & Edquist, 2005; Edquist, 2011; Jan Fagerberg, 2017). In what follows, I explain in more detail what is meant by the broad understanding of an innovation system, the basics of the systemic approach to the study of innovation and how it relates to the empirical papers of this thesis. I also discuss why the approach is relevant and useful.

Definition and application

My understanding of the NIS concept in this thesis is rather broad and flexible. It is broad in terms of the aspects of the system considered. I use the concept in a flexible manner depending on the main purpose of analysis and the theoretical perspective explicitly taken into account. The main reasons for adopting this broad and flexible understanding of NIS, as it stands for the three chapters (3, 4 and 5) of this thesis based on innovation survey data, are that NIS serves as a broad framework for understanding the nature and dynamics of firms' innovation processes in the national context(s) and organising the empirical work where the focus is on specific aspects of NIS.

Broad and flexible approaches to specific analysis, both when focusing on the processes of learning and innovation of firms and/or the wider national setting, are warranted for several reasons. First, many of the structural factors and types of institutions of NIS, as well as the configurations, may be associated with the aspects of the learning and innovation processes of firms. In other words, it is not clear which institutions are the most important in the context of innovation of firms, the extent to which the institutions differ across countries and whether the relationships between institutions and the learning and innovation processes of firms differ across countries. Second, there is no general agreement in the literature about what the most relevant aspects of the innovation practices of firms are. This is partly due to the theoretical differences, the complexity of both the phenomena and the relationships, and the exploratory state of the theoretical and empirical research. Finally, the broad approach is encompassing enough to accommodate analyses of different firms and/or national context(s) that form the empirical basis of the three papers of this thesis (Chapters 3, 4 and 5). In the Aalborg version of the NIS approach, it is argued that the most important basis for innovation at the firm level are activities that promote learning by doing, using and interacting versus science and technology knowledge and formal R&D activities (B.-A. Lundvall, 2016). Moreover, the countries might have more or less developed national innovation systems in a sense of a narrow definition that emphasises the R&D infrastructure. In the case of the less developed innovation systems, the exclusive focus on the narrower R&D infrastructures and institutions at the country level may provide limited insight, since these may play only a marginal role in shaping the patterns of modes of learning and innovation of firms (B.-Å. Lundvall, Johnson, & Andersen, 2002).

In the tradition of a broad definition of NIS associated with Lundvall (1992a), it is useful to make further distinction between the macro-structures or "wider setting" and micro-structures or the "core" of NIS seen as both defining and structuring elements of the system. The "wider setting" and the "core" could also be labelled as the macro- and micro-aspect of the environment for innovation processes of firms. The former refers to a wide array of collective socio-economic factors, political infrastructures, institutions and organisations (including a wide range of public policies) in relation with areas such as national education, labour markets, financial markets, competition in product markets, intellectual property regimes and welfare regimes, as well as the economic structures that affect the generation, diffusion and use of economically useful knowledge (B.-A. Lundvall, 2016; B. Å. Lundvall, 2007). In turn, the "core" includes firms interacting with other firms and with the knowledge infrastructure. The broad definition of the "core" of the innovation system refers to inclusion of all kinds of firms and sectors (not only high-technology ones), as well as the inclusion of all innovation activities (not only those that put emphasis on promoting R&D). Hence, the broad definition of the "core" is not limited to the organisations and institutions of the R&D system (e.g.

universities, research institutes and R&D departments of firms), activities and interactions.

Within these overall framework processes of learning and knowledge creation in the "core" are of central importance, reflecting the theoretical perspective where interactive learning is understood as the most important basis for understanding innovation. More specifically, what happens inside the core (processes of learning and innovation) stands for how the formal processes of R&D (efforts and human resources), learning from interactions within and between firms and the knowledge infrastructure are combined at the firm and macroeconomic level (Jensen et al., 2007; B.-Å. Lundvall, 2007). The emphasis put on the behaviour of firms in terms of processes of learning and innovation (in the core), as defined above, is also common for two papers of this thesis (Chapters 4 and 5).

From the NIS perspective, a wider setting or some specific sub-system such as labour market organisation, condition and shape the micro-dynamics or behaviours of firms. This includes the modes of learning and innovation in the core, which in turn shape the macro-structures (B. Å. Lundvall, 2007). Moreover, the institutional characteristics of NIS in terms of both the wider setting and the core are seen as being intertwined and specific to the national context. Furthermore, the interplay between these two aspects is expected to have an impact on the processes and outcomes of learning and innovation, as well as result in an innovation system with unique dynamics. The dynamics of the system is understood as elements reinforcing each other in support of the processes of learning and innovation or forming into configuration that which blocks these processes.

Thus, the NIS approach associated with Lundvall uses three main concepts to understand the nature and dynamics of innovation in the national context: i) innovation as interactive learning processes that take place in ii) the core, which in turn is embedded in iii) the wider setting (nationally bounded). More broadly, as put forward by Smith (2000), the essence of the systemic interactive approach to innovation is not limited to the national systems of innovation literature. What is common to all systemic approaches, is the understanding that innovation by firms cannot be understood without reference to the context in which firms operate. The analytical approach of studying NIS is organised around the elements and patterns of interaction and communication within and between institutions/organisations at various levels of aggregation (at the level of the firm, groups of firms or a nation) that affect the creation of new resources and support learning and competence building (B.-A. Lundvall, 2016). In dynamic terms, the emphasis is on the match and mismatch between the various subsystems (infrastructural and/or institutional) and patterns of specialisation in production, trade, and knowledge on the one hand, and patterns of interactive learning and innovation on the other hand (B.-Å. Lundvall et al., 2002). In this thesis, Chapters 4 and 5 focus on modes of learning and innovation, as defined above, in the national context(s). Chapter 4 also considers the wider-setting of NIS in which processes of learning and innovation are embedded. The wider setting of NIS is also considered in Chapter 3, where recent advances in the innovation systems research are explicitly taken into account. Thus, different papers of this thesis analyse different aspects of the system.

NIS concept in the different chapters

As pointed out, different papers of this thesis emphasise different aspects of the NIS. Therefore, it is useful to illustrate how the concept of the national innovation system relates to and is reflected in the three empirical papers of this thesis. The focus is on the key aspects included in the analysis, the main purpose of the analysis and the recent analytical advances in innovation-system theory. In Chapter 3, the focus is on the system wide processes as one aspect of the wider setting of the NIS, in the context of European countries, where taxonomy of NISs based on this aspect is proposed. Chapter 4 focuses on the relationship between the (country specific) institutions as an aspect of the wider setting and innovation modes of firms in the context of six small European countries. In Chapter 5 the modes of innovation of firms and the dynamics within the single country (Denmark) are analysed.

In Chapters 4 and 5, my definition of modes of innovation at the firm level is broad and to a large extent consistent with a definition of two modes of learning and innovation in terms of encompassing both formal processes of R&D and the linkages (sources) that promote interactive learning within and between organisations, known as the STI (Science, Technology and Innovation) and the DUI (Doing, Using and Interacting) modes[5] (Jensen et

[5] I will provide more elaborate discussion on the STI (Science, Technology and Innovation) and the DUI (Doing, Using and Interacting) modes of learning and innovation in section 2.2 on *The innovation concept and firm-level modes of innovation*.

al., 2007). Yet, my definition of modes of learning also differs from Jensen et al. (2007) in the following respects. It is broader in terms of including dimensions found in other taxonomic studies on innovation modes or strategies of firms (how firms innovate), mainly based on the firm-level, cross-sectional survey-based evidence and taking a more inductive approach, instead of relying on two previously mentioned modes of learning and innovation (Leiponen & Drejer, 2007; Srholec, Verspagen, Srholec, & Verspagen, 2008). For example, I also include the firm's objectives for innovation as a dimension of modes of innovation, while not considering internal work organisational practices and arrangements of firms associated with the experience-based type of learning. I discuss these points in more detail in section 3.2 on *Mode of learning and innovation*. In Chapter 4, the NIS strand of literature also provides the general framework to analyse that connection between the national institutional characteristics and the organisational aspects of innovation and thereby innovation modes at the country level. The purpose of the paper in Chapter 4 is to analyse differences between countries in terms of both institutional settings and the prevalent modes of innovation. In a more dynamic perspective, the changes of modes of learning and innovation over time in Chapter 5 are discussed in relation to how the core of an innovation system evolves.

In keeping with the above discussion, the arguments from the literature on innovation system suggest the case of stability rather than change in the prevalent modes of learning and innovation of firms. The national institutions that comprise the national innovation system guide behaviours of people and firms, influence communication patterns and organisational forms. Moreover, the national institutions that are most important in that respect are likely to remain rather stable. In addition, a dynamic co-evolution of the economic structure and the institutional setting implies that both will change very slowly (B.-Å. Lundvall, 2007). As a result, these structural and institutional characteristics that are in turn rooted in historical processes are said to be reflected in the strengths and weaknesses of an innovation system in terms of form, content, and rate of innovation and to persist even in a long-term perspective (Lundvall, 2002). The empirical support for the case of stability can be found in the earlier studies that show the persistence of the national differences in innovation processes, such as technological specialisation, organisational location of the activities, and patterns of financial support (Hart, 2009). In terms of the stability, a broad term of path dependency has been used to account for an array of mechanisms at the levels of individuals, organisations and institutions, which prevent or restrict change. The examples include skills and knowledge, organisational routines, interactions among institutions, the co-evolution of industrial structures and the institutions, etc.

It is important to note that several alternative approaches have been proposed for studying the evolution of the system at the country level. Lundvall, Johnson and Andersen (2002) build on ideas by Freeman (1995) and suggest historical analysis of the co-evolution of the structure of production and the institutional setting in order to explore how the changing patterns of matches and mismatches are related to the economic performance (e.g. the growth patterns) of national systems. The main idea is that the co-evolution of the structures and the institutions might result in a mismatch that is not supportive to economic growth and thus needs to be restored. In addition, it was suggested that the core of the innovation system may evolve at a more rapid rate than the wider setting or that slack and incompetence of the core may block such changes (B. Å. Lundvall, 2007). In addition, a focus on the co-evolution of production structures, technologies and institutions can be useful for understanding the historical development and transformation of NIS. This approach is followed in Fagerberg, Mowery and Verspagen (2009). An alternative approach consists of a comparison of the structures, dynamics, and performances of the system at two points in time (Liu & White, 2001). Another analytical approach to study the evolution of the system is an evolutionary game approach, where evolution is regarded as the outcome of a Schumpeterian game where different firms pursue different innovation strategies. In particular, the changing mix of the strategy of the population of firms might provide insight on how an innovation system performs or evolves (B.-Å. Lundvall et al., 2002; Srholec et al., 2008). In comparison to these, the change may also be analysed in terms of changing mixes of modes of learning and innovation that compose a system (Archibugi, Howells, & Michie, 1999), as this approach may provide a more dynamic picture of how firms respond to and interact with the national innovation system at different points in time.

The innovation system framework in Chapter 3 of this thesis puts forward an alternative approach to innovation system analysis that differs from the approach characterising the original work on national innovation systems. It mainly differs in terms of the delineation of the system based on the systems' activities, functions, factors or processes rather than structural characteristics (elements and their relationships) at different levels of aggregations. Here, the nation-specific activities that are carried and shaped by institutions and policies, and that in turn shape the innovation processes of firms, are understood as the context in which firms operate. The analysis is organised around the set of innovation process-related activities or factors in the system that influence the output of NIS (the generation, diffusion and use of technology) (Jan Fagerberg, 2017). Nonetheless, what is common to both approaches is a common understanding of the innovation process as an interactive phenomenon. The paper studies the innovation systems' activities-related problems over time and across countries and discusses these in relation to the role of innovation policy in the context of the innovation system.

Since both the aspects of the wider setting, such as generic processes and the institutional setting, and micro-organisational and behavioural aspects such as modes of learning and innovation of firms in the context of NIS have received a great deal of attention in this thesis, it is worth elaborating on it. The following section starts with the definition of the most important concept, the innovation itself.

2.2. Key processes and the environment

The innovation concept and firm-level modes of innovation

Innovation is a widely used term and the concept has been defined in many different ways in the literature. Probably the most widely accepted definition of innovation, at least in the context of innovation studies, is the one provided by Joseph Schumpeter (Schumpeter, 1934). Moreover, the Oslo Manual's (2005) conceptual framework, which is the foundation for the data collection of the main source of data adopted in this thesis, defines innovation in the Schumpeterian tradition (OECD, 2005). For these reasons, the Schumpeter's perspective of innovation seems like a natural starting point. Schumpeter's (Schumpeter, 1934) conception of innovation covers five cases: i) the introduction of a new good or a new quality of a good; ii) the introduction of a new method of production, including a new way of handling a commodity commercially; iii) the opening of a new market; iv) the conquest of a new source of supply of raw materials or semi-manufactured goods; and v) the carrying out of a new organisation of industry. While the Oslo Manual (2005) defines innovation in Schumpeter's tradition[6], along with the inclusion of additional innovations (organisational and marketing), as compared to the previous edition (OECD/Eurostat/EC, 1997), it only deals with the first two categories of innovation as defined above[7]. For this reason, my definition of innovation is limited to product and process innovations.[8] However, the main focus of this thesis is on the characteristics of innovation practices of firms that might or might not result in innovation outputs (as defined above), which will become evident in the following discussion.

With the previous point in mind, it is important to acknowledge that innovation is a process that consists of the set of inputs, outputs and activities that all fall under the generic term of innovation. The introduction of the concept "innovation modes" in the literature can be seen as an attempt to broaden the analysis of the innovation process in firms based on the insights from modern innovation theory. The attempt also coincides with the emergence of a new source of data, namely CIS[9], that collects data on various aspects of the innovation processes of firms based on the above-mentioned Oslo Manual. The two key points from the advances in innovation theory are especially worth mentioning (Smith, 2000). First, it is emphasised that a wide range of activities are involved in the generation and use of new as well as already existing knowledge in innovation processes of firms. More specifically, it is understood that innovation rests on learning and that learning can be based on activities that generate new knowledge (discovery of new science and technology principles), such as R&D, or which recombine or adapt the existing knowledge, such as design or trial production and marketing. The second point stresses the importance of the context in which firms operate. In particular, it is understood that firms interact with users, other firms and institutions in numerous market and non-market ways in the process of innovation. The arguments presented above imply a more complex view of innovation as a result of a set of interactions and applications of various kinds of knowledge

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[6] In terms of various features of innovation such as degrees of novelty and significance. I will discuss these in more details in the following section.
[7] The later versions of the Oslo Manual (2018) have further broadened the definition of innovation.
[8] In the following section I will provide more information on the adopted definition of innovation and its implication on the categorisation of the innovating firm in this thesis.
[9] I will provide more details about CIS data in the following Method section.

and forms of learning, where context is understood as a framework (at various levels of aggregation) within which the creation and recombination of knowledge involved in innovation takes place and is supported with a range of activities (Smith, 2000).

When it comes to empirical studies, the emphasis on the complex and multidimensional nature of the innovation process is manifested both in the new data sources and the empirical strategies used to derive modes or patterns of innovation. However, there is no universally accepted definition of modes of innovation apart from the common reference to different ways in which innovation is organised or takes place. The differences in respect with what the most important dimensions of the innovation process are mainly stem from the differences in the theoretical basis.

The three streams of literature related to the evolutionary tradition in economics are sectoral (e.g., Malerba and Orsenigo, 1997, 1995, 1993; Pavitt, 1984; for reviews see Archibugi, 2001; Hall and Rosenberg, 2010;), regional (e.g., Asheim et al., 2011; Cooke, 2001; Morgan, 2007) and national systems of innovation (e.g., Edquist, C., & Lundvall, 1993; Lundvall, 1992). These streams have been primarily concerned with the questions of how innovation takes place and whether and why these patterns differ systematically across firms, sectors, regions, and countries. In the evolutionary tradition, the focus has been on identifying firms according to Schumpeter's (1934) distinction between creative and adaptive behaviours. In a nutshell, the research associated with the evolutionary tradition in economics posits that firms show considerable heterogeneity in the ways those firms innovate. Furthermore, these differences have been related to differences in the skills of workers, their experiences and the differences in firms' sizes and organisational forms. Relatedly, the literature on sectoral and national innovation systems posits that the differences in the ways firms innovate, at least to some extent, can be explained by differences in sectors and countries in a comparative setting. In the context of the empirical literature on the sectoral systems of innovation, the focus has been on detecting sector specific modes of innovation. The theoretical underpinnings for the differences between sectors in terms of modes of innovation include the nature of the relevant technological regime, defined in terms of the levels of opportunities, appropriability, and cumulativeness of innovation, and the specificity of the knowledge basis (Malerba & Orsenigo, 1996). Later empirical contributions on innovation patterns at the firm level have challenged the dominant view that the sectoral dimension explains most of the differences in the innovative behaviours of firms (Leiponen & Drejer, 2007; Srholec et al., 2008).

In a nutshell, the proponents of the previously mentioned streams of research argue that modes or patterns of innovation of firms are strongly related to the contextual factors at the level of technology, firm, sector, region or country. From these viewpoints, the contextual factors matter in shaping what firms do and how successful the firms are. While the either/or debate in respect with the role of technological, sectoral, regional, national and global factors in shaping innovation patterns is still ongoing, the concept of the innovation system is flexible and broad enough to account for the relative importance of each factor.

In a more dynamic perspective, previous work has also been focused on providing empirical evidence on whether the patterns of innovation tend to continuously differ across firms, sectors, and countries (Cefis & Orsenigo, 2001). The discussion on patterns of innovation can be extended to facilitate the phenomena of uneven development, or market integration in the EU by focusing on the difference in how firms in different countries generate and use knowledge and the processes of convergence or divergence between national systems of innovation over time (B.-A. Lundvall, 2016; Veugelers, 2017).

In the context of country-level studies, which is of prime interest in this thesis, earlier work provides evidence that patterns of innovation do tend to differ systematically across countries and that persistence in innovation shows country-specific properties (Cefis and Orsenigo, 2001; Malerba and Orsenigo, 1995). In addition, a sectoral dimension of patterns of innovation is also found to be country specific (Malerba & Orsenigo, 1995). Some of the explanations put forward include the peculiar history of firms and industries, and institutional factors that are country specific (Cefis & Orsenigo, 2001). However, these earlier studies on the systemic differences in patterns of innovation activities across countries are based on the Schumpeter's (1934) distinction between Mark I and Mark II patterns of innovation and rely on patent data (Cefis & Orsenigo, 2001; Malerba & Orsenigo, 1997). These patterns stand for the processes of competition and selection in innovation and market activities. In the earlier study by Nelson (1993), it is shown how the systems of innovation (character of actors and institutions and their relationships within country) differ across countries in a qualitative manner and consequently how the systems perform. Here, innovation refers to the processes by which firms master and put into practice new technological innovations. In the earlier studies conducted in the Aalborg tradition of NIS, the emphasis was put on the relationship between the structure of production, the institutional set-up and the patterns of user-producers' relationships in order to understand the innovation and economic performance of NIS (B.-A. Lundvall, 1992). According to the latter, different national contexts provide different possibilities for user-producer relationships and the processes of interactive learning (modes of learning), and thus different conducts and performances of firms and NIS (B.-Å. Lundvall et al., 2002).

In the cross-country comparative setting, the NIS literature has provided evidence for the existence of fundamental differences across EU countries in terms of how work is organised within firms and how firms innovate (Arundel et al., 2007). In Jensen et al. (2007), the conceptual distinction between the two modes of learning was proposed as useful to show how the two different modes are combined at the level of the firm and the economy. The concept "modes of learning" is preferred in Jensen et al. (2007), which follows from the focus on the interactive processes of learning and different forms of knowledge. The term modes of learning refers to how firms create knowledge and engage in learning. The concept puts greater emphasis on the organisational aspects of the innovation process within and between the organisations that support learning, such as internal work organisation practices and upstream and downstream linkages, while also including R&D efforts and personnel (B.-A. Lundvall, 2016; B.-Å. Lundvall, 2007). More specifically, the focus has been on identifying the groups of firms associated with different intensities of practising the two modes of learning associated with science- and experience-based knowledge. The essence of the argument is that there are multiple factors to successful innovation and that different firms and sectors rely on different factors, broadly categorised as science- and technology-based (STI) activities and doing, using and interacting (DUI) based activities. The science-based factors include the formal R&D and skilled scientists and engineers, while the DUI based factors include interactions within the organisations and with different upstream and downstream actors and other public sources of information, including the feedback from the markets. Furthermore, the external interactions are argued to be more frequent within the local networks, creating unique innovation systems at the regional and national levels. In a recent study by Srholec (2015) based on the multi-country dataset on types of innovation cooperation, the thesis for more frequent domestic cooperation has received limited support. At the economic level, the national specificities in patterns of work organisation and cooperation between organisations and modes of learning and innovation should be explained in reference to the systemic features of the innovation system (B.-A. Lundvall, 2016; B.-Å. Lundvall, 2007).

In summary, the literature on NIS builds on the early empirical findings that countries show considerable and long-lasting systemic differences in patterns of innovation as measured along various dimensions as well as in the level of innovation and economic performance (Archibugi et al., 1999; Filippetti & Archibugi, 2010). What is common to alternative approaches to studying NIS is that innovation activities and how firms act are framed in the national context. In what follows, I turn to the discussion of the national environmental conditions in which firms operate and innovate, and in which national governments intervene. I relate this to the new advances in the innovation systems research.

The environment: Institutions and processes

Institutions in the NIS

The main focus in Chapter 4 is on the role of institutions at the national level (as a context or an environment) in conditioning and shaping firms' patterns or modes of learning and innovation as previously defined. The purpose of this section is to present the conceptualisation of institutions from the national innovation systems perspective. The relations between national institutions and the processes of learning and innovation in firms as reflected in modes of innovation are also discussed.

The main argument from the national innovation system literature is that there are several kinds of institutions which matter for innovation. As discussed above, the NIS literature makes a distinction between the "core" of the innovation system (the firms and knowledge infrastructures in terms of relationships) and the wider setting. The wider setting in turn refers to institutions that contribute to competence building and that shape interactions in relation to innovation in areas such as national science and technology systems, education and training systems, labour markets, financial systems, intellectual property rights, competition in product markets and welfare regimes. Other aspects include the historical record of macroeconomic stability and access to finance, the demand from households and public sector organizations, and government and public policy (Lundvall 1992a, p.338). The list was refined and extended over time to include various dimensions of the institutional set-ups that contribute to competence building and shape humane interaction in relation to innovation (B.-A. Lundvall, 2016; B.-Å. Lundvall et al., 2002).

From the Alborg approach to NIS, the relations between the wider setting (national institutional environment) and innovation exist at various levels. For example, the organisational structure of individual firms, forms of work organisation (e.g. institutionalized communication between departments and work practices such as job rotation) and the organised markets between firms and other organisations are understood as reflections of institutional factors, since these affect communication and interaction patterns and therefore learning in the system. In turn, the institutional factors at the national level and outside the enterprise sector (e.g. norms of distribution of costs and benefits and job participation and security) are argued to affect learning (as well as searching and exploring) indirectly through an effect on the firms' organisational and management choices (including choices concerning interactions with the environment), as well as the degree of communication and interaction and the effort put into these activities by workers. Thus, the institutional framework of NIS outside the enterprise sector is understood primarily as a context for communication and interaction (including cooperation) by organisations and individuals. While both institutional set-ups and modes of learning and innovation are understood as determinants of processes of learning and innovation in the NIS literature and in this thesis, the conceptual distinction is important for the analysis and interpretation of the role of institutional settings in the general context of NIS for policy purposes (Chapter 3), and for understanding the role of institutions in firms' innovation behaviours (Chapter 4). In Chapter 3 of this thesis, the general NIS framework is understood broader than the national institutional context in which firms operate and innovate. I will return to this matter in the section below on *Processes in the NIS*.

Another important conceptual distinction in the NIS literature is made between the informal and formal institutional arrangements or factors at the national level in relation to the innovation process at the enterprise level. Here, informal institutions are defined as general social norms, rules and habits without references to specific sub-systems. Lundvall (1998) lists four critical informal institutions determining the form and direction of processes of learning and innovation in the system. These include the time horizon of agents, the forms of authority in connection to industrial relations and inter-firm relationships, the rationality of agents and trust. The examples of formal institutional arrangements include the science infrastructure, property rights including intellectual property rights, contract laws, corporate law, arbitration institutions, and collective bargaining and other labour market institutions (B.-Å. Lundvall et al., 2002). Whereas Chapter 4 takes into account a wide set of both formal and informal types of national institutions of relevance for learning and thus innovation, Chapter 3 considers narrower sets of both formal and informal national institutions of relevance for entrepreneurial (or business) activities of the enterprise sector. However, the common feature is that institutions are broadly understood as regulating how individuals and organisations act (including interactions).

To explain the concept of institutional setting, I provide an example on how firms' activities (modes of learning and innovation) are dependent on the wider setting in areas such as national science and technology systems, education and training systems, labour markets, financial systems, intellectual property rights, competition in product markets and welfare regimes (Lundvall, 2007). More specifically, institutional set-ups in these areas are important for innovation of firms because set-ups shape people in general (how they relate to each other) and affect the patterns of communication and interaction i) within the organisational structure of the individual firms; and ii) between the organisations located in the country - the interactive aspects of the learning and innovation processes. For example, the strength and kind of trust present in the markets, as well as the formal and legal arrangements surrounding these markets is argued to be important for establishing trust relationships, and thus the degree of interactive learning taking place in the systems (B.-Å. Lundvall et al., 2002). In the "learning" or Aalborg perspective on NIS, these patterns of communication and interactions within and between the agents and organisations are at the centre of the learning and innovation processes of firms that sometimes result in innovations. Hence, the institutions (the institutional infrastructures) that regulate the patterns of communication and interactions within and between organisations are fundamental to the process of innovation (B.-A. Lundvall, 1992). Moreover, countries in which firms are located differ from each other with respect to the institutional set-ups in previously mentioned areas. More broadly, different institutional set-ups of countries give people different conditions for communication and interaction and incentives to engage in interactions and learning new competencies. From this perspective, it follows that since countries differ with respect to institutional set-ups that affect interactive learning processes, the prevailing patterns of learning and searching in firms and organisations will differ across countries (B.-A. Lundvall, 1992). Chapter 4 of this thesis explicitly considers various institutional dimensions at the national level. It analyses how differences in institutional arrangements shape firms' patterns or modes of learning and innovation as defined in the previous section on *The innovation concept and firm-level modes of innovation*.

The discussion above suggests that the institutional set-up of countries consists of many different kinds of institutions related to one another. It also suggests that institutional factors affect innovation at different levels of aggregation. However, there is no single definition of institutions or a general agreement about what the most important institutions in the context of innovation are. Moreover, there is lot to learn about how the broader set of institutions are related to each other at different levels of aggregation, in different national contexts, and how they relate to the predominant modes of learning and innovation in firms and countries, which suggests the need for further studies.

Processes in the NIS

As pointed out above, the NIS as an environment in which firms operate and innovate, and in which governments intervene, is understood somewhat differently in Chapter 3 compared to Chapter 4. The difference relates to the definition and delineation of the wider setting of NIS as an environment for innovation based on a set of generic processes or activities in the system that affect innovation processes of firms and that can be shaped by policy makers. Another distinction refers to the shift in focus from the character of the wider setting (economic structure and institutional set-up) to the activities going on in (the public sphere of) the wider setting of NIS. The final distinction refers to the normative aspects. In what follows, I consider each of these points in more detail. The main reason why a different understanding is applied in this chapter is that it is more useful for policy purposes.

Here, NIS as a context in which firms operate and innovate is understood to be broader than the institutional framework in which communication and interaction between people and firms/organisations in relation to production and innovation takes place. More specifically, it is understood as a repository of various factors such as knowledge, skills, demand and financial resources, and home to institutions influencing the provision of these factors within the nation (Fagerberg and Edler, 2017). The provision of factors, labelled as generic processes, functions or activities, is considered to be the responsibility of various areas of national government. These factors are considered complementary and important for successful innovation of firms located in the countries, since firms depend on them during innovation activities. Thus, the functionality or operation of the whole national systems is seen as the responsibility of policy makers. For example, the provision of skills in the national context is largely under the responsibility of the Ministry of Education. Since access to skills have an impact on firms' abilities to innovate and thus the firms' innovation performance, it also has an impact on the technological dynamics of the system as a whole. These arguments also suggest that systems might not sufficiently provide for the factors on which firms depend on during innovation activities which are labelled as system failures hampering firms' innovation activities. In turn, the existence of systemic failures provides a rationale for public action.[10]

The previously mentioned delineation of the system reflects the direction of research taken within the NIS literature in a more recent period. In particular, it is argued that a distinction needs to be made between the aspects that are within the control of policymakers and may be influenced by their actions (activities in the public sphere), and the specific structural features that might be very difficult to change by policy actions. The structural characteristics include the economic structures and the institutional infrastructures, such as the education and financial systems conditioned and rooted in the historical trajectories of each country. More specifically, the resulting pattern of specialisation in production, trade, and knowledge, and the institutional set-up that support it is understood as a result of the historical processes of co-evolution that are only likely to change very slowly (B.-Å. Lundvall, 2007). This distinction is seen as

[10] In the Alborg version of NIS, the functionality of NIS refers to the functionality of the institutional set-up (at various levels of aggregation) in supporting the processes of learning (as well as searching and exploring) and thus innovation through the effect on communication and interaction patterns of organisations and individuals. Thus, one might think in terms of optimal, satisfactory and unsatisfactory states of the institutional set-up.

especially relevant in the context of the analysis of innovation systems for policy purposes.

The early approach to studying NIS has been criticised on the grounds of providing little guidance for policy makers in terms of designing and implementing policies that have an impact on the technological dynamics of the system as a whole (Jan Fagerberg, 2017). To illustrate the point in relation to the challenges of deriving policy-relevant conclusions, I consider one example of the specific features of the institutional settings and its bearing on what firms do and how successful firms are. Firms in certain countries may be better able to flexibly respond to changing demands in the markets due to the different flexibilities of labour markets, industrial relations and inter-firm relationships. The flexible labour market, industrial relations and inter-firm relationships, in turn, are socially constructed and rooted in the historical evolutionary processes of cooperation or policy decisions that match the industrial structure of the country well. Consequently, these institutions might be very difficult to change by policy actions.

This later approach builds on the contributions of (Edquist, 2005; Liu & White, 2001; Rickne, 2000) and was developed on the grounds of overcoming some of the limitations of the traditional approach to studying NIS identified by the authors. Some of the points put forth on the usefulness of the approach are: i) a broad approach to NIS; ii) a multidimensional and dynamic perspective on determinants of innovation; iii) greater usability for empirical analysis; and iv) greater usefulness in terms of deriving policy conclusions (Edquist, 2005; Edquist & Hommen, 2008). However, the approach also received critical remarks, including the following: i) a functional approach that seems to emanate from a version of system theory as practised by engineers might not be relevant for studying the social systems; ii) inclusion of disparate elements under the activities; iii) that the distinction between the three kinds of learning neglects the fact that one is a product of practising the other two and that studying them separately does not lead to a more rigorous theoretical approach; and iv) a different normative focus from those that pioneered the concept of NIS (B.-Å. Lundvall, 2007).

More specifically, the differences in approaches to studying NIS also concerns the role of innovation policy in supporting innovation. From the perspective that puts emphasis on the institutional characteristics of the system, the role of public policy is limited in the short-run and only relevant in the long-run, but especially in the context of the potential technological and institutional "lock-ins" (B.-A. Lundvall, 2016). As an example, Lundvall et al. (2002) argues that the industrial policy through innovation is more likely to reinforce the existing development trajectory of the innovation system due to the vested interests and the kinds of policy "lock-ins" as identified in the case of Denmark and Sweden (Edquist, C., & Lundvall, 1993). From the perspective that puts emphasis on the activities in the NIS, the policy makers need to address system problems and weaknesses. Chapter 3 explicitly combines the innovation system activities and systemic problems in an integrated analysis of NIS weaknesses at the EU level.

The next section provides a description of the main data sources and uses in this thesis, followed by a brief overview of available data as well as strengths and weaknesses.

3. Method

The thesis consists of four papers that are empirical studies. The first paper is a bibliographic study of the IS field of research and uses the Web of Science citation database (WoS) as the primary source of data. The remaining three papers are empirical studies of innovation modes of enterprises and/or the wider innovation systems. These three papers of this thesis are based on data from the European Community Innovation Survey, known by its acronym CIS (Community Innovation Survey).

Since many of the core concepts of this thesis, such as innovation modes of firms, an institutional set-up, or systemic weaknesses of IS are complex and consist of various sets of dimensions, I rely in the empirical analyses on the multivariate techniques (principal component (PCA) and clustering analysis) which allows me to use multiple indicators and to construct more informative, composite measures of modes of innovation and features of IS in the broader sense. Moreover, the methods are well suited to capture and summarise the complexities of various dimensions that characterise the concepts.

The following section is divided into two parts. The first part concentrates on the WoS database, while the second part focuses on the CIS and additional sources of data. The section consists of a description of the main data sources and its uses. In the second part, I also shortly discuss the strengths and weaknesses of the available data and measures of innovation.

3.1. Data

Presenting the Web of Science Core Collection

The Web of Science Core Collection (WoS) is an online citation database of scholarly literature covering disciplines such as science, social sciences, art and humanities from 1900 to the present. Currently, the database is maintained by the Institute for Scientific Information (previously by Thompson Reuters). It consists of articles indexed from approximately 21,000[11] peer-reviewed scientific journals, as well as conference proceedings, books and book chapters – the most recent addition. All publications are indexed directly from the publishers (Clarivate Analytics, 2018). Each record in the database includes standard bibliographic information, such as the title, all the authors, all authors' affiliations, the publication year, the abstract and keywords, funding acknowledgments, as well as information on the cited references and the times cited.

The final corpus of citation data that is used in this thesis is a result of a step-wise selection process. It consists of innovation system (IS) relevant journal articles (6,370) published in English during the period of 1980 - 2018, as recorded in WoS. The corresponding list of selected journal articles' internally cited references (162, 600 unique cited references), including books and book-chapters which are not indexed in the WoS database[12] is also utilised. In bibliographic analysis, articles and the cited references are commonly treated and analysed separately. The WoS database allows for the information on cited references to be matched with the corresponding articles through the cited reference search. More specifically, it allows identifying research areas within the selected articles and the corresponding knowledge bases within the articles' cited

[11] It is impossible to be precise because new journals are being constantly added to the WoS database.

[12] Meaning that for books and book chapters we can only use limited information regarding received citations from our final corpus.

references. The citation linking is a unique feature of the WoS database, which is not readily available in other citation databases such as Scopus or Econlit. By exploiting this feature, it is possible to describe and analyse the field of research in a data driven way and to use an exploratory methodology, instead of relying on predefined categories such as subject disciplines or publication outlets' disciplinary orientations. Moreover, the available textual information contained in the articles' abstracts can be used to provide additional insight on general themes or topics within the field of research. These characteristics are especially relevant when analysing interdisciplinary fields of research such as innovation systems. While the WoS database provides rich and comprehensive bibliographic data on scholarly journals and is typically and increasingly used for bibliographic analysis of academic fields of research, it also has certain limitations. Some of the major limitations include: i) limited coverage of scholarly books and book chapters in general; and ii) limited coverage of books and book chapters reaching far enough back in time. Therefore, a citation database such as WoS certainly has limitations when analysing fields of research such as IS throughout the whole lifecycle since many significant contributions are to be found in books, but especially in the formative stage of the field (pre-2000 period). A more extensive discussion of the uses and limitations of the WoS database is provided in Chapter 2 of this thesis.

Presenting the CIS data collections

The European-wide CIS project, one of the major innovation data collection efforts on innovation activities in enterprises, was initiated and implemented by Eurostat and the DG XIII (SPRINT Programme, European Innovation Monitoring System (EIMS)) in the early 1990s. It was developed in co-operation with independent experts and the Organization for Economic Development and Cooperation (OECD). The overall objective was that of providing useful, high-quality and comparable firm-level innovation data across EU member states for policy makers and researchers (Archibugi, Cohendet, Kristensen, & Schaffer, 1995; Mairesse & Mohnen, 2007; Salazar & Holbrook, 2003).[13] The EU CIS provides information on the types of innovation and the various aspects of the innovation processes at the

[13] For a more detailed account of the history of innovation survey see Arundel and Smith (2013), Mairesse and Mohnen, (2007) and Salazar and Holbrook (2003).

enterprise level such as sources of information, innovation cooperation and the objectives of innovation, as well as some economic indicators such as the number of employees and turnover. It also provides information about innovation environmental factors that facilitate or hinder innovation. The information refers to EU enterprises with at least 10 employees and belonging to core sectors (the manufacturing, primary and service sector) covered under the regulation, the legal basis for CIS. The collection of direct[14] and economy-wide innovation data at the firm level in the European community was deemed necessary by both researchers and policy makers in order to understand the extent and distribution of innovation activity and the effects of innovation on the economy (Arundel, A., & Smith, 2013). The CIS has evolved in the largest innovation survey in terms of the number of participating countries and the number of included enterprises (Arundel, A., & Smith, 2013).

CIS based data collections are maintained and provided by Eurostat, the statistical office of the EU. Eurostat collects the CIS-based aggregates and the CIS microdata sets from the countries carrying out CIS.[15] Eurostat's CIS database contains the comparable aggregated innovation statistics, which are publicly available on Eurostat's website in separate sections by yearly editions. All aggregations making up the Eurostat's CIS database are based on the results from national CIS editions (microdata collections), which in turn follow EU harmonized CIS and a set of harmonized guidelines allowing for cross-country comparisons.

EU harmonized CIS is based on a common core questionnaire, usually referred to as the Harmonized CIS Questionnaire, adopted by all EU member states. The harmonized questionnaire is developed by Eurostat in cooperation with the EU member states and other countries for each round of CIS and is accompanied with a set of harmonized concepts and methodological recommendations on the basis of the Oslo Manual guidelines (OECD, 1992), which has since undergone three revisions, including the 2nd edition of 1997 (OECD/Eurostat/EC, 1997), the 3rd edition of 2005 (OECD/Eurostat, 2005) and the 4th edition of 2019 (OECD, 2019). In contrast to the substantial revisions of the harmonized CIS questionnaire

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[14] Direct here means the potential capacity to directly measure the output of innovation activities.

[15] Member States may transmit on a voluntary basis the national editions of the CIS results to the Commission (Eurostat).

for and prior to the CIS 3rd (1998-2000) edition, the changes have been minor up from and including the CIS4 (2002-2004) collection in order to preserve comparability of CIS results over time (Arundel, A., & Smith, 2013). For a more detailed history and evaluation of the changes of the CIS standard questionnaire in the context of different CIS rounds see Arundel and Smith (2013) and Eurostat (2014).

Prior to CIS4, aggregations were obtained under a gentlemen's agreement. From CIS4 (2002-2004) onwards, all aggregations are obtained from the national authorities on a basis of current Commission Regulations concerning the production and development of community statistics on innovation. From CIS4 (2002-2004) up to CIS7 (2008-2010), the results were collected under Commission Regulation (EC) No 1450/2004, while a new regulation applied from 2012 onward (EC No 995/2012). The Commission Regulations place the aggregated innovation statistics on a statutory basis, make the delivery of certain variables compulsory and provide details of the compilation of innovation statistics with respect to the mandatory target population. All of the above mentioned changes in the new regulation have contributed to improving the quality of collected data.

The mandatory target population refers to enterprises with '10 employees or more' active in the sectors covered under the Regulation (cf. NACE CORE). An enterprise**,** the statistical unit on which CIS data is collected, is defined in the Council Regulation by statistical units or in the statistical business register. Regulation defines enterprise as "the smallest combination of legal units that is an organisational unit producing goods or services, which benefits from a certain degree of autonomy in decision making, especially for the allocation of its current resources. It may carry out one or more activities at one or more locations and it may be a combination of legal units, one legal unit or part of a legal unit" (Council Regulation (EEC) No 696/93 of 15 March 1993). The consequences of the revisions under different Commission Regulations during the time periods considered in the studies of this thesis are discussed in more detail in the separate chapters.

Prior to 2004, the collection of data is carried out every four years, whereas post-2004 the survey is conducted every two years, with the exception of a few EU countries who carry out surveys more frequently (e.g. Germany, Netherlands, Denmark). Currently, Eurostat collects aggregated data from countries every two years. Most of the collected information refers to the three-year reference period for any given wave, while some of the data refers to the first or the last year of the three–year reference period.

In relation to the survey methodology, countries generally carry out a stratified sample survey in order to collect the data, while a number of countries use a census or a mix of a census and sample survey. The target population of the survey refers to enterprises in the Core NACE categories with at least 10 employees as specified in the Commission Regulations. The target population is broken down into strata for sampling purposes. The variables used for stratification include size (according to the number of employees) and the activity classification (NACE). The stratification by size-classes has been in general according to three categories: 10-49 employees (small enterprises), 50-249 employees (medium-sized enterprises), 250+ employees (large enterprises), while stratification by NACE Rev 2 has been in general by 2-digit level (division) or groups of division. The sampling frame used by most countries is the official statistical business register. The results of the EU level synthesis of national quality reports are available for CIS4 (2002-2004), CIS5 (2004-2006) and CIS6 (2006-2008). See Eurostat (2009) and Eurostat (2012).

Eurostat CIS collections of data are an important basis for innovation research and policy making in Europe. The CIS data have received several evaluations in terms of its usefulness for researchers as evident in the two surveys of CIS surveys (Mairesse & Mohnen, 2007; Salazar & Holbrook, 2003) and of policy makers in monitoring innovation and benchmark innovation performances (Mairesse & Mohnen, 2008). Notwithstanding a number of identified limitations, the CIS data have been increasingly utilised by researchers as evident in the growing number of studies since its introduction, but especially since 2000 (Arundel, A., & Smith, 2013). It is also evident in its policy purposes (Bujnowska, 2018). Examples of previous studies using CIS data are numerous and can be categorised by the primary focus of the researchers in economics of technological change, the determinants or reasons for innovating, the effects of innovation on economic performances and the characteristics of innovation (Mairesse & Mohnen, 2008; OECD, 2009).

As noted above, the results of the CIS collections of data are available in Eurostat's CIS online databases which contain the comparable aggregated innovation statistics, and in the form of the microdata sets which provide innovation statistics at the enterprise level. However, the sets are altered due to confidentiality reasons and obtained at the request of the researchers. The separate papers of this thesis utilise aggregate innovation statistics, the microdata sets in the partly anonymized form from Eurostat and the anonymized form from the Danish Statistical Office, respectively. In what follows, I briefly present each in turn.

Eurostat's CIS-based aggregate innovation statistics

The results of the separate survey years' editions are combined in a set of unique databases, containing innovation statistics broken down by participating countries, type of innovators[16], core NACE (economic) activities and size classes. The aggregate innovation statistics based on CIS is limited to the list of specified statistics in the current regulation in the context of the specific survey round. Up to now, Eurostat's CIS database contained the results of the 10 CIS rounds (CIS light[17], CIS2 for 1996[18], CIS3 for 1998-2000, CIS4 for 2002-2004[19], CIS5 for 2004-2006, CIS6 for 2006-2008, CIS7 for 2008-2010, CIS8 for 2010-2012, CIS9 for 2012-2014 and CIS10 for 2014-2016). For an overview of the CIS rounds see Table 2. The most recent comparable data that were available for the papers in Chapters 3, 4 and 5 have a reference period of 2008-2010, 2010-2012 and 2013-2015[20], respectively. The aggregate innovation data of the separate CIS years' editions cover the European Union member countries, as well as some EFTA and EU candidate countries. Since compiling CIS data is voluntary to the countries, the coverage of countries differs across these CIS years' editions. For example, the results of the CIS4 edition cover 25 EU countries, while CIS8 includes all 28 EU Member States and three associated countries (Norway, Serbia and Turkey).

[16] Most of the national aggregate statistics is available in absolute value and as a percentage of all enterprises/total turnover, and as a percentage of all innovation active enterprises/of total turnover from innovation active enterprise (Commission Regulation (EC) No 1450/2004).

[17] Countries were free to choose between two reference periods of three years: 2000-2002 or 2001-2003.

[18] All data referred to the calendar year 1996.

[19] One exception to this is the Czech Republic having a reference period of 2003-2005.

[20] The three-year reference period 2013-2015 is unique to the Danish part of the European Community Innovation Survey due to the fact that the statistics have been collected and published annually since 2007 (Danmarks Statistik, 2013).

Table 2. Overview of the CIS rounds

CIS rounds	CIS light	CIS 2	CIS 3	CIS 4	CIS 5	CIS 6	CIS 7	CIS 8	CIS 9	CIS 10
Reference year/ period	2000-2002 OR 2001-2003	1996	1998 - 2000	2002 - 2004	2004 - 2006	2006 - 2008	2008 - 2010	2010 - 2012	2012 - 2014	2014 - 2016

Source: Eurostat (European Community Innovation Survey).

Eurostat's CIS micro data sets

Eurostat's CIS microdata collection consists of the national CIS microdata sets by the survey years' editions that are obtained from the national statistical authorities of the participating countries. Eurostat's CIS microdata is available for scientific purposes only on the request of researchers in CD-ROM releases (Scientific use file (SUF) - partially anonymised) or in the Safe Centre (SC) at Eurostat's premises in Luxembourg (Secure-use file). Countries' CIS microdata consist of sets of records containing information on individual respondents or business entities. CIS microdata (SUF type of microdata) is partially anonymised, meaning that all identification numbers are removed from the records, as well as some variables that are grouped together or micro-aggregated. The CIS microdata sets contain information on all survey variables. The CIS microdata is available for the seven CIS editions, from CIS3 (1998-2000) onwards. The compilation and provision of CIS microdata sets by participating countries to Eurostat is on a voluntary basis. Consequently, different surveys years' editions cover different countries and the number of countries in these data sets is only a subset of the countries that have been carrying the surveys in the separate rounds and for which aggregate innovation statistics are available. The Eurostat's CIS microdata is released 2.5 years after the end of the survey reference period. In addition, some countries provide access to CIS microdata in an anonymised form (partial or complete anonymisation) through national statistical offices, namely as public use files or confidential microdata files (Bujnowska, 2018).

Inclusion of the CIS and other data sources by separate papers

Table 3 provides an overview of the main data sources and the applications for each of the three separate papers of this thesis. The papers are sequenced from a broad macro-perspective, levels of aggregation and variables towards a more nuanced micro-perspective and analysis, with decreasing country and increasing time coverage. More specifically, Chapter 3 I used the CIS aggregate statistics to characterise the environment factors that hinder innovation – the national framework conditions – relating to innovation in firms, whereas in Chapters 4 and 5 I used the CIS micro-data sets to characterise the firms' ways of innovating or modes of innovation. As I deal with both innovation processes of firms and the characteristics of the national systems in selected countries, the choices of data sets reflect this focus on both a micro- and macro aspect. The next section discusses these choices of data sets in relation to separate papers of this thesis in more detail.

Table 3. Overview of the CIS data and its applications by papers

Characteristics\Papers	**Chapter 3**	**Chapter 4**	**Chapter 5**
Main data source	Eurostat's CIS web collections CIS4 (2002-2004) CIS5(2004-2006) CIS7(2008-2010)	Eurostat's CD-ROM release CIS8 (2010-2012)	Statistics Denmark's CIS database
Data	Aggregated country data	Micro-aggregated (partial anonymisation)	Microdata (anonymised)
Data type	Official national statistics	Scientific-use files (CD-ROM release)	Original microdata (remote access)
Other sources	The Heritage Foundation & Transparency International	Atkinson et al.'s 'Global Innovation Policy; Eurostat; The European Social Survey data & Transparency International	Statistics Denmark (Business register data)
Country coverage	29 countries (Austria, Belgium, Bulgaria, Cyprus, Croatia, Czech Republic, Germany, Denmark, Estonia, Greece, Spain, Finland, France, Hungary, Iceland, Ireland, Italy, Lithuania, Luxemburg, Latvia, Malta, Netherlands, Poland, Portugal,	6 countries (Bulgaria, Estonia, Lithuania, Hungary, Norway, and Portugal)	1 country (Denmark)

	Romania, Sweden, Slovenia, Norway and Turkey) [21]		
Time	2002-2010 (three CIS waves)	2010-2012 (one CIS wave)	2002-2015 (five CIS waves)
Key CIS variables applied	Barriers to innovation activities	Innovation activities Source of information	Innovation activities Source of information Objectives of innovation
Main strengths of CIS data	Public access to data Large number of countries Comparability across countries	Disaggregated data from more than one country.	Disaggregated data from more than one CIS wave. Can be linked with data from other sources.
Main weaknesses of CIS data	Different coverage of countries and variables for the chosen period. Limited availability and/or comparability of variables over a longer period of time. A few survey items.	Limited coverage of countries/time periods and variables. Limited comparability across countries.	Limited availability of variables over an entire period. Limited comparability over time.

Informing the selection of countries and time periods included

Chapter 3 draws on the EU-wide, comparable innovation statistics aggregated at the country level, publicly available on Eurostat's website. Even though the use of the micro-aggregated data was an option, it would have implied a considerably lower coverage of countries[22] and the analysis

[21] Not all included CIS waves are available for all countries. The CIS4 was available for 25 countries, CIS5 for 18 countries and CIS7 for 22 countries.

[22] The paper in Chapter 3 provides more detailed information on the coverage of countries by the separate rounds of CIS.

of a single reference period due to limited microdata availability. In comparison, CIS aggregate innovation statistics covers a large number of countries and a longer time period. For the purpose of this paper, I use time series of aggregate innovation statistics for the reference periods 2002-2010 (CIS4 (2002-2004), CIS5 (2004-2006) and CIS7 (2008-2010)), covering 25 countries. As previously indicated, the aggregates based on CIS are limited to the list of specified statistics in the Commission Regulation in the context of the specific round of the survey. As of the CIS4 edition, the list of specified statistics includes aggregates on the number of enterprises facing important factors (including the breakdown on types of factors) hampering innovation activities as a percentage of all innovative enterprises, which is the main indicator of interest for the analysis of this paper. The availability of comparable national statistics for a large sample of countries and different reference periods permits analysis of the environmental factors hampering innovation activities both across countries and over time. This is important because the NIS approach disregards the notion of optimality and thus the possibility to identify systems' strengths and weaknesses by means of comparing specified systems of innovation with an optimal one. From this follows that the only possible way to identify systems' strengths or weaknesses is by comparing them with one another (Edquist, 2005, 2011). Variables related to the following types of hampering factors are considered: costs, knowledge and market, as well as reasons not to innovate. The availability of several indicators on each kind of hampering factors allows for illustration of multidimensional characters of the features of IS in terms of factors – the framework conditions. The statistics are used for empirically identifying kinds of problems that can arise in given systems of innovation in countries and for classifying innovation systems in countries based on the pattern of identified kinds of problems as perceived by enterprises.

The core data for Chapter 4 are CIS micro-aggregated datasets provided by Eurostat via CD-ROMs. Micro-aggregation is a procedure used by Eurostat to protect statistical confidentiality in the data by averaging data for three similar firms. In preparation, I requested access to the micro-data available in the CD-ROM releases of CIS7 (2008-2010), CIS8 (2010-2012) and CIS9 (2012-2014). When the paper was conducted, the most recent data that were available were CIS7 and CIS8 for 14 countries. In order to address the research question, we needed a dataset that is as comprehensive as possible in terms of the relevant aspects of both firms' modes of innovation (based on CIS) and institutional setups and time and country coverage.

Based on further consideration of CIS micro-aggregated datasets for 14 countries and potentially relevant indicators on institutional set-ups from other sources, we narrowed down the sample to six small European countries and the most recent time period 2010-2012 (CIS8)[23]. Thus, the availability of the multiple European-wide cross-sectional CIS micro datasets, which are structured and administered in a relatively comparable way, permits me to construct a dataset that combines information from multiple countries and to conduct more refined cross-country comparisons of innovation modes of enterprises (paper in Chapter 4). Yet, limited coverage of countries/time on variables of interest considerably limited the scope of the study. The paper also utilises several other sources that provide internationally comparable country-level data on the institutional settings. The main sources on the institutional setting are Atkinson et al.'s (2012) 'Global Innovation Policy Index' for the variables reflecting institutional settings related to intellectual property rights (IPR) and the Eurostat's electronic database for the labour market system indicators, drawing on Lorenz (2015). These sources, in turn, mainly draw on a range of underlying survey-based data sources. The European Social Survey data are used to construct an aggregate index of trust in others, whereas Transparency International, a global civil-society organisation with a declared aim of fighting corruption, is the source for the survey-based corruption perception index.

The primary source of data for Chapter 5 is the Danish part of the European Community Innovation Survey, from 1998 to 2006 carried out by the Danish Institute for Studies in Research and Research Policy, but from 2008 and onwards conducted and provided by Statistics Denmark.[24] For the purpose of this study, I use micro-data sets from five waves of the Danish Community Innovation Survey, covering the period of 2002-2015.[25] Due to

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[23] The CIS8 is based on a standard core questionnaire, the third edition of Oslo Manual 2005 (OECD/Eurostat (2005)) and the Commission Regulation No 995/2012.

[24] Prior to CIS2000, three innovation surveys had been carried out at four-year intervals with the reference years 1992, 1996 and 2000. However, the questionnaire used in these years are not comparable to the questionnaire used from 1998 onwards (Danish Institute for Studies in Research and Research Policy, 2000). From the reference period 2007, the statistics are collected and published annually (Denmarks Statistik, 2012).

[25] In 2003, the Danish Institute for Studies in Research and Research Policy decided to conduct a combined R&D and innovation survey covering the period 2000-2002.

the lower quality of the Danish CIS data prior to 2000 and limited comparability with the forthcoming versions of CIS, the oldest wave of the survey data that is included in this paper refers to 2002-2004. I complement this data with the official business register data on additional structural characteristics of firms such as firm size, age, ownership and sectoral affiliation. This register data is also provided by Statistics Denmark and can be linked to CIS. The existence of several rounds of CIS results for the Danish business sector, that is, the cross-sectional CIS micro-data sets at different points in time, allows me to analyse firms' modes of innovation over a longer period (Chapter 5). The decision to look at the longer time interval came with cost since not all the variables of interest were available or comparable for the whole period of the study.

Both Chapter 4 and 5 rely on CIS microdata and utilise information on types of innovation activities. Other information taken into account for identifying and deriving firms' modes of innovation include sources and objectives of innovation. Both chapters focus on the multidimensional character of the innovation processes of firms in terms of organisation and strategic orientations.

While it is not the purpose of this section to provide a complete survey of available measures of innovation, a brief overview is in place to inform the selection process. The existing measures can be broadly categorised into: i) indirect and ii) direct measures of innovation. The indirect measure of innovation, an older area of data collection, include information on the efforts (expenditures and personnel resources) devoted to research comprising activities, outcomes of these activities (such as patents) or changes in the broader economic performances or structures (Vértesy, 2016). The direct measures of innovation can be further divided into two main types. The first of these types is based on the so-called "object" approach, since it focuses on the objective innovation output, usually identified through experts' assessments, through announcements of new products in trade journals or through literature-based surveys. Another distinction of this approach relates to the focus on significantly new technological innovation. Perhaps, the best-known example of the "object"

However, the number of questions related to issues of innovation is strongly limited in comparison to CIS2000 and later surveys (Danish Institute for Studies in Research and Research Policy, 2000).

approach is the Science Policy Research Unit (SPRU) database, which collected information on major technical innovations in British industry, based on a panel of technical experts (Smith, 2005). The second of these types is referred to as following a "subject" approach due to its focus on innovating firms, in terms of asking questions about innovation inputs (R&D and non-R&D activities) and outputs through surveys. The latter approach also includes incremental change in terms of innovation outputs. The example of the "subject" approach is the Oslo/CIS approach. Both "object" and "subject" approaches to measuring innovation also include various dimensions of the innovation process and rely on the common definition of innovation (Smith, 2005). Clearly, the indirect measures mentioned above differ from the direct measures also in terms of a more narrow conception of innovation activities and the outcomes they aim to measure. More specifically, there is a general consensus in the innovation studies literature that R&D activities (expenditures and personnel resources) and patents are rather input and output measures of the invention process rather than the innovation process. Moreover, there is a wealth of evidence, but especially since the availability of CIS data, that R&D activities are only one of the activities that firms use to innovate and that they account for only a fraction of the innovation activities occurring in firms.

The degree of comprehensiveness, the type and volume of the CIS microdata is an improvement and the most notable advantage in comparison to previously used innovation statistics such as patents and R&D statistics. In comparison to other sources of data such as R&D surveys and patent statistics, CIS covers: i) a wider range of innovation expenditures and activities than R&D; ii) different types of innovation outputs such as the product, process, organisational and marketing innovation as well as the percentage of sales due to incremental or radical innovation; and most importantly for this thesis iii) the information about the various aspects of the innovation process such as the sources of information on innovation, the cooperation partners, the aims or effects of innovation and the perceived barriers to innovation (Mairesse & Mohnen, 2007). The most important feature of the CIS microdata for the purpose of this thesis is that it provides information on the various activities and multiple aspects of the innovation processes of firms. Many of these aspects are considered as ingredients of the innovation processes that firms combine to innovate. For these reasons, I used information on types of innovation activities and aspects of innovation processes at the enterprise level such as information sources and objectives of innovation to identify and analyse firms' ways of innovating or modes of innovation that focus on multidimensional character rather than a single aspect of the innovation processes of firms (Chapters 4 and 5).

While the CIS data have a number of advantages over the R&D surveys and patent statistics, it also has several drawbacks. Mairesse and Mohnen (2007) point to several limitations related to the character of data from the CIS survey. The critical points that are also relevant for this thesis mainly refer to the subjective and censored characteristics of the data (Mairesse and Mohnen, 2007). Most of the data obtained from CIS are in the form of dichotomies; ordered and unordered categories. Clearly, these types of data are less precise and noisier than data in the form of real numbers. The lack of precision comes in part from the subjective nature of many of the responses that are based on the personal perceptions and judgments of the respondents. For example, what is defined as a “new or improved product” or “new to the firm” and “new to the market” is subject to a great deal of subjective judgment (Mairesse and Mohnen, 2007). Concerns have also been expressed about the possibly different interpretation of the concept “new to market” in environments with less developed infrastructure (OECD/Eurostat, 2005). The interpretive flexibility of the concepts may certainly be a significant source of variation in the data between firms, sectors and countries. This is in contrast to R&D or patent statistics because these are objective measures. This lack of precision is also the case for some CIS-based measures of innovation output. To illustrate, the sale measure of innovation output is based on respondents’ estimates of the percentage of sales in total sales due to new or significantly changed products (values rounded up to 15%, 20%, etc.). However, the results of the pilot and experimental surveys from the 1980s (Smith, 2005) showed that firms were able to make these estimates and the concerns about precision remained problematic. In addition, some of the quantitative variables are of low quality due to the high unit non-response rate or low accuracy. This is particularly the case for variables related to innovation expenditures on non-R&D activities. Some of the reasons for the low response rate or accuracy of data on the latter variable includes the absence of systematic, separate or detailed tracking of data on different categories of non-R&D activities on which respondents can draw from. Another weakness of the CIS data stems from the censored nature of variables that are collected only for a subset of firms in the total population. For example, questions on innovation activities are not required to be answered by the so-called non-innovators[26]. One of the implications of this approach is that we have very limited information on non-innovators. This is particularly relevant in the realm of econometrics studies due to issues such as selection bias. Another related issue that is worth mentioning is the advantages and disadvantages of using retrospective questions in the survey. The positive side relates to the potential to decrease some biases in the measurements of change, while the negative side relates to the so-called "recall error" (Greenan, N., & Lorenz, 2013).

3.2. Definitions and methodological considerations

Innovative firm

The objects of this CIS-data based study are innovative firms. My interpretation of the concept innovative firm is in line with the categorisation of innovators in the Oslo Manual-based CIS questionnaire, which is based on the introduction of at least one type of innovation and/or having ongoing or abandoned innovation activities in the three-year reference period, as specified by the definition. Due to the fact that the CIS questionnaire follows the Oslo Manual in terms of the definition of innovation, its different types and innovation activities, and hence innovative firms, this section discusses these terms in reference with the relevant Oslo Manual.

I also consider changes in the definitions of concepts between the subsequent CIS waves following the revised editions of the Oslo Manual, since different papers of this thesis cover data from different CIS editions that are based on the second, third or both editions of the Oslo Manual (OECD/Eurostat/EU, 1997; OECD/Eurostat, 2005). The definition of concepts innovation and innovation activities differs between the CIS rounds from CIS4 (2002-2004) to CIS7 (2008-2010) that are based on the second edition of 1997's Oslo Manual[27] and from CIS8 (2010-2012) onward

[26] As defined more narrowly, excluding those firms that have ongoing or abandoned innovation activities which have not (yet) resulted in the implementation of a new innovation in the reference period.

[27] The first two waves of the survey CIS light (2000-2002 or 2001-2003) and CIS2 (calendar year 1996) are based on the first edition of the Oslo Manual issued in 1992 (OECD/Eurostat/EC, 1997), while the third wave of the survey CIS3 (1998-

that are based on the third edition of 2005's Oslo Manual. The latest fourth edition of the Oslo Manual (2018) was published in 2018, but has not yet been used as a basis for collecting data on innovation. For this reason, I will not consider this edition of the Oslo Manual here.

In the second edition of the Oslo Manual (OECD/Eurostat/EU, 1997), the concepts technological product and process (TPP) innovations, activities and innovating firm are used. TPP innovations are defined as "implemented technologically new products and processes and significant technological improvements in products and processes" (OECD/Eurostat/EU, 1997, p. 31). TPP includes two types of innovation: product innovation (implementation/commercialisation of new and significantly improved goods and services) and process innovation (implementation/adoption of a new and significantly improved production or delivery method). Innovation activities related to TPP innovations are defined as "a series of scientific, technological, organisational, financial and commercial activities" (OECD/Eurostat/EU, 1997, p. 31). Finally, the TPP innovating firm is defined as "one that have implemented technologically new or significantly improved products and processes during the period under review" (OECD/Eurostat/EU, 1997, p. 31).

The exact definition of the concept innovation in the third edition of the Oslo Manual is "the implementation of a new or significantly improved product (good and service) or process, a new marketing method, or a new organisational method in business practices, workplace organisation or external relations" (OECD/Eurostat, 2005, p. 46). As compared to the previous definition of innovation, it is broader in scope, including two additional types of innovation: organisational (the implementation of a new organisational method) and marketing (implementation of a new marketing method). The additional change concerns the removal of the term "technological product and process - TPP". In addition, the definition of innovation activities has been modified, including the extension "steps which actually, or are intended to, lead to the implementation of innovation" and the removal of the term TPP (OECD/Eurostat, 2005, p. 47). The removal of the term TPP reflects the decision to capture the innovation outputs and activities of the service sectors more adequately. In turn, the

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2000) is based on the Oslo Manual — second edition of 1997 and third edition of 2005.

basic definition of innovative firm is “a firm that has implemented at least one innovation” (OECD/Eurostat, 2005, p. 58).

What is common to definitions of innovation in two editions of the manual is that all changes in firms’ products and functions as a minimum criterion must be new (or significantly improved in case of products and processes) to the firm in order to be regarded as an innovation. Moreover, the definition focuses on the implementation; it should be either implemented/commercialised in the case of product innovation or used/adopted in the case of the process, marketing or organisational innovations. Thus, the definition covers both generation and adoption of innovation developed by others.

An innovative firm in CIS can be defined on the output side, by the fact of having implemented one particular combination of any of the types of innovations in the reference period, as specified by the definition. An alternative strategy is to define innovative firms more broadly by also including enterprises with abandoned or ongoing innovation activities during the period under review, regardless of having successfully implemented an innovation. Finally, an innovative firm can be defined on the input side, by the fact of having pursued innovation activities for product and process innovations during the reference period (Mairesse & Mohnen, 2007). My definition of innovative enterprise throughout this thesis is uniform. I define innovative firms broadly as ones that have over the period under consideration successfully introduced a product (goods and services) and/or process innovation, but also firms that have abandoned innovation activities and/or ongoing innovation activities for product and process innovations. The adopted broad definition of innovative enterprises in this thesis reflects the main focus of research on innovation process itself rather than its outputs, as well as the encountered empirical considerations.

My definition of innovative firms does not include firms with other types of innovation, only namely organisational and/or marketing innovation, since these firms were not asked questions on activities and sources of innovation that were used for operationalising the modes of innovation. The problem is that some variables of interest are censored in CIS, that is, collected only for the subsets of innovative firms as defined in this thesis. An alternative strategy is to define innovative firms only on the input side, by the fact of having pursued innovation activities for product and process innovations as suggested by Mairesse and Mohnen (2007). This would have resulted in the same restrictions. In relation to Chapter 3, the aggregate statistics on factors hampering innovation activities of firms for all considered CIS editions were only available for the subsets of innovative firms as defined throughout this thesis.

Salazar and Holbrook (2003) emphasise a number of shortcomings associated with the dichotomous categorisation on innovators and non-innovators in the Oslo Manual-based CIS questionnaire, which is based on the definition of innovation that focuses on output rather than on the innovation process. More specifically, Salazar and Holbrook (2003) argue that exclusively focusing on particular types of innovation output such as product and process innovation might be of limited relevance to firms in service and resource-based sectors, under the assumption that firms in these sectors differ in terms of the types of innovation introduced from firms in the manufacturing sector. This concern is even more pronounced in the context of a growing predominance of the service sector in the last two decades, as well as in the case of economies in which resource-based sectors play a dominant role. While there is no general consensus, some studies have shown that the service sector does not differ that much from the manufacturing sector in terms of types of innovations and the ways innovation activities are carried out, and that a synthesis approach to the concept of innovation in the service as well as the manufacturing sectors is justified on the grounds of the existing empirical evidence (Drejer, 2004). Thus, while the categorisation of innovators based on other kinds of innovation would potentially more effectively capture innovative firms in other sectors, the data at hand do not allow me to solve this issue.

Despite this narrower definition of innovation, my definition of the innovative firm is not only limited to those firms that have successfully introduced any of the two types of innovation but is enlarged to include firms that have unsuccessfully tried to implement innovation or are in the process of implementing innovation. In addition, this narrower definition of innovation is necessary in order to ensure comparability with the results of earlier CIS waves that are based on different editions of the Oslo Manual.

Modes of learning and innovation

My definition of the term modes of innovation throughout the two chapters (4 and 5) of this thesis refers to how firms innovate or how different aspects of the innovation practices and/or strategies are combined. In turn my definition of modes of innovation encompasses various measures of the different features of the innovation practices of firms. I operationalise firms' modes of innovation by drawing on three broad measures provided in the harmonized CIS questionnaire: firms' innovation activities, the importance of sources of information for innovation, as well as the relevance of the aims of innovation activities. In both papers, I do not rely on innovation output measures – product, process, organisational and managerial innovation – to identify modes of innovation. The main reason for this is that the main interest in these chapters is on different ways of innovating in firms regardless of whether the practices resulted in the implementation of any of the types of innovation in the period under review.

In doing so, I rely on the methods of multivariate analysis, namely principal component analysis applied to the survey data, which allows for simultaneous analysis of three or more variables, as common in existing taxonomic studies that explicitly focus on the multifaceted phenomena of innovation practices or strategies of firms. One of the advantages of the adopted empirical approach is that it goes beyond a single measure or "generic" mode of innovation and therefore can provide a multi-dimensional description of the properties of the innovation modes of firms. Many of the concept indicators would also almost certainly display a high correlation amongst each other. That is why dimensionality reduction techniques are helpful here. Moreover, the complexities and non-linearities of innovation practices of firms (often assumed to be a more realistic representation of reality) are well captured and summarised by this empirical strategy. Thus, the observed patterns of innovation practices/strategies are used to inform the concept of modes of innovation guided by the research questions of the two papers of this thesis.

The choice of variables is based on reading a strand of research in connection with identifying innovation modes or strategies of firms. Modes of innovation or patterns of innovations have been studied at different levels of aggregation and along various dimensions, using a number of measures to capture the prominent features of the innovation process. As a result, a number of taxonomies and/or typologies of the innovation modes at the levels of firms, sectors and countries have been suggested. The common denominator for more recent taxonomic studies at the firm level is the appreciation of the complex, multidimensional and/or multilevel nature of the innovation process and the heterogeneity in the firms' innovative behaviours, activities, strategic orientations, work organisations, external interactions and outcomes. The emphasis on the complex and multidimensional nature of the innovation process is manifested both in the data sources and the empirical strategies used to derive the taxonomies. However, there is no universally accepted definition of modes of innovation apart from the common reference to different ways in which innovation is organised or takes place. Two dominant empirical strategies also reflect the differences in respect to more theoretically or data-driven approaches in deciding the most important dimensions of the innovation process.

My definition and use of the concept modes of innovation in Chapters 4 and 5 is to a large extent in line with the strand of IS literature that focusses on how firms combine practices to generate knowledge and engage in learning. However, I include aspects of firms' innovation practices that are also common in broader literature, such as the relevance of objectives for innovation. I also employ exploratory data analysis. Building on the argument of Srholec et al. (2008), one reason is that the innovation mode of a firm is a multifaceted phenomenon in terms of various aspects of innovation processes, which might not necessarily be captured in too broad and *a priory* specified modes of learning. More importantly, other aspects of firms' innovation practices are not incompatible with the concept modes of learning, but allow for better understanding on how modes of learning considered to be an aspect of a firm's strategy are related to other aspects of innovation strategies of firms. Finally, the quality of data at hand puts limitations on having a strict and precise definition of innovation modes.

The variables feeding into the analysis of modes of innovation differ between the two papers presented in Chapters 4 and 5, due to differences in available and internationally or temporally comparable data or encountered trade-offs depending on the research aim of the given paper (see Table 4). One implication of different variables feeding into the analysis of modes of innovation within the two papers is that reported innovation modes differ and are not straightforwardly comparable. The main difference across the two papers is the extent to which innovation activities and the relevance of different aims of innovation are covered by the modes, resulting in either a narrower or broader definition. In Chapter 4, innovation modes are identified through information on types of innovation activities such as internal and external R&D activities and training for innovation activities as well as a number of variables on sources of innovation. Information on sources of innovation is based on firms' assessments of the importance of the following ten sources: sources within the enterprise, suppliers of equipment, etc., clients or customers, competitors, consultants, etc., universities, government or public and private research institutes, conferences, etc., journals, etc. and professional organisations. In reference to the paper presented in Chapter 5, the information on types of innovation activities is limited to R&D activity only, while including measures on the importance of various objectives of innovation activities in addition to sources of information. Information of relevance is based on firms' assessments of the relevance of the following seven objectives: increased market share; improved quality of goods and services; improved production flexibility; improved production capacity; reduced costs of produced units; and improved environmental impacts or health and safety aspects.

Table 4. Overview of Chapters 4 and 5 identifying modes of innovation

Paper	Data	Measures used for modes of innovation	Methodology
Chapter 4 ***"Institutional Context and Modes of Innovation in National Systems of Innovation: A Study of Six Small European Countries"***	Eurostat's CD-ROM release CIS8 (2010-2012)	• **Innovation activities** (In-house and external R&D; and training for personnel for innovation activities) • **Importance of source of information**	Exploratory principal component analysis
Chapter 5 ***"Continuity and Changes in Modes of Innovation "***	Statistics Denmark's CIS database (2002-2015)	• **Innovation activities** (FTE of R&D personnel) • **Importance of source of information** • **Importance of aims of innovation activities**	Exploratory principal component analysis

However, the CIS data provide additional information on the aspects of the innovation practices of firms that could have been used for describing how firms innovate, such as information on a range of innovation activities in addition to R&D and training of personnel for innovation, types of cooperation partners and methods of protecting innovation. For example, CIS provides information on four additional categories of innovation activity, such as acquisition of machinery, equipment and software, acquisition of external knowledge, market introduction of innovations and others. The large number of missing values on additional variables on the aspects of innovation practices for most of the considered countries in reference to the paper presented in Chapter 4, restricted my consideration of those aspects. The inclusion of the full breadth of variables would have provided a more nuanced and complete picture of how firms innovate, but it would have made any type of cross-country analysis impossible. Similarly, information on additional aspects of innovation practices of firms had to be left out of the analysis in Chapter 5 due to a large number of missing values and/or breaks in the variables of interest for some waves of the survey, as well as inconsistencies in the variables of interest across the waves of the survey. While taking into account greater number of variables would clearly have resulted in a broader view of firms' innovation modes, it would have considerably limited the investigation period. This limitation would have limited the examination of changes in modes of innovation over a shortened period of time, which is not preferable for the issue at hand since changes are expected to occur over an extended timescale and therefore might not be capturable within the shorter time period. Consequently, my operationalisation of the innovation modes of firms in the two papers of this thesis does not cover all aspects of firms' potential variations in innovative practices/strategies, but is limited to certain aspects that still enable me to assess differences in modes of innovation, given the specific objectives of the two papers. Moreover, the composite measures of dimensions of modes of innovation that CIS data allow me to derive, measure a broad interpretation of innovative behaviours of enterprises.

It is worth noting that both papers use categorical data on whether the firm has engaged in a specific innovation activity(s) rather than an alternative measure provided in CIS, namely, the expenditures on various categories of innovation activity. An obvious weakness of the former measure is that it treats each CIS innovating respondent firm equally, whether the firm spends a lot or a little on each activity. The issue is that the categorical variables measuring innovation activities might not be able to capture the essence of the firms' innovation activities. In comparison, the measures of expenditure on each innovation activity are useful for providing insight on both the propensity and the intensity of innovation activity. However, the variables related to innovation expenditures, but especially on non-R&D activities, are generally of low quality due to the high unit non-response rate or low accuracy. Some of the reasons for the low response rate or accuracy of data on the latter variable includes the absence of systematic, separate or detailed tracking of data on different categories of non-R&D activities on which respondents can draw from (Mairesse & Mohnen, 2007). Nevertheless, I am primarily interested in understanding what kinds of innovation practices a firm engages in and how they are combined, rather than how many resources firms devote to any specific innovation activity.

The environment: Institutions and processes in the NIS

While the paper in Chapter 4 focuses on the national institutional environment for firms' organisation and modes of innovation, the paper in Chapter 5 focuses on the national environmental conditions or processes for firms' abilities to generate technological dynamics (i.e., innovation, diffusion and use of technology) and for the technological dynamics of a nation. Here, it is important to keep in mind the different understandings of the NIS as an environment outlined earlier.

Institutions in the NIS

The literature reviewed in Section 2.2, the related IS theory and research, and more particularly the Aalborg strand of NIS literature provides the general framework to analyse the connection between the national institutional characteristics and the organisational aspects of innovation, and thereby innovation modes at the country level. The aspects of the institutional context of countries that are analysed in Chapter 4 and the adopted broad methodology are guided by this general formulation. In the existing empirical studies, from the NIS perspective, the most commonly measured aspect of the national institutional context that may affect the differentiated application of modes of learning and knowledge creation across firms and countries are related to labour market organisation. Nevertheless, other kinds of both formal and informal institutions related to intellectual property rights (IPR), levels of trust, welfare state characteristics, and education systems and vocational trainings are also mentioned in the literature as obvious candidates for assessing the institutional context of countries in relation to how people work and learn (Arundel et al., 2007). In addition, how firms and/or countries combine modes of learning and innovation (Jensen et al., 2007) are obvious candidates. In this work, we focused on both formal and informal institutional settings related to levels of IPR protection and enforcement, labour market organisation characteristics, levels of trust in others as well as corruption perceptions, while neglecting other kinds of institutions. Thus, the considered types of institutions provide a broader view of the institutional context compared with the existing comparative empirical research exploring the links between the modes of innovation and institutional contexts of countries within Europe. Arguable, these additional aspects are useful to include, since on the one hand, all of these aspects fall within the realm of institutional contexts and some of these aspects may be strongly interrelated on the other hand. For example, as argued by Holm et al. (2010), high degrees of trust might be a necessary ingredient in order for the national systems of countries to benefit from adopting the flexible security model of organising a labour market.

The patterns of institutional settings are identified through clustering analysis, which allows the simultaneous grouping of the sample countries based on the similarities and differences in institutional profiles along several dimensions. The method makes it possible to usefully account for the interdependent and complex nature of the various dimensions of the institutional environment and varieties of institutional profiles across country groups, which is of great relevance for analysis of national innovation systems. Consequently, similar systems can have quite different outcomes, and different systems can have similar outcomes. What matters is the particular configurations and the complementarities/synergies it triggers. Therefore, clustering is a highly appropriate technique.

Nevertheless, the identification of institutional settings carried out in this paper has weaknesses mainly due to the lack of high quality and internationally comparable data on a complex phenomenon such as institutional setting for a large group of countries. I discuss these issues in more detail and make explicit suggestions for future data collection at the end of Chapter 4.

Processes in the NIS

The main argument put forward in the earlier IS literature is that for the government to be able to determine what needs to be done in order to promote innovation in the system, it is useful to understand the context and the characteristics of the economic and institutional environment, which determine the rate and direction of innovation activities. The risks of not taking into account the context in which government intervenes is that weaknesses of the system might be reinforced and mechanisms may be introduced that might further undermine effective functioning of the system (Bengt-Åke Lundvall, 2010). The recent example of this approach is an empirically oriented attempt to quantify the dimensions that characterise NIS and to provide micro-level data based descriptions of the varieties of the National Innovation Systems in Europe (Wirkierman, Ciarli, & Savona, 2018). Wirkierman et al. (2018) operationalise the characteristics of NIS based on micro CIS-based indicators along the four dimensions: innovation inputs and demand sources (e.g. average total expenditures per innovative firm); geography and type of cooperation links (e.g. share of innovative firms engaged in co-operation with clients or customers from the public sector); public sector policies in the form of public procurement and indirect support to firms (e.g. share of enterprises that received funding from central governments) and innovation outputs (e.g. share of innovative firms that applied for patents). The authors proceed by qualitatively analysing differences in country rankings across the four dimensions in terms of how well the countries perform, as well as the relevant combinations between the four dimensions, including country clustering based on these dimensions (Wirkierman et al., 2018). While I rely on the CIS data and follow a similar empirical strategy in quantifying the dimensions that characterise NIS and in mapping the varieties of NIS, there is only limited overlap with the conceptual basis of the dimensions of NIS and no overlap with the indicators used in the present analysis to identify the weaknesses that characterise NIS. Here, I mainly consider publicly available innovation statistics based on aggregated CIS data.

The approach taken in the paper presented in Chapter 3 is in line with the strand of IS literature, where the focus of analysis is on the operation of the innovation system as a whole broken down by activities affecting the innovation processes that happen within the existing systems of innovation rather than on the features of components and relationships between them or the outputs, as discussed above. The examples of activities are provision of knowledge inputs, financing of innovation and the provision of demand.

From this perspective, understanding the weaknesses in each of the activities in systems of innovation is the starting point for understanding the role of government in supporting innovation as well as for the design of innovation policy (Chaminade & Edquist, 2005). However, the latter literature does not provide a single definition of activities that capture the dimensions of the system as a whole, and that can be linked to innovation apart from the common emphasis on the determinants of the development and diffusion of innovation in the context of NIS (Chaminade & Edquist, 2006). Moreover, there is no widely accepted or agreed upon method of measurement of innovation activities at the system level or methodology for comparative empirical assessment of such activities. The examples of how this approach can be used for studying IS at the national level for the purpose of policy analysis are Edquist (2011), Edquist et al. (2015) and more recently Fagerberg (2016).

The related line of research that is worth mentioning here and that somewhat overlaps with the "activities approach" includes work on complex, composite indices and micro-grounded indexes of the national innovation systems' performance based on the indicators that are of direct relevance to firms' innovation activities (Arundel & Hollanders, 2005; OECD, 2009). In Arundel and Hollanders (2005), the large number of mainly CIS-based indicators of innovation are arranged into six broad themes: innovation diversity, market demand, innovation skills, innovation investment, knowledge flows, and innovation governance. The resulting thematic indices and an overall summary index that averages the results of indices are then used to rank countries and to compare performance. Finally, it is worth mentioning a Summary Innovation Index, provided by the European Commission which is based on a large number of indicators divided into three categories (e.g. input, output and enablers) and eight dimensions (e.g. human resources, research systems, finance and support, innovation investments, linkages and entrepreneurship, intellectual assets, innovators and economic effects). Here, EU member states are grouped into different performance groups based on average innovation performances scores. The latter index has been criticised on the grounds of providing limited discussion on the conceptual and theoretical background of the selected dimensions and categories, as well as the specific indicators and their relationship (Edquist et al., 2015). The main differences between the two approaches are in what are considered to be the relevant indicators for policy purposes and the need for clear distinctions between the determinants-core dimensions and output indicators of IS and a systemic analysis.

Although Chapter 3 complements previously discussed empirical work by quantifying the complex dimensions of NIS and by providing a new mapping of national innovation systems in Europe, my approach differs in several respects. The main purpose of this chapter is to empirically identify and map out the composite dimensions of NIS in terms of system-wide activities, with particular emphasis on the weaknesses and areas of need for political interventions at the country level, and to explore the possibility of using CIS-data for these purposes. Thus, my aim is not to provide the comprehensive study of national innovation systems in different countries, but to shed light on some weaknesses of NIS and varieties of NIS in Europe in this respect. For this reason, I employ the theoretical framework that has been developed with innovation policy in mind and that can usefully be applied in analysis of the activities and, thereby, the weaknesses in innovation systems at national levels. In this framework, the public policies and programs are the starting point of the analysis and only those activities and institutions in NIS that can be influenced by public intervention are considered. Here, NIS is understood as a framework for interaction, but also a repository of various resources on which successful innovation in firms depend on, as well as a home to different influential institutions (Fagerberg et al., 2017). In other words, NIS is understood as a framework of incentives and obstacles as well as a framework of enabling or hindering factors. In turn, the system-wide activities or processes in NIS are interpreted as provisions of those factors on which successful innovation in firms depend on, and which policy may influence. These activities are grouped into five broad categories: knowledge, skills, demand, finance and institutions (Fagerberg, 2016). In line with the previous definition of NIS and activities/processes in NIS, the weaknesses in any of the previously discussed activities in NIS is understood as "system failure" hampering innovation activity that policy needs to address. Examples of systemic weaknesses include lack of knowledge generation or R&D, inadequate skills to generate innovation, uncertainty about the demand for innovation or incomplete legal protection of knowledge. Thus, from this perspective the systemic weaknesses are related to insufficient provision of factors in the system that affect the generation and diffusion of innovation and that can and are shaped by policy action in these areas at the national level.

The dimensions of NIS feeding into the analysis and the proposed methodology for empirically identifying and mapping the weaknesses of NIS in the context of European countries are guided by the selected theoretical framework. The NIS dimensions analysed in this paper are empirically derived by drawing on several system-wide indicators at the national level in order to provide more informative composite measures of system weaknesses in NIS. I distinguish indicators referring to the five generic processes labelled as knowledge, skills, demand, finance and institutions, all contributing to the multi-dimensional representation of weaknesses in NIS. For the empirical analysis of the dimension representing knowledge, market and finance, I use CIS aggregate indicators, which in turn are constructed based on the CIS question of the perceived importance of “knowledge”, “market” and “costs” as factors hampering innovation activities of firms. For the analysis of the dimensions representing institutions, I used two indexes covering the degree of protection and enforcement of the property rights and the efficiency of government regulation of business from the Heritage Foundation’s Index of Economic Freedoms, and one index from the Transparency International Corruption Perception Index measuring the degree of perceived corruption. The three indicators are general measures of quality of governance in a more broad relation to innovation and economy.

The main advantage of the use of aggregate CIS indicators on the importance of various factors hampering innovation activities of firms is that it allows me to represent systemic weaknesses in terms of how country-specific innovative firms perceive the conditions in which the firms operate, at least with respect to generic processes such as knowledge, market and finance. The innovation indicators based on aggregate data, such as those published by the OECD and Eurostat, are commonly used for benchmarking innovation performance of countries and for identifying gaps in NIS (e.g. the proportion of innovative firms may be smaller than in other countries) (OECD, 2009). However, the weakness is that the results could be confounded by other factors, as pointed out by Arundel (2005). For example, poor quality of skills could be due to a combination of true education factors that we want to measure and the characteristics of firms’ technical competencies and skills that we do not want to measure here (the ability of the firms to make use of the skills available in the system). In order to assess the firm-level indicators of the proposed system’s weakness, it could be useful to compare the country-ranking on additional sets of general, economy-wide aggregate indicators, such as educational attainment, and see whether the ranking of countries is significantly different. Nevertheless, this invites other problems. First, the indicators of general education attainment might or might not be directly relevant for innovative firms. Second, the differences in the ranking of a country on the two suggested types of indicators could also be driven by the time lag between the supply and demand of skills or the net loss of skills due to negative migration flow in a country (Borras et al., 2015), rather than true insufficient ability of an educational system to provide for the skills that its firms need for innovation or the inability of firms to make use of these skills. Moreover, general trends in the socio-economic conditions may influence firms' perceptions of the conditions, adding to the complexity. Another obvious drawback is that the information in CIS on factors hampering innovation in IS is limited to respective areas. So, the available indicators give a partial picture of what we intend to measure.

The indicators of factors hampering innovation activities are not the only available CIS indicators that may relate to IS as an environment (e.g. infrastructure, networks, institutions, government support). Alternative indicators include the characteristics of the public-private linkages or the nature of public support. However, I decided to leave out these indicators since these reflect the specific linkages or support instruments for innovation; that is policy actions, rather than generic features of the market context and institutions that are the main focus of this paper. Yet, as pointed out by Borras et al. (2013), it may be difficult to make a clear distinction between the weaknesses that are the direct outcome of the wider environmental features or when they are related to the dynamics created by public policies. Despite these complexities and limited numbers of indicators used, the exploration of weaknesses in IS across countries and over time based on CIS national statistics is helpful to uncover the existence of patterns and varieties of NIS.

While the empirical methodology adopted in this thesis can be seen as a useful first attempt in the identification of systemic weaknesses and hence areas where public intervention is needed, it also has its weaknesses and requires further refinements as the knowledge about the role of the innovation environment, including policy actions, increases. This is in addition to improvements in the quality and availability of data.

4. Conclusion

This last section includes a summary of the four papers presented in this thesis (Section 4.1), a contribution for the research field and policy (Section 4.2) and a detailed overview of the main limitations of the analysis with suggestions for future data collection efforts and research (Section 4.3).

4.1. Thesis Summary

This thesis starts with the paper in Chapter 2 that takes a rather different approach and investigates the topic of the current state and evolution of IS as a field of research, rather than nation-specific distributions of the firms' modes of innovation or the broader context in which firms operate and innovate. Chapter 2 can be seen as relevant to all other papers in this thesis as it can provide an illustration of how the papers presented in this thesis overlap with and embrace other streams of literature. The papers that are presented in Chapters 3-5 explore various aspects of the questions posed in the introductory section. Chapters 4 and 5 deal with the modes of innovation (both at the firm and national levels) and/or how these modes are combined in different NIS(s) or at different points of time, whereas Chapter 4 also considers the institutional factors outside the enterprise sector (the nation specific institutional set-ups and how these are related to modes of innovation of firms). Chapter 3 only deals with the factors outside the enterprise sector, but here the main focus is on the systems' processes (or the activities of subsystems such as the financial system) shaped by government policy measures and institutions and the different (in)abilities of different national systems to fulfil the function of effectively supporting the generation, use and diffusion of innovation (at the national level). The following section presents a short summary of the four papers of this thesis.

Chapter 2 analyses the IS as a field of research that has grown in importance and undergone expansion in terms of an accumulated body of literature, as well as a growing community of users from other fields of research. These trends have resulted in a blurring of field's boundaries as reflected in the diversity of research efforts and theoretical foundations it consists and draws from in advancing the field. It analyses the current state of IS research, its internal structure of specialisations and the knowledge bases it draws from. Using the bibliometric corpus of data extracted from the Web of Science (WoS) database and consisting of IS-related publications (6,370) and cited references (162,600) covering the 1980–2018 period, this paper delineates the field of more recent IS research and identifies consistent research areas and knowledge bases that the field consists of and that have contributed to the field's advances. In addition, the paper makes use of the conceptual and analytical distinction between the research areas and knowledge bases to explicitly consider the process of knowledge integration in the identified research areas and the field of IS. When it comes to the process of knowledge integration, two indicators of coherence and diversity are used to describe it. It highlights the distinct patterns of knowledge integration and the heterogeneity of processes of knowledge integration taking place in different research areas. In terms of the IS field, a growing tendency towards increasing diversity in the knowledge bases, accompanied by a decreasing coherence of collective research efforts is evident in this paper. Overall, we argue that the pursuit of further knowledge integration in the IS field requires effort towards obtaining both higher diversity and internal coherence. The findings of this paper point towards the field's internal dynamics of coherence and diversity, the crucial role that the interdisciplinary journals such as *Research Policy* and the intergovernmental organisations such as the Organisation for Economic Cooperation and Development (OECD) and academic entrepreneurs played in shaping the developments of interdisciplinary and diverse fields. Moreover, a tendency of fragmented specialisation of collective research efforts as the field grows larger in size and more diverse in terms of thematic orientations may provide insights for other research fields, but especially those that thrive towards responding to the grand challenges posed by policy and society that requires a diversity of knowledge basis to address them.

Chapter 3 deals with the broader setting of NIS as a nation-specific context in which firms operate and innovate. As noted above, particular attention is given to the systems' activities or processes in the public sphere as one aspect of the broader setting of NIS that influences the technological dynamics of a nation, and to assess the varieties of NISs at the EU level with respect to the extent to which these processes might be systemic problems in regards to hampering innovation activities of firms operating within. Here, the system problems are defined from a policy point of view in relation to the processes (including policies) that prevent the system from accomplishing the objective of supporting the development, use and diffusion of economically useful knowledge and innovation. Using aggregate CIS-based indicators on the degree of importance of various nation-specific hampering factors from the three waves of surveys referring respectively to the three time periods, 2002-2004 (CIS4), 2004-2006 (CIS6) and 2008-2010 (CIS10), and covering 26 EU countries (Austria, Belgium, Bulgaria, Cyprus, the Czech Republic, Germany, Denmark, Estonia, Greece, Spain, Finland, France, Croatia, Hungary, Ireland, Italy, Lithuania, Luxembourg, Latvia, Malta, the Netherlands, Poland, Portugal, Romania, Slovenia and Sweden) and three non-EU countries (Iceland, Norway and Turkey), I find that the relative importance of the five identified system problems differ across innovation systems and over time. Overall, the findings may provide insights for policy makers to define their innovation strategies and chose policy instruments in line with the specificities of their innovation systems in terms of the systems' weaknesses or problems as perceived by firms operating within.

Chapter 4 explores the association between the national institutional settings and firms' modes of innovation from an NIS perspective. The particular focus is on institutions at the national level related to intellectual property rights protections, labour market systems, as well as customs and perceptions related to trust due to the potential effects on the types of innovation efforts undertaken and the ways that firms organise innovation activities, mainly in terms of internal and external R&D, training regarding innovation activities and the sources of firms' modes of innovation. The institutional settings and modes of innovation are identified by using a range of primarily survey-based data on the characteristics of national institutional settings and micro-aggregated data obtained from the Community Innovation Survey 2012 for six small European countries (Bulgaria, Estonia, Lithuania, Hungary, Portugal and Norway), respectively. By linking the patterns observed in the two cluster analyses, this paper finds some support for the proposition of national institutional settings being reflected in firms' modes of innovation. However, the results are most conclusive for the two countries (Norway and Bulgaria) where the innovation modes identified as being dominant represent a relatively good reflection of the countries' institutional settings. The association found in the remaining country(s) groups is more complex, which in turn might reflect the need to take the broader, country-specific context into account for this type of analysis. The findings direct attention to policy-related evidence that could be gained through the development of better quality data for this type of analysis and by analysing a larger number of countries.

Chapter 5 is again identifying firms' modes of innovation, but this time in the context of a single country and focusing on stability and change over time at both the country and the firm level. By using the pooled firm-level data from both the Business Register and the Danish part of the European Community Innovation Survey (five waves) covering the period 2002-2015, I found that the composition in terms of the frequency of the four distinct firms' modes of innovation in the population of innovative firms has changed very little over time. These findings point towards the stable evolving nature of the Danish innovation system in terms of the stable mix of strategies in the population of innovative firms, but mainly with the predominant process-external mode of innovation. Moreover, while all identified initial firms' modes of innovation negatively affect the probability of change or upgrading in the subsequent period, I found different degrees of stability across firms' modes of innovation. The paper contributes to research in the tradition of both evolutionary theory of the firm and the strategic management literature that focuses on the determinants of the persistence of firms' innovation output behaviours as aspects of the long and lasting strategic choices of firms with respect to the ways of pursuing innovation goals. It does so by formally testing in the Danish case, the underlying assumption that firms' strategic choices on the ways of pursuing innovation are stable and differentiated over time in terms of the stability and differentiated nature of innovation modes of firms within countries.

4.2. Contributions

This thesis makes several contributions. It contributes to the innovation studies research more broadly and the innovation system research more particularly. It also provides insights for policy makers that aim to create favourable framework conditions for the innovation processes in firms, and thus shape the technological dynamics of the system as a whole.

The contribution of this thesis to the innovation studies and the innovation system research is as follows:

i) Mapping the current knowledge frontier of the innovation systems field of research, identifying the distinct research areas advancing the literature on systemic approaches to innovation and knowledge bases, tracing the processes of knowledge integration across the research areas and over *time, and reviewing the current state and the evolving nature of the field of research.*

The previous research provides rich evidence on the origins, context and the evolution of NIS or innovation studies research fields more broadly, starting from what is considered as fields' historical core literature and mainly focusing on the institutional and organisational dimension in terms of the intellectual structure of the field and its changes over time. However, to our knowledge no previous work has taken into account the emergence of new contributions and their relative importance across diverse research areas and over time. Similarly, no previous attempt has been made to analyse the structure and processes of knowledge production in terms of research areas composing the field. Chapter 2 addresses these research avenues by utilising a novel methodology in the context of the academic research field analysis. It turns out that the chosen methodology proves useful for: i) delineating an interdisciplinary academic field with blurry boundaries; ii) identifying and disentangling the structure of knowledge production and the underlying knowledge bases; iii) creating summaries of distinct research areas and content; and iv) creating insights into the knowledge integration processes within and across the research areas and over time and the accompanying dynamics of coherence and diversity. Moreover, the conceptual framework and methodology of Chapter 2 may be applied to map and understand other academic fields with similar characteristics. Chapter 2 provides insights on distinct research areas of the IS field and heterogeneous knowledge bases, as well as different trajectories in the underlying knowledge integration process across the identified research areas and over time. These insights contribute to a more nuanced understanding of the diversity of research efforts that constitute the IS field of research, and that have contributed to its advances, as well as a tendency over time towards increasing diversity and decreasing coherence of collective research efforts within the field. More broadly, such insights further advance our understanding of how research fields in general develop and the promising development paths.

ii) Assessing NISs at the EU level in terms of perceived problems or weaknesses in systems' activities

The NIS literature that focusses on functions, activities or processes in the national system or the public sphere that influence the technological dynamics of a country provide several analytical frameworks to analyse IS for policy purposes. Similarly, the literature on systemic problems offers various definitions and typologies of systemic problems that may occur in the IS. However, the efforts to empirically identify and quantify these activities and related problems in the NIS context have been less forthcoming. Moreover, the empirical assessment of NIS at a country or varieties of NISs at the EU level in terms of the extent to which these processes might be system problems in regards to hampering innovation activities of firms remains a challenge. The activities in the public sphere of NIS in areas such as knowledge, skills, demand, finance, and institutions are chosen since firms depend on them in innovation activities and policy makers can address them by policy interventions. Chapter 3 shows that the relative importance of identified systems' problems differs across innovation systems and over time suggesting that these differences need to be taken into account when analysing national innovation systems and innovation performances. Thus, the findings show that the actual or most pertinent systems' problems or weaknesses might not be revealed by studying a single process of the systems, and more importantly that these should not be treated as equally important in different national contexts and at different points in time. This contributes to the literature that deals with the determinants of the innovation or learning/capabilities of a national system of innovation, and more particularly to literature dealing with the activities in NIS and the literature on systemic problems. It does so by combining both innovation system processes (or activities) and systemic problems in an integrated analysis to assess the varieties of NISs at the EU level, by testing the framework empirically and proposing the methodology for assessing the NISs at the EU level in terms of weaknesses or problems. In doing so this paper helps answer the research question: How different features of the wider national contexts (systems' activities) in which innovation activities of firms take place are related to each other in a systemic way, in particular regarding the broad patterns and varieties of NISs at the EU level with regards to weaknesses in systems' activities.

iii) Exploring the role of national institutions in NIS in affecting the behaviours of innovative firms

The role of national institutions in NIS is explicitly discussed in only a few contributions, while the empirical evidence on how national institutions affect the behaviours of innovative firms is limited. Furthermore, the distinctions between the institutional factors at the national level and regularities of behaviours embedded in the organisational practices and forms of firms and the organised markets between firms and other organisations is rarely made explicit in empirical settings. The firms' innovation behaviours as expressed in modes of learning and innovation are usually assumed to reflect the institutional specificities in the areas such as education and training systems, labour markets, trust and welfare regimes at the national level. Moreover, national institutional differences are assumed to remain substantial and to have a systemic character. However, the issues of whether and the extent to which broader national institutional settings or some particular aspects of it is reflected in firms' innovative behaviours are rarely considered. Finally, most of the existing work on innovation modes of firms has been conducted at the level of single countries or a single industry across several countries. While studies conducted at the level of a single country allow for identifying the specificity of modes of innovation in the given country, the question of the differences in firms' modes of innovation in different institutional settings remains unexplored. Chapter 4 tackles these questions and shows some support for the idea that the national institutional setting is reflected in firms' modes of innovation. While assessing the relationship between the firms' modes of innovation and institutional settings at the national level is an inherently complex endeavour, since both phenomena are intrinsically multidimensional, measurement efforts enabled me to explore the proposed relations along several dimensions. Such insights contribute to a broader understanding of the role played by national institutions in the functioning of national innovation systems, as reflected in the behaviours of innovative firms, thus contributing to the NIS literature both theoretically and empirically. This paper contributes to answering all three research questions: i) How innovation and competence building takes place inside firms and between firms/other organisations, and across countries, in particular, national patterns of modes of innovation; ii) How different features of the wider national contexts (institutional settings) in which innovation activities of firms taking place are related to each other in a systemic way, in terms of the institutional profiles of NISs in considered countries; and iii) How alternative (nation-specific institutional and policy related) set-ups are related to innovation and competence building, in particular to the link between institutional settings and firms' modes of innovation.

iv) Assessing the stability and change of firms' modes of innovation in NIS

Although the innovation studies literature dealing with identifying firms' modes of innovation based on innovation survey databases provides a wealth of evidence on the natures and backgrounds, the dynamic aspects of these modes has received much less attention. This is mainly due to the fact that most of the studies that deal with identifying firms' modes of innovation take into account only a single wave of the innovation survey. Chapter 3 addresses the issue of stability and changes in firms' modes of innovation by constructing a panel database from repeated innovation surveys in a single country. By doing so, Chapter 5 shows that the distribution of the identified firms' modes of innovation in the Danish context is rather stable and no systematic tendency towards the adoption of any specific mode is observed over time, despite the fact that switches in modes of innovation of firms do take place. It also shows that firms' initial modes of innovation have negative effects on the probability of change, but the negative effects increase with broader scope in the initial modes of innovation (i.e. firms initially found in the low-profile modes of innovation are less likely to change and upgrade modes). These insights contribute to a better understanding of the differences in the degrees of persistence across firms' modes or strategies of innovation as well as how an innovation system evolves in terms of the changes in the mix of strategies in the population of innovative firms. The approach adopted in this paper, which depends on the joining of several waves of CIS, represents an improvement over the most common analysis of firms' modes of innovation that is based on innovation activities of firms in a single period. This paper answers the following research questions: i) How innovation and competence building takes place inside firms and between firms and over time (nation-specific modes of learning and innovation), in particular regarding the temporal patterns of modes of innovation.

In what follows, these findings are viewed in an innovation policy context.

With regards to the contribution of this thesis to innovation policy, the findings in Chapter 3 suggest that the knowledge about the systems' weaknesses or problems[28] as perceived by innovative firms, and the differences in relative importance across different NISs across EU countries and over time allows policy makers to take into account these specificities

[28] Systems' weaknesses or problems are understood in relation to a system's capacity to sufficiently provide for factors in areas such as knowledge, skills, demand, finance and institutions which firms depend on in innovation activities.

when designing, implementing and evaluating innovation policies. By using this knowledge, policy makers can focus their actions on areas where system problems occur (e.g. a lack of skills hindering innovation activities) and select policy measures with respect to distinct kinds of system problems. It can be used to give priority to the most pertinent system problems when implementing these policy measures. By providing more specific policy recommendations, this knowledge may also prevent policy makers from adopting too narrow or generic innovation policies ("one size fit all"), as well as from copying or borrowing innovation policies developed elsewhere since these might not match the actual system's problems and therefore might not deliver the desired or intended results. For example, a government might choose to support business innovation by subsidising R&D, where the actual obstacle is access to skills. More importantly, it can be used for evaluating current government policies regarding whether the right problems or weaknesses have been addressed or whether the major problems have been prioritised. This can be done by comparing the identified system's problems and actual applied policy programs. Such mismatches between adopted innovation policy instruments and systems' problems and the resulting policy gaps have been identified in Thailand (Chaminade, Intarakumnerd, & Sapprasert, 2012). Potentially, the "fit" between the system's identified weaknesses and already applied policy measures can be used to evaluate the success of policy measures as suggested by Woolthuis et al. (2005). Therefore, by adopting more differentiated and flexible policies based on the knowledge of systems' specific problems, policy makers in different national systems of innovation may help to address needs and eventually rectify some of the actual or perceived system's specific problems. Such knowledge can be complementary to knowledge about the system's favourable features such as the high R&D intensity or the participation rate in the higher education system of the country. In other words, having both knowledge about the system's problems or weaknesses and its favourable features may allow policy makers to design better policies addressing problems and supporting (or renewing) strengths in their respective systems. This in turn raises further implications for the need for more systemic assessments of both weakness and strengths of innovation systems and competencies to do so, as well as more coordinated implementations of policy initiatives by policy makers.

Moreover, Chapter 4 suggests that the knowledge concerning the extent to which institutional settings may be associated with particular modes of innovation allows policy makers to take into account the institutional barriers as well as the facilitating features when assessing whether – and which – initiatives should be implemented to support particular modes of innovation. Such institutional features are often not considered when designing and implementing innovation policies, despite being a context in which policy instruments are implemented. Such omissions, in turn, may result in failure to recognize that the current institutional setting may undermine or obstruct the innovation policy instruments' impact on innovation by providing fewer conducive conditions for implementation. For example, a lack of trust in society represents an implicit rule that can hinder innovation through its effect on the possibility for interactions and communication within firms and in non-market relationships and the degree of knowledge exchange and learning taking place therein, and therefore the amount of innovation introduced. In a system characterised by a low level of trust, the impact of innovation policy measures directed at supporting collaboration may prove less successful without the simultaneous effort to overcome a general lack of trust, particularly in countries with low innovation performance. What policy makers can do in order to overcome a lack of trust, at least to a certain degree, is to build an effective framework of regulation and the general legal system relating to employment and intellectual property rights (IPR) since these may positively affect the incentives of firms and employees within to commit to knowledge exchange and learning in the long run. On the contrary, an innovation system where the tendency to trust is strong and the regulatory and general legal framework is sufficiently effective might provide more conducive institutional conditions for implementing a range of innovation policy measures to support innovation in firms.

Finally, the results of Chapters 4 and 5 provide further support for the view that broader and more nuanced understanding of the innovation processes in firms within individual economies as represented by variations in modes of innovations of firms is needed by policy makers that aim to support innovation. Moreover, the heterogeneity in distribution of firms' modes of innovation across countries suggests continuing importance of the NISs. Public knowledge sources such as universities and public research institutions play an important role in the strategic orientation of some but not all identified innovation modes, which share variations across countries, indicating that this is only part of the NIS that firms rely on in innovation activities and that its relative importance differs across countries. Moreover, the findings in Chapter 3 shows that the importance of public knowledge sources as a complementary asset in the strategic orientation of firms as reflected in firms' modes of innovation did not increase over time. Firms in other modes of innovation rely on complementary knowledge from a diverse set of market and non-market sources in innovation activities and thus may face challenges in pursuing innovation goals due to a lack of access to the relevant networks of customers or suppliers. Access to these other sources may be stimulated by government action supporting linkages to the different parts of the knowledge infrastructure. In addition, there is no single best mode of innovation that overall contributes positively to the impact of innovation on the economic performance of countries. The innovation performance of countries is more likely to be dependent on the distribution of firms in each mode of innovation and firms' competencies, as well as the interactions between firms with different strategic orientations in innovation. In other words, understanding heterogeneity of firms' modes of innovation may prevent policy makers from a very narrow way of thinking about the innovation processes in firms as being exclusively linked to modes of innovation associated with the science and technology-based activities and sources, and accordingly from adopting innovation policy with a narrow focus on increasing support to the R&D system. Very narrow focus in innovation policy is likely to miss out on the innovation processes in many firms and hence hinder the enhancement of innovation capabilities that are of a less science and technology-based nature, such as those based on other forms of knowledge and forms of learning that are at least equally important for success in innovation. The policy implications point towards instruments that balance support for the strategic orientations of firms under different modes within individual economies rather than generic approaches.

4.3. Limitations and future data collection and research

In the end, some final notes of caution are needed for using the CIS data in this thesis as a basis to portray the complex picture of problems or weaknesses within the given systems of innovation of countries, as well as in analysing the patterns of firms' modes of innovation across EU countries over time. The analytical work in this thesis sheds light on some of the limitations of exploiting Eurostat's CIS collections, in general, that restrict research possibilities and lower usefulness for policy makers at both national and EU levels to address important policy issues. The following section details these limitations and provides suggestions for future data collection and research.

Turning to aggregate statistics on important environmental factors related to innovation activities of enterprises, several caveats are worth acknowledging.

First, despite the broad time/country coverage, the availability of relevant aggregate statistics differs across countries and over time due to different geographic coverages of the different CIS editions as well as due to missing values. The different coverages of countries across different CIS editions clearly restrict some cross-country comparisons as well as comparisons over longer periods of time. Therefore, CIS gives an incomplete picture of the countries' environmental factors that hinder innovation activities in the enterprise sectors.

Second, due to the late introduction of the main variables, the presence of alterations of the specific question on environmental factors in the standard harmonized questionnaire in different CIS editions and the availability of aggregate statistics on hindering environmental factors are limited to the time period of 2002 to 2010 (for which the comparable statistics were available). This in turn further restricts the analysis of the most recent trends.

Third, in terms of the questionnaire design, the question on hampering factors covers all enterprises. Those that answered introduced product, service or process innovations, had been involved in any innovation activities abandoned or still ongoing and had no product or process innovations or innovation activities during the three year reference period. This is because both innovative and non-innovative enterprises may face important barriers. However, in the former case, the indicators reflected the factors affecting innovation intensity while in the latter case, the variables captured the factors affecting the propensity of firms to engage in innovation. Yet, the comparable aggregate national statistics broken down by type of hampering factors are only available as a percentage of all enterprises and as a percentage of all innovation active enterprises. For this reason, I only considered aggregate statistics concerning a subset of innovative enterprises. Consequently, I am only able to account for factors affecting the intensity of innovative enterprises.

Fourth, CIS provides information on the importance of various kinds of factors hampering innovation activities of firms within countries. Yet, it could be argued that CIS provides only limited information on potential hampering factors within the given innovation systems of countries. Thus, the CIS data allow me to capture some but not all factors that may exist. Relatedly, the identified problems based on CIS data only reflect the viewpoints of innovative business enterprises, which might be a too narrow description in comparison to the list of potential systemic problems in the literature. I partly account for this problem by including several other sources that provide internationally comparable country-level data on some additional aspects of the institutional settings, which also has its own flaws. This is due to the fact that the relevant and internationally comparable data are sparse, and the data that are available are not necessarily very well described in terms of statistical processing procedures. In addition, the available data are generally based on various sources of primary statistics, and its basis tends to differ depending on the availability from these other sources and over time.

Finally, despite the use of the common harmonized questionnaire and methodology by countries, the inter-country differences in the patterns of responses might arise due to the cultural and linguistic understandings of the concepts. However, since the aggregate indicators on the importance of hampering factors are transformed from ordered categorical (five-point Likert scale) to dichotomous (binary), according to whether enterprises perceived the specific barriers to innovation as highly important, the problem should be present to a lesser extent.

Overall, I concluded that the classification of the considered countries into groups based on the patterns of systems' problems or weaknesses was a good starting point to explore the usefulness of CIS aggregates to provide insights on areas where policy actions might be targeted in different national contexts. However, it is an explorative attempt, which hopefully can also set the direction for future data collection procedures and analyses.

Clearly, improving the quality of the national CIS data collections and the international and intertemporal comparability on the aspects noted above seems to be especially desirable from a policy point of view. This can be done by a continued harmonization of the survey questionnaire across countries and further efforts to move beyond CIS harmonization towards

CIS homogenisation with respect to the way innovation data is collected across countries. Furthermore, a stable set of questions about hampering environmental factors which are not changed or modified over time is needed to allow for a trend analysis over a longer time period. Finally, more information is needed on the environmental factors and non-innovators in order to gain a more complete picture of the varieties of NIS in terms of weaknesses, as well as differences in the perceptions of both innovators and non-innovators.

Nevertheless, considering and exploring various other sources of data on both hampering and supporting factors of the national environmental conditions in which firms operate, combined with a more qualitative assessment of the national contexts, is needed to provide a comprehensive assessment of systems' problems or weaknesses and the relative importance, which is beyond the scope of this thesis. Such attempts are obvious candidates for future research where the possibilities of using new data sources, such as the new OECD STI Policy compass for innovation policy indicators, could be pursued.

When it comes to CIS micro-data collections, the availability of disaggregated data on various aspects of the innovation processes of firms allows for a broader approach to innovation that captures its multidimensional nature and dynamics. Yet, the value of this information is considerably lowered in both the cross-country comparative setting and when taking the longitudinal perspective into account due to the limited coverage, availability and comparability of the data across countries and over time.

Although the national community innovation surveys take a point of departure in a standardised questionnaire and a set of conceptual and methodological recommendations as specified in the OECD Oslo Manual (OECD/Eurostat, 2005), there are deviations across countries in the way that questionnaires are structured and the questions are phrased. As previously noted, despite the use of the common questionnaire, the inter-country differences in the patterns of responses might arise due to cultural and linguistic understandings of the concepts.

In addition, the surveys' sampling rules, the response rates and the coverages also differ across countries, thus affecting the representativeness and comparability of the data. The problem is that if the country's statistics are biased (due to conceptual and/or measurement differences) and we are not able to know the direction and size of the bias, the comparisons are less reliable. While we are able to correct for differences due to coverage and response rate dissimilarities for most of the countries by using weights provided by Eurostat/national statistical offices, this was not possible in the case of one country where weights were absent.

Moreover, comparability of countries is also influenced by structural composition, size and time factors, which are not readily available from the same source. We account, at least partly, for this by considering similarities and differences among countries along several dimensions by drawing from other sources.

An additional concern with respect to using the CIS data when doing an international comparison that is especially relevant for Chapter 4, includes the use of micro-aggregated data for the six included countries. The choice of using micro-aggregated data is dictated due to confidentiality reasons. Nevertheless, the study by Mairesse & Mohnen (2001) examines the robustness of the micro-aggregation procedure used by Eurostat and shows that results are rather similar when firm-level and micro-aggregated data are used.

Finally, the cross-sectional character of the CIS micro-aggregated data at hand is not well suited to capture a dynamic picture of modes of innovation of firms within or across different institutional settings. As panel data becomes available, it would be possible to provide a better picture of the dynamics of firms' modes of innovation within and across countries and to determine whether there is one mode of innovation that predominates at the national level within a particular institutional setting over time. This type of data can stimulate future research on other aspects of the dynamics of innovation.

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CHAPTER 2

II The state of innovation system research: What happens beneath the surface

Marija Rakas (rakas@business.aau.dk)

Daniel S Hain (dsh@business.aau.dk)

Department of Business and Management

Aalborg University, Denmark

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Marija Rakas*, Daniel S. Hain

Aalborg University, Department of Business and Management, IKE/DRUID, Denmark

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ABSTRACT

Since its emergence in the 1980s, the concept of "Innovation Systems" (IS) has inspired research and shaped discussions in academia and policy alike, leading to a cascading development of approaches and extensions at various analytic levels. IS research has expanded far beyond its initial focus by generating new knowledge within but also attracting increased attention from adjacent fields. As a result, the broad understanding of IS and its diversity in applications has resulted in blurry boundaries of the field, making its contemporary delineation, synthesis, and assessment of its progress challenging. Using a combination of data-driven techniques from bibliometrics, natural language processing, and network analysis, this paper maps and analyzes the structure of knowledge production and the process of knowledge integration in current research. We find an overall growing tendency toward increasing diversity in the knowledge bases from which the field draws, accompanied by a decreasing coherence of collective research efforts. We point to the crucial role of institutions and academic entrepreneurs in shaping these developments in interdisciplinary and diverse fields, illustrating this by the role of the Organisation for Economic Co-operation and Development (OECD).

1. Introduction

The late 1980s saw the emergence of a new and more systemic understanding of innovation and diffusion processes. The resulting "National Innovation System" (NIS) framework[1] (Lundvall, 1992; Nelson, 1993; Freeman, 1987) has attracted significant attention among both researchers and policymakers, resulting in the increased importance of the larger field of Innovation Systems (IS) research.

Subsequent research generated a cascade of further IS frameworks differing in their analytical and conceptual focus, highlighted elements and dimensions, system boundaries, and units of analysis, such as regional (Cooke, 2001; Malmberg and Maskell, 2002), sectoral (Breschi and Malerba, 1997; Malerba, 2002, 2005), technological (Carlsson and Jacobsson, 1997; Bergek et al., 2008; Hekkert et al., 2007), business (Whitley, 2000), and social systems of innovation and production (Amable, 2000), as well as national systems of entrepreneurship (Acs et al., 2014). Consequently, a substantial body of literature on IS has accumulated. Along the same lines, its community of users has expanded as researchers from adjacent fields have become interested in a systemic approach to studying innovation. The resulting blurred boundaries of the field in its current state call for efforts to delineate both what it currently consists of and the theoretical foundations it draws from.

Previous research has provided insights on the historical origin and context from which the approach emerged (Sharif, 2006; Godin, 2009; Lundvall, 2007; Soete et al., 2010; Edquist, 2005), its users and role in the world of science (Fagerberg and Sapprasert, 2011; Teixeira, 2013; Uriona-Maldonado et al., 2012), the unifying elements that bind these contributions together, and their role in a more narrow context of innovation studies (Fagerberg et al., 2012). Most studies have taken the field's historical core contributions as a point of departure and identified their users, thereby providing an account of its influence on the broader social science discipline. Such an approach comes with the implicit assumption that what is considered as the field's historical core literature remains stable over time, but this involves the risk of overlooking potential diverging characteristics in terms of the core contributions in the field.

In this article, we take a more contemporary perspective, starting from the highly cited journal publications on IS and the works cited therein. Applying an inclusive, data-driven methodology, we aim at providing a comprehensive overview of the current state of IS research, its internal structure of specializations, and the knowledge bases it draws from. To accomplish this, we identify in an iterative process in IS-related publications from Thompson Reuter's "Web of Science" (WoS)

* Corresponding author.
E-mail address: rakas@business.aau.dk (M. Rakas).

[1] While the terms "National Innovation System" (NIS) and "National Systems of Innovation" (NSI) are used interchangeably in the literature, we consistently use the term NIS for research on national innovation systems.

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database (6,370) and their cited references (162,600) for the 1980–2018 period. In a bibliographic network analysis, we map the literature's current research and knowledge base, and we deploy clustering techniques to partition them into consistent areas. We augment this mapping by employing techniques from the field of natural language processing (NLP) to discover common topics in the publication abstracts. Finally, we provide insights into the unfolding process of knowledge integration in the field's research areas and the accompanying dynamics of coherence and diversity.

Overall, we find a tendency of increasing diversity of knowledge bases from which the field draws, accompanied by a decreasing coherence of collective research efforts. We highlight the heterogeneity of how this process takes place and identify distinct patterns of knowledge integration. For IS-related research, we argue that the pursuit of further knowledge integration requires effort toward obtaining both higher diversity and internal coherence. In fields that are interdisciplinary and diverse by nature, we point to the role of external forces in shaping these developments, which we exemplify with the role of the Organisation for Economic Co-operation and Development (OECD).

The remainder of the paper is structured as follows: Section 2 presents an overview of the literature and introduces important theoretical building blocks. Section 3 describes the data and introduces the methods used in our analysis. Following this, Section 4 presents the field's identified knowledge bases and research areas and illustrates trends in their relationship. Finally, Section 5 concludes, discusses the implications of the analysis, and provides avenues for future research.

2. Theoretical considerations

2.1. Variations and nuances in the initial conceptualization of IS as a field of research

While the intellectual foundations for the IS literature go further back in history and are broader in scope (Carlsson et al., 2002), the contributions associated with the initial conceptualizations of the NIS framework propelled the field to prominence (Soete et al., 2010). These initial conceptualizations are commonly attributed to three founding researchers, namely Christopher Freeman, Richard Nelson, and Bengt-Åke Lundvall (e.g., Fagerberg and Sapprasert, 2011). Below, we point out the distinctiveness and commonalities between the approaches, complemented by a condensed overview in Table 1.

The NIS concept introduced by Freeman (1987) refers to the network of public and private institutions with activities and interactions intended to initiate, import, modify, and diffuse new technologies. The main focus of the qualitative analysis is on the ways in which the resources are organized and managed at the enterprise, industry, and country level, including the organization of research and development (R&D) and production in firms, relationships among firms, and the government's role. The concept is seen as having the greatest importance in explaining both the emergence and the rate at which the “technological gaps” between countries are closed.

Nelson (1993) defines the system as a set of institutional actors whose interactions determine the innovative performance of national firms. The main orientation of this work involves describing the mechanisms and institutions that support technological advances and how they came to be, as well as relating this to the differences in countries' economic performances in such dimensions as productivity, income, income growth, export, and import performances.

The distinctiveness of the approach developed by Lundvall (1992) features a broader understanding of the concept, including all organizations and institutions that affect the production, diffusion, and exploitation of economically useful knowledge, and focusses on user–-producer linkages and interactive learning as a basis of innovation. The concept is viewed as an analytical and policy tool or framework to link innovation to economic performance at the national level.

In sum, the differences between the approaches can be attributed to narrower or broader definitions of the concept, a main focus of the analysis, and elements of the system included in studying NIS. What is regarded as common to all three approaches is the focus on the relationships between the institutions, organizations and the interactions between them on the one hand and learning, innovation, and economic performances at the national level on the other.

2.2. Meta-survey on the development of IS studies

Attempts to review the field and developments of the NIS literature adopting a qualitative approach based on literature review include Balzat and Hanusch (2004), Sharif (2006), Carlsson (2007, 2006),

Table 1
Comparison between the original versions of the NIS concept.

	Freeman, C. (1987)	Nelson, R. R. (1993)	Lundvall, B. Å. (1992)
Concept definition	“*The network of institutions in the public and private sectors which activities and interactions initiate, import, modify and diffuse new technologies may be described as 'the national system of innovation'.*” (p. 1)	“*[...] a set of institutions whose interactions determine the innovative performance, in the sense above, of national firms.*” (p. 4)	“*[...] all parts and aspects of the economic structure and the institutional set up affecting learning as well as searching and exploring - the production system, the marketing system and the system of finance present themselves as sub-systems in which learning takes place.*” (p. 13)
Term “System”	Not explicitly defined	“*[...] a set of institutional actors that, together, plays the major role in influencing innovative performance.*” (p. 4-5)	“*[...] a system of innovation is constituted by elements and relationships which interact in the production, diffusion and use of new and economically useful, knowledge and that a national system encompasses elements and relationships, either located within or rooted inside the boarders of a nation state.*” (p. 2)
Term “Innovation”	“*[...] continuing process of technical change, involving the introduction of new and improved products and novel ways of organizing production, distribution and marketing.*” (p. 1)	“*[...] the processes by which firms master and get into practice product designs and manufacturing processes that are new to them, if not to the universe or even to the nation.*” (p. 4)	“*[...] on-going process of learning, searching and exploring, which result in new products, new techniques, new forms of organization and new markets.*” (p. 8)
Analytical framework	• Relationship between technology, socio-economic structures, and institutions	• Linking institutional arrangements to technological and economic performances.	• Interactive learning anchored in the production structure (including “demand conditions” and “supporting industries”) • Institutional set-up including “firm strategy” • Modes of cooperation and competition
Type of the analysis	• Single case study (Japan)	• Comparative case study (15 countries divided into large high-income, small high-income, and low income countries)	• Conceptual/Theoretical

Lundvall (2007), Godin (2009), and Soete et al. (2010). A critical assessment of the weaknesses and strengths of the approach, and the implications and suggestions for its further development are discussed in Hart (2009). Critical assessments of IS concepts more broadly are found in Carlsson et al. (2002) and Edquist (2005).

A few contributions adopt a mix of qualitative and quantitative approaches. Fagerberg and Sapprasert (2011) investigate the emergence and role of NIS in IS, based on a combination of expert assessment to identify the most important contributions and the users of the literature. Similar approaches are found in mapping the field of IS (Fagerberg et al., 2012), entrepreneurship (Landström et al., 2012), and science and technology studies (STS) (Martin et al., 2012). Teixeira (2013) proposes a taxonomy of the main topics and methods, roots, and influence of the NIS literature based on a combination of qualitative assessment and bibliometric evidence. However, the main focus in these studies is more on the origins and less on the recent research contributions.

Recent accounts of the state of the IS field rely primarily on a quantitative bibliometric approach, and they study the institutionalization of IS literature. Uriona-Maldonado et al. (2012) provides a descriptive account of the chronological distribution of publications, author relevance, articles and cited references, journals, institutions, and countries of relevance based on the citation count. Liu et al. (2015) identify and visualize the intellectual structure, turning points, and dynamics of IS research based on co-word and co-citation analysis.

2.3. Conceptual framework: diversity and coherence

To understand the development of a research field, it is useful to map changes in its *structure of knowledge production* and output in terms of novel knowledge generation. In an interdisciplinary field of research like IS,[2] we conceptualize this development mainly as a “process of knowledge integration”, in which distinct and previously disconnected bodies of knowledge become related over time. To analyze this process, we conceptually distinguish between the field's current “knowledge frontier”, where new knowledge is produced (which we label “research areas”), and the bodies of knowledge to be utilized (which we label “knowledge bases”). This enables us to explicitly analyze the process of knowledge integration at the research frontier, which we envision as a dynamic process that can be expressed by changes in patterns of how the field's knowledge bases are (re-)assembled, (re-)used, and (re-) combined. The capacity for and extent and success of knowledge integration in a field of research can be described by the joint development of two central indicators–coherence and diversity (Porter et al., 2006).

Coherence: Coherence captures the extent to which a system's elements are consistently articulated and form a meaningful constellation. It can be viewed as a general system property capturing its functionality. Systems with low coherence are characterized by loosely connected or isolated elements that are unlikely to produce meaningful collective output. Within a bibliographic analysis of a field of research, coherence can be understood as the degree to which the publications under study exhibit common citation patterns, thereby indicating higher or lesser consensus on the content of research, developed and applied theories, and methods.

Diversity: The diversity of a research field can be expressed by the number, balance, and similarity of the bodies of knowledge from the categories it comprises (Stirling, 2007). In our bibliometric analysis, we conceptualize diversity by the pattern the field's research areas draw from the knowledge bases (cf. section 3 for details).

[2] We follow Porter et al. (2006) in defining interdisciplinarity as a mode of research that integrates concepts, theories, methods, techniques, or data from different bodies of knowledge.

The combination of the two dimensions leads to four position characteristics of research, as illustrated in Fig. 1. It can be used to describe the static structure of knowledge production, as well as the dynamic process of knowledge integration in a field or narrow research area, as follows:

1. **Fragmented Specialization (Low diversity–Low coherence):** This includes specialized research areas that draw from a small number of knowledge bases without overlapping. It is an indicator of a field's immaturity or a temporal state in the process of internal reconfiguration and knowledge integration;
2. **Fragmented Diversification (High diversity–Low coherence):** Here, the research areas in a field are diversified and draw from a larger number of knowledge bases, yet without overlap. It is an indicator of fragmentation or lacking consensus on theoretical foundations;
3. **Coherent Specialization (Low diversity–High coherence):** The research areas within a field are specialized and draw from a small number of knowledge bases, which are the same across areas. It is an indicator of a strong consensus on dominant theories or a temporal state of refocusing; and
4. **Coherent Diversification (High diversity–High coherence):** In this category, the research areas in a field are diversified and draw from a large number of knowledge bases, which are used coherently across research areas. It is an indicator of a successful process of knowledge integration and cross-fertilization.

The relationship between coherence and diversity describes the dynamic process of knowledge integration in the normal progress of science; thus, it should be assessed not as a static state, but rather in terms of a temporal derivative (Rafols and Meyer, 2010). Here, it is argued that diversity and coherence should develop in the same direction, since the increasing focus on “exploiting” a narrow knowledge base may lead to decreasing creativity and novelty, while excessive but not coherent “exploration” may lead to a fragmentation of the research field and limit its ability to produce deep and meaningful insights and results (March, 2005). Generally, for research areas of fields aiming at interdisciplinary knowledge integration, moving toward higher levels of diversity while maintaining the level of coherence suggests successful achievement of this integrative mission (Rafols and Meyer, 2010).

Applying a network perspective, further useful analogies can be drawn from insights on how individual and collective learning processes are affected by the underlying (social) structure. The literature on social capital has featured a long-lasting debate on the benefits of open or closed local network structures, where it is argued that open network structures provide their actors information advantages in terms of access to a diverse set of novel information (Burt, 1992, 2001), as well as that closed structures facilitate the exchange of in-depth information through frequent, trust-based interaction (Uzzi, 1997, 1996). Differences in collaborative learning are also attributed to the composition of networks (e.g., homogeneous vs. heterogeneous) (Reagans and McEvily, 2003; Fleming et al., 2007), and more recently, the interaction of structure and composition (e.g., TerWal et al., 2016). Consequently, the methodological choice of applying a network analysis and theoretical choice of accentuating the aspects of structure and composition appear complementary to the concepts of diversity and coherence, promising new insights into the process of collective learning and knowledge integration.

3. Methods, data, and empirical strategy

This section presents the methods used and our rationales for applying them. First, we delimit IS research in an iterative “bottom-up” process. Second, we carry out a thematic mapping of the field by employing techniques from the field of NLP for discovering common topics in the publication abstracts. Third, based on a co-citation analysis, we

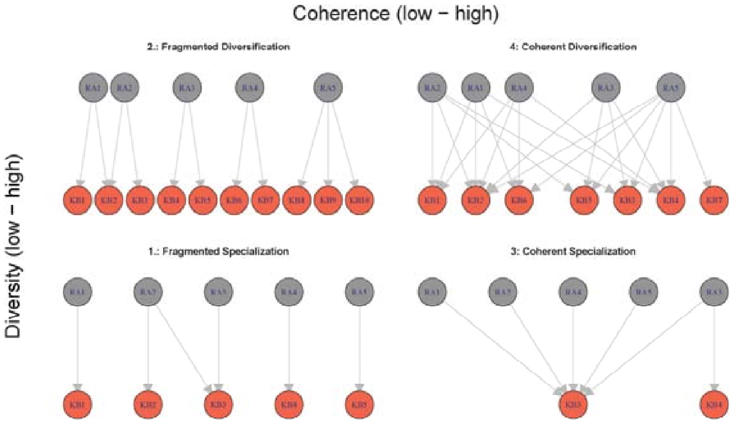

Fig. 1. Knowledge base diversity and network coherence.

identify the most prominent knowledge bases IS literature has drawn from during its development. Fourth, we carry out a bibliographic coupling analysis for identifying the current research frontier in IS. Finally, we explore the development of IS in terms of diversity and coherence of research efforts by analyzing how heterogeneous bodies of knowledge are utilized and integrated over time.

3.1. *Delimiting the IS field: initial corpus creation*

The common challenge of delineation is especially prevalent in an interdisciplinary field like IS, which draws from a variety of academic disciplines, such as economics, organizational studies, sociology, and psychology. In attempts to delineate the somewhat blurry boundaries of IS or related (sub-)fields, different methodologies have been applied.

To start with, one can apply a string-search-based approach to identify publications in an academic database where the title, abstract, or keywords include certain terms, for example, “System(-s) of Innovation” (e.g., Teixeira, 2013; Uriona-Maldonado et al., 2012). Assuming all the relevant publications clearly state their association to a field of research by including some related keywords in the publication's description, this approach is likely to deliver a low rate of *false positives*. However, in the case of fields with blurry boundaries and without fully coherent terminology, a high rate of *false negatives* will also be evident.

Another possibility is following an authority-based approach, where the research field is delimited by the author's (e.g., Lundvall et al., 2002; Godin, 2009) perception of the field and relevant contributions, surveyed experts (e.g., Sharif, 2006), or authoritative surveys like handbooks (e.g., Fagerberg et al., 2012). Assuming the selected authorities’ ability to delineate what is part of the field and what is not, this approach is less dependent on the use of consistent terminology.

If there is a wide consensus on a field's origins and core literature, an origin-based approach can be applied. Here, one starts with a predefined set of core contributions and then expands the corpus with the publications citing them (e.g., Meyer et al., 2004). This is helpful for assessing the influence of the core contributions independently of disciplinary associations of publications and authors, but it may miss later developments in the field that diverge from the original core.

Finally, more inductive “snowballing” approaches can and have been used, combining the identification of certain “seed” publications from previous studies and authorities in the field and further related publications based on various methodologies (e.g., Martin, 2012a; Jurowetzki et al., 2018).

To leverage the main advantages of the discussed approaches, we combine several of their features in a multistep process. We first apply a string-based strategy, searching WoS for publications including the terms “Innovation System(-s)” or “System(-s) of Innovation” in their titles, abstracts, or keywords (2,885).[3] First, we reduce the list to the top 1% of publications, both in terms of total citations and average annual citations received (the overlap is > 90%). This leads to a total of 38 *seed* publications[4] (cf. Table A1 in the appendix), representing the most cited (journal) articles directly associated with IS. However, a sole focus on highly cited publications may exclude research that has contributed to the field in a more incremental way (Macroberts and Macroberts, 1987), as well as strongly related research that does not use a certain terminology. Therefore, we take this selection of publication as the initial point of departure for an iterative process. To create our final corpus, for every initial “seed”, we extract the 500 publications for the 1980–2017 period with the highest bibliographical overlap (i.e., highest number of shared references cited by both publications). The intuition behind this step is that a bibliographic overlap between two publications indicates similarities in the theoretical frameworks, applied methods, or context of the study (Boyack and Klavans, 2010).

When excluding duplicates and publications that were not cited at least once, our final corpus contains a total of 6,370 publications. In a last step, we extract the complete list of references (162,600 unique cited references) for each of these publications, to be analyzed separately. This process is illustrated in Fig. 2.

The benefit of our multistep approach is that it considers both the use of an exact terminology and strong bibliographic overlap as a sufficient but not a necessary condition to be associated with a research field, and that it allows for a dynamic expansion of what can be considered a field's core. As a result of this inclusiveness, it will not provide a sharp boundary of the field under study, but rather a blurry one that tends to include publications from adjacent fields that also substantially relate to the literature relevant to IS. Yet, it will not provide an overview of all systemic approaches to innovation (which is also not our aim). Centered around IS, by design, it will miss systemic approaches without any literature and terminology overlap, such as “Innovation Ecosystems” (Moore, 1993).

Our choice of utilizing the WoS database has certain implications,

[3] Clearly, Technological IS (TIS), National IS (NIS), Sectoral IS (SIS), and Regional IS (RIS) with the additional prefix are also included.

[4] We use the term “seed” in a technical manner, indicating the starting points in our data-driven approach of iterative corpus expansion. Hence, it should not be understood metaphorically as the seminal contributions that gave rise to the “growth” of the field.

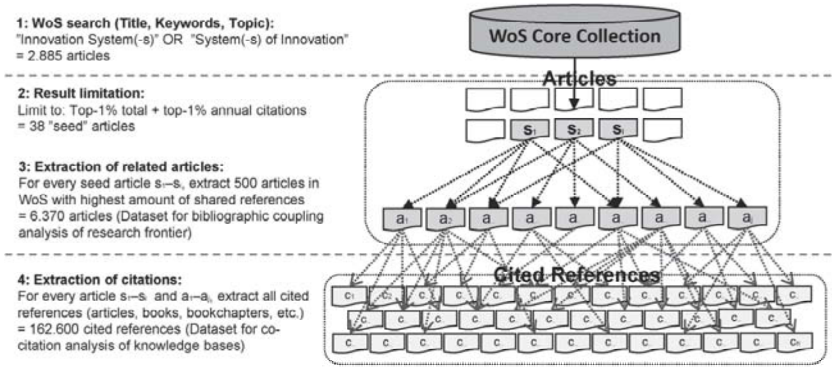

Fig. 2. Illustration: Multistep literature identification and selection process.

especially that it does not provide bibliographic data for books. We are unable to treat significant contributions in the form of books equally to journal articles, since the latter are used as "seeds" for assembling our final corpus and mapping the research frontier, while the former can only be used to map the field's knowledge base. In addition, we can characterize journal articles by their composition of cited references, but for books, we can only use information regarding *received* citations from our corpus. To be confident regarding the use of the present methodology on a corpus solely based on journal articles, one has to assume that they represent a major part of a field's literature in terms of volume and significance and characterize the knowledge frontier sufficiently. In case of doubt, potential bias has to be approximated to assess the method's limitations.

Analyzing the references cited by the journal articles in our corpus can provide an indirect approximation regarding the relevance of books compared with journal articles. We find that, during the emergence of the field in the 1980*s*, books account for 59% of all the cited references in our corpus, which is indeed substantial. However, this share steadily decreases to 25% in the post-2010 period. Likewise, while books in the 1980*s* received about the same average amount of annual citations, this shifted in favor of journal publications since 2000, which nowadays on average receive 1.5 times more citations than books.[5] Previous studies point in a similar direction, highlighting that books represent an important part of the field's body of knowledge and many of its seminal contributions, especially during its formative stage (Martin, 2012a). However, this is much less the case in more recent periods, where the relevance of books as a publication outlet and citations to the field's defining books steadily declined (Fagerberg and Sapprasert, 2011).

In conclusion, it cannot be ruled out that the omission of books in our selection of "seed" publications, as well as our final corpus, will result in an incomplete map of the IS field. This potential bias should be especially prevalent in the pre-2000 formative stage, where many significant contributions are to be found in books. Accordingly, our pre-2000 results have to be interpreted with a healthy degree of skepticism. While recognizing the problem, we expect it to be less worrisome for our main analysis of interest regarding the more recent years of IS research (post-2000). It is our impression that a more inclusive bibliometric study covering journal and book publications alike would result in a broader and more detailed overview of the field, especially in its formative stage, without significantly altering our main results. Yet, in the absence of empirical evidence, this claim remains speculative.

3.2. Topical mapping: NLP

The way science progresses is largely reflected in the use of language, which can indicate general research trends and the emergence of a consensus or dispute (Kuhn, 1971). To provide a first intuition about general themes and topics in the IS literature, we facilitate our bibliometric analysis by deploying exploratory methods from the field of NLP on the publication abstracts. We create a *topic model* via latent Dirichlet allocation (LDA) (Blei, 2012), a graphical Bayesian probability model for discovering thematic structures in text document collections. Such models identify `topics`[6] by the way words and word combinations are used in text documents. The basic idea is that documents are represented as mixtures over latent topics, where each topic is represented as a probability distribution over the words used in the corpus. An iterative process then generates a set of topics that describes the documents in the corpus and assesses the strength with which each document exhibits those topics. An inspection of the words with the highest assigned probability to each topic tends to provide an interpretable qualitative description of the topic's meaning and content.

3.3. Mapping the structure of research activity: bibliometric methods

While the commonly used analysis of direct citations is helpful for identifying and summarizing the most important publications in a scientific corpus, the dichotomous nature of this measure limits its usefulness to expressing the relationship between publications, and thus, a structural mapping of research fields (Üsdiken and Pasadeos, 1995). Here, more nuanced methods leveraging the information found in a publication's bibliography can be utilized, such as co-citation and bibliographic coupling analysis (Boyack and Klavans, 2010).

Technically, both measures exploit the bipartite nature of the publication→references data structure, which is common to bibliographic data,[7] and are equivalent to the projection of a two-mode network (publication → reference) to a one-mode network (publication ↔ publication or reference ↔ reference). For bibliographic coupling analysis, the projection is done on the level of publications, and for co-citation analysis on the level of references. The logic behind each approach is illustrated in Fig. 3.[8]

[5] This indicator is only meaningful when assuming there is no systematic bias of journal articles against citing books. While we cannot directly prove this assumption, the fact that many of the most cited references are books (cf. Table 2) gives no strong indication that this should be the case.

[6] In this paper, we indicate the reference to a topic with a `typewriter` font.

[7] In bibliographic analysis, publications and their cited references are commonly treated as separate entities, and consequently, they are analyzed separately.

[8] We refer to the publication ↔ publication mode as the RESEARCH AREA network (formatted in SMALL CAPS) and the reference ↔ reference mode as the *knowledge base* network (formatted in *italics*).

Table 2
Final corpus characteristics.

Institutional Affiliation			Most Occurring Journals			Internally Cited References	
Institution	N	%	Journals	N	%	Reference Name	Cit
Utrecht	104	2	Res. Policy	655	10	Cohen W, 1990	1014
Sussex	91	1	Eur. Plan. Stud.	224	4	Nelson R, 1982	869
Lund	85	1	Reg. Stud.	221	4	Lundvall B, 1992	654
Manchester	73	1	Tech. Forecast. Soc. Ch.	195	3	Audretsch D, 1996	530
Toronto	56	1	J. Int. Bus. Stud.	135	2	Nelson R, 1993	491
Eindhoven	52	1	Technovation	121	2	Jaffe A, 1993	445
Erasmus	51	1	Tech. Anal. Strg. Mng.	120	2	Porter M, 1990	440
Amsterdam	46	1	Strateg. Manage. J.	118	2	Barney J, 1991	413
Cambridge	45	1	Small Bus. Econ. Group	116	2	Edquist C, 1997	409
Uppsala	41	1	Ind. Corp. Change	110	2	Cohen W, 1989	393
Wageningen	40	1	Scientometrics	109	2	Granovetter M, 1985	382
Cardiff	38	1	J. Econ. Geogr.	104	2	Powell W, 1996	376
Harvard	37	1	Int. Bus. Rev.	89	1	Bathelt H, 2004	368
LSE	36	1	J. Evol. Econ.	83	1	Burt R, 1992	361
PennState	35	0	J. Technol. Transf.	82	1	Dosi G, 1982	359
Delft	34	0	Int. J. Technol. Manage.	66	1	Boschma R, 2005	355
Leuven	34	0	Ind. Innov.	65	1	Schumpeter J, 1934	345
Bocconi	32	0	Organ Sci.	64	1	Saxenian A, 1994	340
Singapore	32	0	Energy Policy	62	1	North D, 1990	320
Valencia	31	0	Entrep. Reg. Dev.	62	1	Etzkowitz H, 2000	310

Note. This table reports some basic information on the articles in the WoS corpus, such as the most often appearing institutions, journals, and the most (corpus internally) cited references. Overall, the corpus contains 6,368 articles, published between 1980 and 2018 (August).

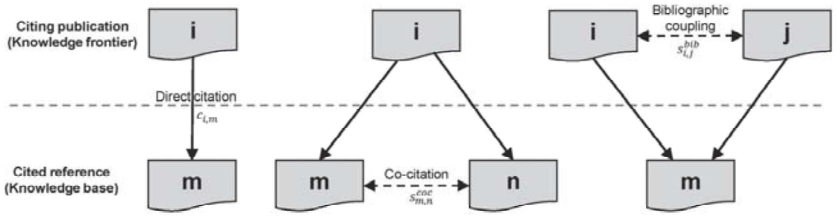

Fig. 3. Illustration: Direct citation, co-citation, and bibliographic coupling measures in a bipartite publication↔reference network.

3.3.1. Identifying the structure of the IS field's knowledge base: co-citation analysis

Our first step in mapping the structure of the *knowledge base* in the IS literature is performing a co-citation analysis, where the cited references and not the original publications are the unit of analysis. Here, the strength of the relationship between a reference pair *m* and *n* ($s^{coc}_{m,n}$) is expressed by the number of publications *C* that jointly cite references *m* and *n*, as illustrated in equation (1). The intuition here is that references that are frequently cited together are likely to share commonalities in theory, topic, methodology, or context. This can be interpreted as a measure of similarity as evaluated by other researchers deciding to cite both references. Because the publication process is time consuming and citations accumulate over time, co-citation is a backward-looking measure, which is appropriate for mapping the relationships in the core literature of a field (Boyack and Klavans, 2010):

$$s^{coc}_{m,n} = \sum_i c_{i,m} c_{i,n}. \tag{1}$$

Since co-citations between two publications tend to correlate with their total number of citations, we avoid a general clustering of highly cited publications by normalizing the co-citation strength with the Jaccard similarity coefficient (cf. Leydesdorff, 2008; Hamers et al., 1989), where we weight the intercept of two publications' co-citations by their union. The resulting weight (cf. equation (2)) is bounded between zero and one, where one indicates that two references are exclusively cited together and zero that they are never cited together:

$$S^{jac\ cocit}_{m,n} = \frac{C(m \cap n)}{C(m \cup n)} = \frac{s^{cocit}_{m,n}}{c_m + c_n - s^{cocit}_{m,n}}. \tag{2}$$

3.3.2. Identifying the structure of the IS field's KNOWLEDGE FRONTIER*: bibliographic coupling analysis*

We identify the IS literature's current knowledge frontier by carrying out a bibliographic coupling analysis of the publications in our corpus. This measure uses bibliographical information of publications to establish a similarity relationship between them (Kessler, 1963). This "coupling strength" between publications is determined by the number of cited references they share, assuming a common pool of references to indicate similarity in context, methods, or theory. More recent articles have a higher pool of possible references to co-cite to; hence, they are more likely to be coupled. Consequently, bibliographic coupling represents a forward looking measure and the method of choice for identifying the current "knowledge frontier". In contrast to co-citations, bibliographic coupling is not influenced by a publication's number of citations. Hence, a publication's coupling strength is a measure of academic relevance (as indicated by the author's choice of references and the implied association with certain bodies of literature) rather than significance. Publications with a high degree of coupling strength should be interpreted as typical examples of work in a certain field rather than its core contributions.

Formally, the strength of the relationship between a publication pair *i* and *j* ($s^{bib}_{i,j}$) is expressed by the number of jointly cited references, as illustrated in equation (3). Since our corpus contains publications that differ strongly in terms of the number of cited references, we again normalize the coupling strength using the Jaccard similarity coefficient. It is again bounded between zero and one, where one indicates that the two publications have an identical bibliography and zero that they do not share any cited reference. Thus, we prevent publications from having high coupling strength due to a large bibliography (e.g., literature surveys):

$$s_{i,j}^{\text{bib}} = \sum_{m} c_{i,m} c_{j,m} \;\Rightarrow\; S_{i,j}^{\text{jac bib}} = \frac{C(i \cap j)}{C(i \cup j)} = \frac{s_{i,j}^{\text{bib}}}{c_i + c_j - s_{i,j}^{\text{bib}}}. \tag{3}$$

The choice of representing our corpus as a similarity network of publications based on a citation pattern comes with some implications and additional requirements in terms of data quality compared with a traditional bibliometric analysis of citation frequencies. Especially, the resulting network structure is sensitive to both false positives and false negatives. This becomes problematic when working with WoS data, since they provide information on cited references as free-text entries prone to inconsistent annotation (e.g., misspellings, full first name, only initials, with or without special characters). Consequently, we strove to homogenize the notation of references, where we first manually inspected all the most cited journals, publications, and authors and corrected inconsistent spelling patterns, and further, we deployed rule-based algorithms to correct commonly made mistakes in the references.[9]

3.4. Categorizing knowledge bases and research areas: clustering techniques

To summarize the knowledge structure of scientific fields, most previous research (e.g., Fagerberg et al., 2012) has clustered publications according to similarity in characteristics like scientific discipline, publication outlet, and author affiliation. In contrast, we utilize the information of the corresponding bibliographic coupling or co-citation network and cluster publications according to their pattern of connectivity with other publications or cited references.[10] To partition networks into components or clusters, we deploy a "community detection" technique based on the Lovain Algorithm (Blondel et al., 2008) on our publication network to identify research areas, and on the network of cited references to identify *knowledge bases*.[11]

3.5. Analyzing the development of the field: diversity and coherence

As a final step, we analyze the development of the IS field and its research areas, focusing on the coherence of the structure of knowledge production and diversity of knowledge integration. The coherence of the IS field is operationalized as the aggregated coupling strength *between* its research areas, indicating a higher or lesser consensus on important and useful bodies of knowledge. A similar approach can be applied for measuring the coherence in a research area by looking at the density of the bibliographic coupling network of publications belonging to the same area.

[9] Here, we follow the advice of Raffo and Lhuillery (2009) on how to play the "name game". We also ran a fuzzy string matching algorithm on our list of references to match it with the most common spellings of core articles and the official journal abbreviation scheme used in WoS.

[10] In the jargon of network science, which we will adopt throughout our analysis, a network's elements are called *nodes* and the connections between them *edges*.

[11] The Lovain Algorithm is a heuristic method attempting to optimize the modularity of communities in a network by maximizing within- and minimizing between-community connectivity. Due to its proven high computational efficiency, accuracy in identification, and ability to handle weighted networks, this algorithm appears to be an appropriate choice for our task. In Table A5, we benchmark the results with other popular community detection algorithms for undirected weighted large-scale networks, where for both networks, we identify the highest modularity and overall most desirable characteristics.

In our context, diversity refers to how the corresponding research area draws from the identified IS knowledge bases. Generally, it can be measured by the variety (V), balance (B), and distance (D) of knowledge bases drawn from by the whole field or a specific research area (Stirling, 2007). We operationalize this concept using the diversity measure proposed by Leydesdorff (2018):

$$\text{Div}_c = V{*}B{*}D = \frac{n_c}{N}{*}(1 - \text{Gini}_c){*} \sum_{i=1, j=1, i\neq j}^{i=n_c, j=n_c} \frac{d_{\text{ij}}}{n_c{*}(n_c - 1)}. \tag{4}$$

Here, N denotes the number of existing knowledge bases, n_c is the number of knowledge bases the field or area is citing, $Gini_c$ represents the Gini coefficient of the distribution of knowledge bases, and d_{ij} the distance between the corresponding knowledge bases as (measured as 1 - [sum of normalized co-citation strength between the publications in knowledge bases i, j]).

Similar approaches have been used for describing and analyzing the state and development of interdisciplinarity in research fields (e.g., Rafols and Meyer, 2010; Rafols et al., 2012). In contrast, our aim is not to analyze the integration of cross-disciplinary knowledge in a research field, but more broadly, the integration of distinct bodies of knowledge (*knowledge bases*), which may have their origin in different or the same scientific disciplines. Thus, we emphasize the pervasive heterogeneity of knowledge *within* a scientific discipline and develop a delineation approach that does not depend on predefined disciplinary categories.

4. Results and discussion

4.1. Basic characteristics of initial "seed" and final corpus of publications

The process of selecting our initial "seed" publications, as described in the previous section, resulted in 38 articles (listed in Table A1 in Appendix). Here, the largest group (16) is associated with conceptual/theoretical frameworks and their empirical application, namely the following: i) the "Triple Helix" model of university, industry, and government relations (Etzkowitz and Leydesdorff, 2000); ii) "multilevel perspective on transitions" (Geels, 2004); iii) "sectoral system of innovation and production" (Malerba, 2002); iv) "regional systems of innovation" (Cooke et al., 1997); v) "technological IS" (TIS) (Hekkert et al., 2007; Jacobsson and Johnson, 2000; Carlsson and Stankiewicz, 1991); vi) a synthesis of a "TIS" and "multilevel framework" (Markard and Truffer, 2008); vii) "national innovation capacity" (Furman et al., 2002); viii) a functional approach to a "national innovation system" (Liu and White, 2001); and ix) a "national system of entrepreneurship" (Acs et al., 2014). The empirical applications include articles dealing with the typologies: x) regional systems (Asheim and Coenen, 2005), xi) the national modes of learning (Jensen et al., 2007); xii) the modes of university–industry interactions (Meyer-Krahmer and Schmoch, 1998); xiii) the role of knowledge-intensive business services (Muller and Zenker, 2001); and xiv) regulation in regional IS (Cooke, 1992). Another group of articles (6) is associated with a historical account of NIS (Freeman, 1995), a synthesis of research on networks of innovators (Freeman, 1991b), and surveys of a single or various systems concepts (Lundvall et al., 2002; Markard et al., 2012; Carlsson et al., 2002; Morgan, 2004). Three articles focus on policy contributions (Asheim et al., 2011; Acs et al., 2014; Bergek et al., 2008), and one is concerned with the data used for measuring innovation (Acs et al., 2002a). Overall, the list of seed publications appears to be relevant,capture the variety of research in the IS field, and does not indicate systematic biases against certain frameworks or methodologies.[12]

In Table 2, we report some basic characteristics of our final corpus of 6,370 publications. Our corpus overlaps with the results of previous

[12] It must still be noted that most of our "seeds" were published after 2000, demonstrating that indeed, most seminal contributions to the IS literature pre-2000 are to be found not in journal articles but in books.

Table 3
Topics and associated terms.

Topic	Top-10 Associated Terms
Firms, Capabilities &Strategic Alliances	Firms, Capability, Strategic Alliances, Competitive Advantage, Resources, Dynamic Capabilities, Strategy, Partner, Organization, Resource-based-View
Learning, Organizations &Interaction	Learning, Model, Process, Design, Organization, Interaction, Integration, Complexity, Mechanism, Transfer
Globalization, Processes &Global Economy	Production, Global, Business, ICT, Communication, Relation, Service, Globalization, World Economy, Trade
R&D, Patents &Productivity	R&D, Patents, Data, Productivity, Analysis, Growth, Indicator, Trade, Efficiency, Invention
Localization, Clusters &Spillovers	Local, Clusters, Spatial Proximity, Industry, City, Agglomeration, Geography, Location, Knowledge Spillovers, District
University, Industry &Technology Transfer	University, Science, Collaboration, Academic, Technology, Interaction, Researchers, Intellectual Property, Collaborative, Technology Transfer
Firm-Level Innovation Determinants	Firms, Industry, Manufacturing, SME, Sector, Size, Survey, Characteristics, Market, Determinant
Innovation Policy, Evaluation	Policy, Government, Support, Innovation Policy, Sector, Evaluation, Barriers, Challenges, Incentives, Implication
HR Management, Practices &Outcomes	Institution, Organization, Management, Work Practices, Outcomes, Adoption, Formal, Informal, Quality, Employees
Open Innovation, External Sources &Users	Process Innovation, Product Innovation, Open Innovation, Strategy, External Sources, Radical, Innovation Activity, Innovation Process,
Technological Change &Industrial Dynamics	Technological Change, Industry, Evolution, Diffusion, Dynamics, Development, Patterns, Competition, Trajectory, Emergence
Innovation Systems	Innovation System, National, Function, Actor, Sectoral, Framework, Systemic, Approach, Regional, Foresight
Networks, Embeddedness &Social Capital	Networks, Social Capital, Relationships, Structure, Embeddedness, Community, Position, Exchange, Innovation Networks, Information
Literature, Framework, Theoretical &Conceptual	Literature, Theory, Framework, Concept, Approach, Understanding, Implication, Contribution, Issues, Review
International Entrepreneurship &Cultural Distance	Entrepreneurship, Cultural Distance, Opportunity, Entry Mode, Culture, International, Uncertainty, Joint Venture, Acquisition, Differences
Transitions, Sustainability &Environment	Transition, Energy, Governance, Sustainability, Niche Management, MLP, Socio-Technical, Transformation, Climate, Regime, Political
Internationalization, MNE's &Entry Modes	Foreign, International, Emerging, Strategy, Subsidiary, Institution, MNE, Host, FDI, Internationalization
Knowledge Transfer, Absorptive Capacity	Knowledge Creation, Capacity, Knowledge Transfer, Knowledge Flows, Absorptive Capacity, Tacit Knowledge, Knowledge Base, R&D, Knowledge Production, External Sources
Regional Performance, RIS &Higher Education	Region, Economic Growth, Economic Development, Regional Innovation, Related Variety, RIS, Europe, Competitiveness, Economic Geography, Higher Education
Empirical Evaluation, Econometrics, Performance	Performance, Effect, Impact, Relationship, Results, Firm Performance, Data, Findings, Influence, Factor

Note. This table lists the topics identified with the LDA analysis of the abstracts of our main corpus, and their 10 most associated terms. The topic name reflects the authors' own description.

studies in terms of high-impact works in the field of science policy and innovation studies (Fagerberg et al., 2012; Martin, 2012a), illustrating the reproducibility of stylized facts across different corpora and methodologies. As for the publication outlet, the biggest shares of articles in our final corpus were published in *Research Policy* (10%), *European Planning Studies* (4%), *Regional Studies* (4%), and *Technological Forecasting and Social Change* (3%). The most cited references in our corpus include foundational books, book chapters, and journal articles on many of the fields core topics, such as the seminal book by Nelson and Winter (1982), the initial formulations of the NIS concept (Lundvall, 1992; Nelson, 1993; Edquist, 1997), and the concept of absorptive capacity (Cohen and Levinthal, 1990).

4.2. Results of the topic modeling and identification of themes

Table 3 reports the identified topics and associated terms based on the LDA. They can be interpreted as themes in the corpus, as expressed by the authors' description of the publications' theory, applied frameworks, context, and method. The topics have to be interpreted broadly, since some of them indicate an association with a certain theoretical framework (e.g., the topic IS, which appears to be strongly associated with the IS framework), the study of a certain phenomenon (e.g., the topic University-Industry Relations & Technology Transfer), or the application of particular methods (e.g., the topic Empirical Evaluation & Econometrics). Overall, the identified topics appear to appropriately capture different academic and policy themes discussed in the IS literature. They will subsequently be used to capture the context of research effort in the research areas and derive specialization measures of those areas.

4.3. Results of the community detection analysis

4.3.1. Knowledge bases: co-citation network

Table 4 provides a condensed summary of the identified knowledge bases, which are the result of a clustering exercise on the co-citation network of cited references. These knowledge bases can be interpreted as the distinct bodies of knowledge the IS field at its current state draws from or has been drawing from during its development. Below, we provide a brief qualitative summary of their content and context.

Territorial Innovation: This largest among the identified knowledge bases includes seminal contributions on NIS (Lundvall, 1992), the competitive advantage of nations (Porter, 1990), and regional clusters (Saxenian, 1994), as well as prominent theories on externalities and the economics of agglomeration (Marshall, 1920; Jacobs, 1969; Glaeser et al., 1992), which are also identified as core literature in IS from former researcher (e.g., Fagerberg et al., 2012; Martin, 2012a). The remainder consists of early work by economic geographers interested in spatial dimensions of innovation activity, such as R&D spillovers (Jaffe et al., 1993) and the geography of innovation and production (Audretsch and Feldman, 1996). More recent references discuss the competitiveness of clusters (Bathelt et al., 2004) and the influence of proximity on interactive learning and innovation (Boschma, 2005). The most central journals are *Regional Studies*, *Research Policy*, and the *Journal of Economic Geography*.

Organizational Learning: Mainly originating from strategic management and organizational studies, the most central references include seminal contributions on defining central concepts of intra-organizational learning, such as the resource-based view and the firm's sustainable competitive advantage (Barney, 1991), "absorptive capacity" (Cohen and Levinthal, 1990), "combinative capabilities" (Kogut and

Table 4
Knowledge bases summary.

Central References		Central Authors		Central Journals		Central Concepts
Reference	C_{int}	Author	C_{int}	Source	C_{int}	
Knowledge Base 1: Territorial Innovation, N: 8396 (25%)						
Lundvall B, 1992	0.32	Cooke P	1.00	Reg. Stud.	0.80	–Competitive advantage of nations
Bathelt H, 2004	0.30	Boschma R	0.55	Res. Policy	0.53	–Geography of innovation production
Boschma R, 2005	0.29	Asheim B	0.39	J. Econ. Geogr.	0.27	–Localization of knowledge spillovers
Jaffe A, 1993	0.28	Amin A	0.36	Am. Econ. Rev.	0.18	–Proximity &interactive learning
Audretsch D, 1996	0.27	Storper M	0.24	Eur. Plan. Stud.	0.15	–MAR &Jacob's externalities
Knowledge Base 2: Organizational Learning, N: 6259 (19%)						
Cohen W, 1990	0.37	Gulati R	0.61	Strg. Mng. J.	1.00	–Absorptive capacity
Powell W, 1996	0.29	Burt R	0.38	Adm. Sci. Q.	0.31	–Organizational learning
Nelson R, 1982	0.27	Cohen W	0.27	Organ. Sci.	0.26	–Collaboration networks
Burt R, 1992	0.22	Hagedoorn J	0.23	Acad. Mng. J.	0.17	–Firm resources &strategy
Ahuja G, 2000	0.20	Baum J	0.23	Res. Policy	0.17	
Knowledge Base 3: Internationalization, Institutions &MNEs, N: 5137 (15%)						
Kogut B, 1988	0.63	Dunning J	0.80	Int. Bus. S.	1.00	–Cultural distance &foreign entry mode
Johanson J, 1977	0.56	Cantwell J	0.51	Strg. Mng. J.	0.16	–Cultural distance &FDI
Hofstede G, 1980	0.51	Luo Y	0.49	Acad. Mng. J.	0.06	–MNE/TNE activities &performances
Kostova T, 1999	0.46	Rugman A	0.47	Acad. Mng. Rev.	0.03	
Shenkar O, 2001,	0.37	Peng M	0.43	Int. Bus. Rev.	0.03	
Knowledge Base 4: Transitions &Sustainability, N: 4309 (13%)						
Kemp R, 1998	0.31	Geels F	1.00	Res. Policy	0.65	–Multi-level perspective
Geels F, 2002	0.31	Kemp R	0.24	Energ. Policy	0.33	–Strategic niche management
Geels F, 2007	0.31	Smith A	0.16	Tech. For. Soc.	0.20	–Transition management
Rip A, 1998	0.21	Garud R	0.11	Tech. Anal. S. M.	0.12	–Technological innovation systems
Hekkert M, 2007	0.21	Bergek A	0.10	J. Evol. Econ.	0.04	
Knowledge Base 5: Knowledge Production, N: 3514 (10%)						
Etzkowitz H, 2000	0.44	Leydesdorff L	0.63	Res. Policy	1.00	–Modes of knowledge production
Cohen W, 2002	0.39	Etzkowitz H	0.32	J. Tech. Transfer	0.12	–University-industry interaction
Gibbons M, 1994	0.25	Mowery D	0.04	Scientometrics	0.11	–University-industry collaboration
D'Este P, 2007	0.25	Bozeman B	0.04	Technovation	0.02	–Economics of science
Meyer-Krahmer F, 1998	0.24	Nelson R	0.03	Sci. Publ. Policy	0.01	
Knowledge Base 6: Entrepreneurship, N: 3218 (10%)						
Shane S, 2000	0.56	Audretsch D	0.97	J. Bus. Vent.	0.99	–Entrepreneurial opportunity discovery
Baumol W, 1990	0.38	Acs Z	0.86	Small Bus. Econ.	0.98	–Entrepreneurship &competition
Davidsson P, 2003	0.36	Shane S	0.38	Entrep. Theo. Pract.	0.65	–Entrepreneurship effect on the economy
Reynolds P, 2005	0.36	Davidsson P	0.26	Acad. Manage. Rev.	0.08	–Entrepreneurial traits
Shane S, 2000	0.31	Aldrich H	0.23	Strg. Entrep. J.	0.04	
Knowledge Base 7: HR Management &Performance, N: 1821 (5%)						
Huselid M, 1995	0.75	Osterman P	0.76	Int. J. HRM.	0.55	–HRM practices &firm performance
Ichniowski C, 1997	0.61	Hofstede G	0.74	Acad. Manage. J.	0.51	–Strategic HRM
Macduffie J, 1995	0.58	Schwartz S	0.67	Ind. Labor Rel. Rev.	0.33	–High performance work practices
Appelbaum E, 2000	0.58	Guest D	0.63	Ind. Relat.	0.21	
Osterman P, 1994	0.55	Godard J	0.51	Int. Bus. Stud.	0.16	
Knowledge Base 8: Institutional Entrepreneurship, N: 1088 (3%)						
Seo M, 2002	0.30	Lawrence T	0.80	Acad. Manage. J.	0.76	–Institutional entrepreneurship
DiMaggio P, 1988	0.30	Greenwood R	0.51	Organ. Stud.	0.66	–Institutional change &innovation
Greenwood R, 2006	0.30	Suddaby R	0.36	Acad. Manage. Rev.	0.43	–Organizations &institutional environments
Maguire S, 2004	0.27	Battilana J	0.30	Admin. Sci. Quart.	0.28	
Battilana J, 2009	0.26	March J	0.29	Organ. Sci.	0.18	

Note. This table reports the most central references, authors, and journals within the identified knowledge bases in the co-citation network. All calculated centralities are Jaccard-weighted. It also summarizes the main central concepts (author's interpretation).

Zander, 1992), and exploration and exploitation (March, 1991). Furthermore, the initial formulations of central concepts in inter-organizational learning such as "structural holes" (Burt, 1992) and "structural embeddedness" (Uzzi, 1997), and broadly, the role of collaboration networks for innovation (Ahuja, 2000; Powell et al., 1996), are to be found here. It also includes the field's defining book by Nelson and Winter (1982), *An Evolutionary Theory of Economic Change*. The most central journals are associated with management or organizational fields of study, such as the *Strategic Management Journal*, *Administrative Science Quarterly*, *Organizational Science Journal*, and *Research Policy*.

Internationalization, Institutions, and Multinational Enterprises: This knowledge base mainly includes contributions in international business and management studies. Central references are concerned with the role of multinational enterprises (MNEs) (Buckley and Casson, 1976) and transnational organizations (Bartlett and Ghoshal, 1989), as well as the internationalization process (Johanson and Vahlne, 1977) more generally. Another group of references relates to the role of work-related cultural dimensions (Hofstede and Bond, 1984) and foreign entry mode choices (Kogut and Singh, 1988), which are also critically reflected on (Shenkar, 2001). Some contributions are grounded in institutional theory and include work on "new institutionalism" (North, 1990) and the concept of "institutional isomorphism" (DiMaggio and Powell, 1983), while others apply an evolutionary perspective on firm growth (Kogut and Zander, 1993; Kostova and Zaheer, 1999). The most central journals are the *Journal of International Business Studies*, *Strategic Management Journal*, and *Academy of Management Journal*.

Transitions and Sustainability: The references in the relatively young field of sustainability transition research include central concepts like technological systems, technological regimes, niches, and the multilevel perspective (MLP) (Geels, 2004, 2002; Geels and Schot, 2007a; Rip and Kemp, 1998). Representative examples of topics are the development of a strategic niche management perspective on how to transition into a new regime (Kemp et al., 1998), the governance of sociotechnical transitions (Smith et al., 2005), and transition management in public policy (Rotmans et al., 2001). Another body of work in this group focuses on a functional approach to studying TIS (Hekkert et al., 2007; Bergek et al., 2008). The most central journals are *Research Policy, Energy Policy*, and *Technological Forecasting and Social Change.*[13]

Knowledge Production: Research in this knowledge base is centered around the role of universities in innovation in "knowledge-based" economies. It includes seminal work on the "Triple Helix" concept of university, industry, and government relations (Etzkowitz and Leydesdorff, 2000; Etzkowitz, 1998), as well as work on new modes of knowledge production in contemporary societies (Gibbons et al., 1994). Other central references deal with different aspects of university-industry interactions, such as on the influence of public research on industrial R&D (Cohen et al., 2002), the different channels (D'Este and Patel, 2007) and patterns of university-industry interaction and cooperation (Meyer-Krahmer and Schmoch, 1998). Other contributions propose a "new economics of science" framework (Partha and David, 1994), discuss the role of patents as knowledge transfer indicator (Agrawal and Henderson, 2002) and the impact of regulation on university patenting (Mowery et al., 2001; Henderson et al., 1998). The most central publication outlets are concerned with different aspects of science (*Scientometrics*), technological innovation (*Technovation*), and the practice of technology transfer (*Journal of Technological Transfers*).

Entrepreneurship: This knowledge base includes mainly contributions concerned with different aspects of entrepreneurship, most notably classical works on entrepreneurship and competition (Kirzner, 1997, 1973). Other central references analyze productive, unproductive, or destructive contributions of the society's entrepreneurial activities (Baumol, 1990). More recent references address the promise of entrepreneurship as a field of research (Shane and Venkataraman, 2000), a general theory of entrepreneurship (Shane, 2003), and the limitations of the existing theories in entrepreneurship (McMullen and Shepherd, 2006). Further central references deal with the role of the entrepreneurs' knowledge, social and human capital in the discovery and utilization of opportunities (Shane, 2000; Davidsson and Honig, 2003). The most central journals are *Journal of Business Venturing*, *Small Business Economics* and *Entrepreneurship Theory and Practice*.

Human Resource Management (HRM) and Performance: This is the smallest of all identified knowledge bases, where the most central references include contributions dealing with human resource management (HRM) practices more generally, and with "high-performance" work practices or systems for organizing work and managing employees mainly in the manufacturing sector, more particularly. Most of the studies in this knowledge base are empirical studies dealing with different aspects of the relationship between the HRM practices or systems and the performances of firms (Huselid, 1995; Ichniowski et al., 1997; MacDuffie, 1995; Osterman, 1994, 2000; Appelbaum et al., 2000; Arthur, 1994; Becker and Gerhart, 1996; Cappelli and Neumark, 2001). However, it also includes a contribution on modes of theorizing in strategic HRM (Delery and Doty, 1996). The most central journals are *International Journal of Human Resource Management*, *Academic Management Journal*, *Industrial and Labor Relations Review*, and *Industrial Relations*, but also include journals from the field of psychology.

Institutional Entrepreneurship: The knowledge base consists mainly of central references sharing an institutional approach to organization theory and the role of agency in institutional change. It includes work on a sensemaking perspective on organisations (Weick, 1995), and the conception of human agency (Emirbayer and Mische, 1998). Different aspects of "institutional entrepreneurship" (DiMaggio, 1988; Greenwood and Suddaby, 2006; Maguire et al., 2004; Battilana et al., 2009; Garud et al., 2007; Seo and Creed, 2002), the concept of "cultural entrepreneurship" (Lounsbury and Glynn, 2001), and the relationship between innovation and established institutional fields (Hargadon and Douglas, 2001) are also addressed. Most central publication outlets are journals in the field of strategy, management, and organization theory, but journals covering the field of sociology more broadly can also be found.

In Fig. 4, we depict the development of citations received by the corresponding knowledge bases, which serves as an indicator of popularity in a certain period. For most knowledge bases, the annual number of citations received constantly grows (upper figure). Particularly *Organizational Learning* and *Territorial Innovation* over time become the by far dominant knowledge bases when measured in absolute terms.

In relative terms (lower figure), the field's main initial knowledge base in the 1980s was *Organizational learning*, a time when many of its core contributions were written (Nelson and Winter, 1982, eg.,][; Teece, 1986; Granovetter, 1985). Soon after, *Territorial Innovation* started to increase in influence, and punctuating the dominance of *Organizational Learning* in years of its seminal contributions (Freeman, 1987, eg.,][; Pavitt, 1984; Freeman and Soete, 1982). *Organizational Learning* (Cohen and Levinthal, 1990, eg.,][) and *Territorial Innovation* (Porter, 1990, eg.,][; Lundvall, 1992; Nelson, 1993), with a range of seminal publications remained relevant in the 1990s, yet we also witness new knowledge bases to emerge, particularly *Internationalization* (mainly its foundation in institutional as well as evolutionary economics, such as North (1990), and Kogut and Zander (1993)), and to some extent *Knowledge Production* (Gibbons et al., 1994, eg.,][; Zucker et al., 1994; Etzkowitz and Leydesdorff, 2000). In the late 2000*s* and afterwards, further knowledge bases gain prominence, particularly *Entrepreneurship* (Acs et al., 2014, eg.,][; Acs et al., 2013; Bruton et al., 2010) and *Tranistions* (Markard et al., 2012, eg.,][; Geels and Schot, 2007b; Bergek et al., 2008).

In summary, we see that the IS field during its development has stretched far beyond its original knowledge bases *Organizational Learning* and *Territorial Innovation*, by borrowing, adapting, integrating, or developing new bodies of knowledge, and thereby undergone a considerable reconfiguration of its theoretical foundation.

4.3.2. *Research areas: bibliographic-coupling network*

We proceed with the main part of our analysis, the community detection analysis on a bibliographic-coupling network of articles. We interpret the here identified communities as RESEARCH AREAS, which capture common trends at the field's research frontier. Again, bibliographic coupling analysis tends to favor current over older publications, therefore deemed as suitable to depict the state of more recent research. Since bibliographic coupling strength is not influenced by a publication's number of received citations or other measures of popularity, the most central publications within a research area are the most thematically relevant (as signalled by the authors' selection of references), and not the most academically significant ones, and can be seen as "typical" examples of research in terms of content, methods and theories applied. Consequently, the combined results of such an analysis provide insights and intuition of a research area's main content in general, rather than pinpoint seminal contributions in particular.[14] A graphical illustration of this network of publications is provided in Fig. 5, and a condensed summary of the identified research areas in Table 5, accompanied by a qualitative description.

Economic Geography: This research area focuses on the role of geography for knowledge spillovers (Audretsch, 2003), and innovation activity (Audretsch, 2002), mostly in form of empirical and policy contributions. Commonly, the concept of the "knowledge production function" is applied. Further topics discussed are inter-regional

[13] The results are highly in line with the results obtained in the study by Markard et al. (2012) on identifying the intellectual contours of the emerging field of sustainability transition research.

[14] Therefore we, for the sake of brevity, do not report them here and limit ourselves to a general overview, while providing a list of the most central publications and internally cited references per research area in Table A2.

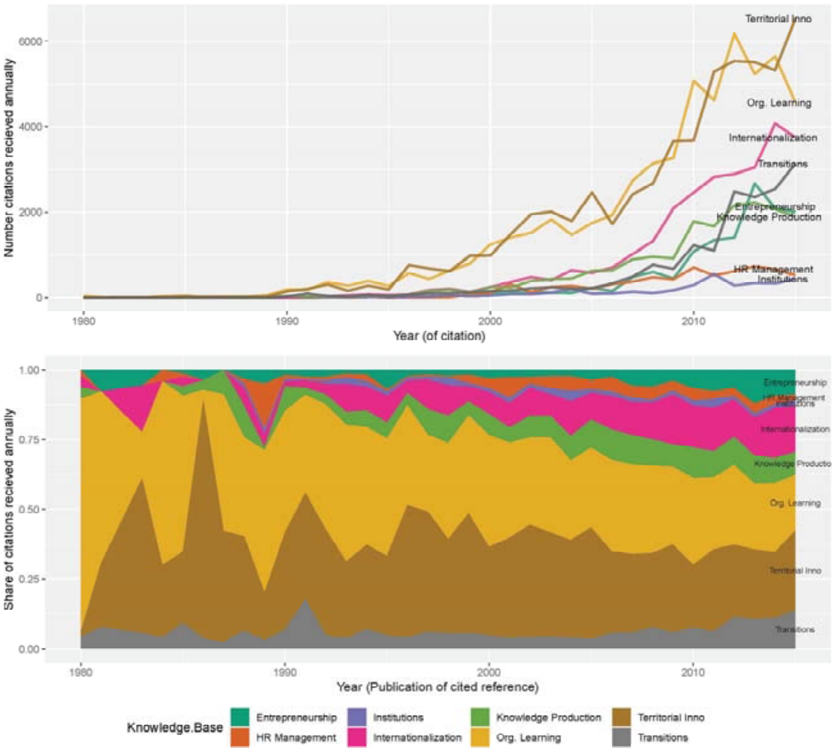

Fig. 4. Development of citations to the corresponding knowledge bases. *Note.* These figures illustrate the knowledge bases' absolute (upper) and relative (lower) amount of annual citations received. Only citations originating from our corpus are taken into account. Absolute citations are associated with the year of the citing publication, relative citations by the year of the corresponding reference.

(Greunz, 2003), inter-state (Smith, 1999) and university-industry knowledge spillovers (Acs et al., 2002b), the economic effect of spatial decentralization (Andersson et al., 2004), specialization and diversification (Feldman and Audretsch, 1999), urban economics (Andersson et al., 2005) and the innovation advantages of cities (Audretsch, 2002), as well as the international comparative advantage (Audretsch, 1998).

The most cited references are almost exclusively to be found in the knowledge base TERRITORIAL INNOVATION, include defining works on externalities in general (Marshall, 1920; Jacobs, 1969; Romer, 1990), spatially bounded knowledge spillovers (Jaffe, 1989; Jaffe et al., 1993; Griliches, 1979, 1990), and urban economics (Glaeser et al., 1992). Two most prominent journals are *Regional Studies* and *Research Policy*. Publication outlets generally reflect the main focus of the research area being on economic geography of innovation and regional science, the exception being *Small Business Economics* and *Journal of Technology Transfer*.

Networks and Inter-Organizational Learning: This mainly empirical research area includes publications thematically focused on firms' capabilities, strategic technology alliances, and inter- and intra-organizational networks as means of knowledge creation, diffusion, absorption and use. It includes work on different aspects of the firms' alliance networks and their influence on firms' learning and innovation (Gilsing et al., 2008; Karamanos, 2012; Phelps, 2010; Paruchuri, 2010; Vanhaverbeke et al., 2015; Soh, 2003; Schoenmakers and Duysters, 2006), and models of alliance partner selection (Baum et al., 2010). Theoretical contributions mainly aim at augmenting the resource-based view with a network perspective (Lavie, 2006).

The most cited references include Cohen and Levinthal (1990) on the concept of "absorptive capacity", Barney (1991) on the link between firm resources and sustained competitive advantage, Kogut and Zander (1992) on the knowledge-based-view of the firm, Powell et al. (1996) on the inter-organizational networks of learning in biotechnology, Burt (1992) on the concept of "structural holes", Nelson and Winter (1982) on evolutionary theory of economic change, and Ahuja (2000) on collaboration networks, structural holes and innovation. Other highly influential references include work by Granovetter (1985) on the concept of "embeddedness" of economic behaviour in social relations, and March (1991) on exploitation and exploration in organizational learning. The most central publication outlets are *Strategic Management Journal* and *Research Policy*.

International Business (IB): This is a relatively homogeneous research area mainly consisting of work on various dimensions of cross-national, cultural, and institutional differences, and the internationalization process of firms in the context of international business, management, and strategy studies. Central publications address the role of the host country's local demand on the relationship between cross-national distance and foreign direct investment (FDI) (Bailey and Li, 2015), cross-cultural distance on the establishment mode choice of the MNEs (Slangen and Hennart, 2008), the role of host country's "governance quality" on the relationship between cross-cultural distance and MNEs' entry mode (Chang et al., 2012), the impact of added cultural distance and diversity on MNEs' expansion patterns (Hutzschenreuter et al., 2011), the level of local isomorphism adopted by foreign firms from institutionally distant home countries (Salomon and Wu, 2012), the institutional determinants of the foreign subsidiary staffing policies (Ando, 2011), and the interaction effect of institutional differences on foreign market entry mode (Ang et al., 2015). Other central publications discuss the operationalization and measurement of the concepts of distance and international experience (Dow and Larimo, 2009), the impact of entry mode choice on foreign affiliate performances (Kim and Gray, 2008), and the relationship between cultural distance, international entry mode choice and performances (Wang and

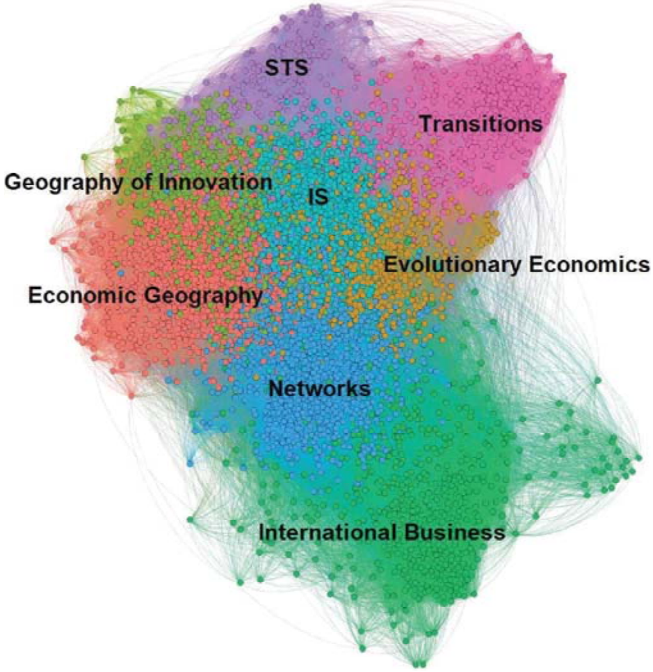

Fig. 5. Bibliographic coupling network of the IS literature. *Note.* Nodes represent the identified publications within the IS field of research, edges the bibliographic-coupling strength between them. Nodes are colored according to their association with identified research areas.

Schaan, 2008).

The highly cited references in this research area address dimensions of cultural differences among nations (Hofstede and Bond, 1984), the effect of national culture on the choice of firms' entry mode (Kogut and Singh, 1988), the institutional isomorphism and collective rationality (DiMaggio and Powell, 1983), an analytic framework for explaining how institutions and institutional changes affect economic performances of countries (North, 1990), a model of the internationalization of the firm with the main focus being on the knowledge of foreign markets and operations in explaining the extension of the firm's operations in individual countries (Johanson and Vahlne, 1977), the relationship between the institutional theory and the study of organisations (Scott, 2014), and the organizational legitimacy in the context of the MNEs (Kostova and Zaheer, 1999). The most central publication outlets are *Journal of International Business Studies* and *International Business Review*.

Innovation Systems (IS): This research area can be identified as the one most related to the original core concepts, context, and literature of the IS field. Its thematic orientation includes the systemic, evolutionary and spatial approaches for innovation analysis as well as theoretical and innovation policy contributions and focus on external sources of knowledge. The most central publications are concerned with the characteristics of RIS from the view of the Triple Helix model (Danell and Persson, 2003) or NIS (Chung, 2002), the characteristics of collaboration in the RIS (Edquist et al., 2002), a policy framework for IS-based strategies (Woolthuis et al., 2005), the regional strengths and weaknesses in the specific research domains (Islam and Miyazaki, 2010), the styles of innovation diffusion dynamics across countries (Weber and Hoogma, 1998), the role of firm's social capital formed in the context of NIS (Baba and Walsh, 2010). Other contributions discuss the usefulness of the NIS approach and the concept of "style of innovation" (Lundvall, 1998), the relevance of NIS from policy and managerial perspectives (de la Mothe and Paquet, 1998), and the usefulness of the IS approach for spatial innovation analysis (Fischer, 2001).

The most cited references are four books explicitly dealing with the NIS: Lundvall (1992), Nelson (1993), Freeman (1987), and Edquist (1997). Other highly influential references include Nelson and Winter (1982), and Porter (1990) on the patterns of competitive success of nations. They further include contributions on the relevance of national and regional systems of innovation as a domain of economic analysis (Freeman, 1995), a chapter on innovation as an interactive process in the seminal book on *Technical Change and Economic Theory* (Dosi et al., 1988), the concept of RIS (Cooke et al., 1997) and "absorptive capacity" (Cohen and Levinthal, 1990). *Research Policy* is by far the most prominent journal in this research area.

Geography of Innovation: The thematic orientation of this research area includes regional development, the role of localization, clusters, knowledge spillovers, patterns of knowledge sourcing and innovation activity, as well as globalization and non-localized interaction pattern. Central publications are concerned with the geography of innovation, and collaboration in emerging industries (Blažek and Žížalová, 2010), the relationship between innovation and the wider spatial structure (Doloreux and Shearmur, 2011), the sources of firms' product and process innovation (Fitjar and Rodríguez-Pose, 2013), the variety in knowledge sourcing and the relevance of geography for firms' innovativeness (Grillitsch et al., 2015), the design and progress of regional innovation strategies (Blažek et al., 2013), the geography of linkages at the industry level (Chaminade, 2011), and the role of proximity for knowledge collaboration (Moodysson and Jonsson, 2007). The remainder of the most central contributions deal with the knowledge bases of a region (Martin, 2012b), the dangers associated with the use of RIS as a normative concept (Uyarra and Flanagan, 2010), and the impact of various dimensions of proximity and

Table 5
Summary of research areas.

Research Area	N	Central Journals	Relevant Topics	Related Knowledge Bases
Economic Geography: Externalities, Growth, Urban Economics	1.146 (18%)	Reg. Stud. (1.00)	R&D, Productivity (0.09)	Territorial Innov. Models (0.22)
		Res. Policy (0.90)	Localization, Spillovers (0.09)	Knowledge Production (0.07)
		Ann. Reg. Sci. (0.76)	Reg. Performance, RIS (0.07)	Entrepreneurship (0.04)
		J. Econ. Geogr. (0.59)	Empirical (0.06)	Organizational Learning (0.04)
		Small Bus. Econ. (0.56)	University-Industry (0.06)	Internationalization (0.02)
Networks: Strategic Alliances, Interfirm Relations, Open Innovation	1.103 (17%)	Strateg. Manage. J. (1.00)	Capab., Strateg. Allian. (0.11)	Organizational Learning (0.32)
		Res. Policy (0.67)	Networks (0.08)	Internationalization (0.06)
		Organ. Sci. (0.58)	Empirical (0.06)	Territorial Innov. Models (0.05)
		Acad. Manage. J. (0.42)	Knowledge Transfer (0.06)	Knowledge Production (0.04)
		Technovation (0.34)	Open Innovation (0.06)	Entrepreneurship (0.03)
International Business: Distance Studies, Institutions	1.041 (16%)	J. Int. Bus. Stud. (1.00)	Int., Entrep., Distance (0.12)	Internationalization (0.29)
		Int. Bus. Rev. (0.64)	Internationalization (0.11)	Entrepreneurship (0.15)
		Manage. Int. Rev. (0.47)	HR Management (0.08)	HR Management (0.1)
		J. World Bus. (0.42)	Empirical (0.07)	Organizational Learning (0.05)
		J. Int. Manage. (0.38)	Literature (0.06)	Institutional Entrep. (0.03)
Innovation Systems: National, Regional &Sectoral Approaches	783 (12%)	Res. Policy (1.00)	Innovation Systems (0.09)	Territorial Innov. Models (0.14)
		Tech. Forecast. Soc. Ch. (0.61)	Innovation Policy (0.06)	Knowledge Production (0.07)
		Eur. Plan. Stud. (0.56)	Tech. Change, Industry (0.06)	Transitions (0.05)
		Scientometrics (0.45)	Reg. Performance, RIS (0.06)	Organizational Learning (0.04)
		Technovation (0.42)	Open Innovation (0.06)	Internationalization (0.02)
Geography of Innovation: Knowledge Sourcing, Flows, & Bases	669 (11%)	Eur. Plan. Stud. (1.00)	Localization, Spillovers (0.09)	Territorial Innov. Models (0.18)
		Reg. Stud. (0.76)	Reg. Performance, RIS (0.09)	Organizational Learning (0.02)
		J. Econ. Geogr. (0.41)	Knowledge Transfer (0.06)	Knowledge Production (0.02)
		Eur. Urban Reg. Stud. (0.34)	Globalization (0.06)	Transitions (0.01)
		Environ. Plan. A (0.33)	Networks (0.05)	Entrepreneurship (0.01)
Technological Change &Evolutionary Economics	635 (10%)	Res. Policy (1.00)	Technol. Change, Industry (0.1)	Organizational Learning (0.08)
		J. Evol. Econ. (0.84)	Open Innovation (0.06)	Territorial Innov. Models (0.06)
		Ind. Corp. Change (0.7)	Learning Processes (0.06)	Transitions (0.05)
		Tech. Anal. Strg. Mng. (0.48)	Firm Innov. Determinants (0.06)	Knowledge Production (0.04)
		Small Bus. Econ. (0.47)	Literature (0.06)	Entrepreneurship (0.03)
Transitions: TIS, MLP, Regimes, Niches, Sustainability	605 (10%)	J. Clean Prod. (1.00)	Transitions, Sustainability (0.19)	Transitions (0.36)
		Environ. Innov. Soc. Tr. (0.92)	Innovation Systems (0.08)	Territorial Innov. Models (0.02)
		Tech. Forecast. Soc. Ch. (0.91)	Innovation Policy (0.07)	Institutional Entrep. (0.02)
		Energy Policy (0.78)	Literature (0.06)	Knowledge Production (0.01)
		Tech. Anal. Strg. Mng. (0.67)	Tech. Change, Industry (0.06)	Organizational Learning (0.01)
Science Technology Studies: Modes of Knowledge Production	386 (6%)	High. Educ. (1)	University-Industry (0.14)	Knowledge Production (0.24)
		Scientometrics (0.95)	Globalization (0.06)	Institutional Entrep. (0.03)
		Minerva (0.86)	Literature (0.06)	Transitions (0.03)
		J. Technol. Transf. (0.8)	Innovation Policy (0.06)	Organizational Learning (0.01)
		Sci. Public Policy (0.72)	Learning Processes (0.06)	Territorial Innov. Models (0.01)

Note. Summary includes most central journals; the most relevant topics; and the most related knowledge bases. All calculated centralities are Jaccard-weighted.

entrepreneurial dimension on the functioning of an RIS (Sternberg, 2007).

The research area's most cited references include studies on local buzz, global pipelines, and the process of knowledge creation (Bathelt et al., 2004), the impact of proximity on innovation (Boschma, 2005), the RIS (Asheim and Isaksen, 2002; Asheim and Gertler, 2005; Asheim and Coenen, 2005; Cooke et al., 1998), and tacit knowledge and the economic geography of context (Gertler, 2003). Other most cited references include the seminal works on the concept of "absorptive capacity" (Cohen and Levinthal, 1990), knowledge formation and management (Amin and Cohendet, 2004), and the process of regional development (Cooke et al., 1998). *European Planning Studies*, *Regional Studies*, and *Journal of Economic Geography* appear as the most central publication outlets.

Technological Change and Evolutionary Economics: This research areas focuses on various aspects of the process of technological change and the application of an evolutionary perspective in economics, management and organizational studies. Central publications include work on the sources and obstacles to entrepreneurial behavior across technological regimes (Marsili, 2002), the relationship between the technological regimes and Schumpeterian patterns of innovation (Breschi et al., 2000), the economics of technological systems and the environmentally sustainable economic development (Kemp and Soete, 1992), the concept of "architectural innovation" and its competitive consequences for the established firms (Henderson and Clark, 1990), the consequences of incumbent's business patterns of introducing incremental innovations (Banbury and Mitchell, 1995), the effects of the introduction of the new technology on the innovative firms' survival (Levitas et al., 2006), and the effect of the demand heterogeneity on the development and evolution of technology (Adner and Levinthal, 2001). Other most central publications discuss the nature of the selection environment for innovations and the concept "techno-economic paradigms" (Freeman, 1991a), and the opportunities, incentives and collective patterns of technological change (Dosi, 1997).

The work by Schumpeter (1942), Nelson and Winter (1982), Dosi (1982), Dosi and Orsenigo (1988), Dosi et al. (1988), and Freeman and Soete (1982) are the most cited references. Other highly influential references include work by Abernathy and Utterback (1978) on patterns of industrial change, and Pavitt (1984) on sectoral patterns of technological change, as well as Rosenberg (1994) collection of essays on technological change. *Research Policy* and *Journal of Evolutionary Economics* are the most central publication outlets.

Sustainability Transitions: This research area is thematically focused on transitions towards sustainability from a systems as well as evolutionary economic perspective, and includes conceptual, literature review and policy contributions. Central publications are studies concerned with a framework for analyzing sustainable innovation policy (Meelen and Farla, 2013), the multi-level perspective (MLP) framework for assessing policy to stimulate socio-technical transitions (Kern, 2012), an integrated framework of TIS and MLP approaches on technological change (Markard and Truffer, 2008), a system dynamic model that crosses over the TIS and MLP frameworks (Walrave and Raven, 2016), a review of the current transition research and on the limitations of the MLP approach (Genus and Coles, 2008), the socio-technical regimes (Fuenfschilling and Truffer, 2014), and a comparison of empirical approaches and results of two "path creation" frameworks (Lovio and Kivimaa, 2012). Empirical contributions include studies on the interactions between niche and regime (Ingram, 2015), the actor strategies and resources in transition processes (Farla et al., 2012), and the translation mechanisms in socio-technical niches (Raven et al., 2011).

The most cited references in this line of research include a multi-level perspective on technological transitions (Geels, 2004, 2002; Geels and Schot, 2007a), a strategic niche management perspective on transitions (Kemp et al., 1998; Smith et al., 2005; Rip and Kemp, 1998; Schot and Geels, 2008), and a functional approach to studying TIS (Hekkert et al., 2007; Bergek et al., 2008). Here, the *Journal of Cleaner Production* and *Environmental Innovation and Societal Transitions* are the most central publication outlets.

Science and Technology Studies (STS): In STS, we find a strong thematic focus on different aspects of modes of knowledge production, such as university–industry interactions, and the role of university in the context of the global knowledge economy, as well as literature review and policy contributions. The most central articles address the paths of commercial knowledge occurring in scientist-sponsored firms (Shinn and Lamy, 2006), different approaches to measuring the relationships among university, industry, and other sectors in the NIS (Sun and Negishi, 2010), the management of the multiple criteria for knowledge production in the context of collaborative research projects (Wehrens et al., 2014), the role of novel organizational forms on framing science-industry activities (Merz and Biniok, 2010), the limits of entrepreneurialism in the traditional public university (Tuunainen, 2005), the multiple forms of university–industry linkages (Ramos-Vielba and Fernández-Esquinas, 2012), the role of higher education in various knowledge society discourses (Välimaa and Hoffman, 2008), and the place of the university in the knowledge production system (Godin and Gingras, 2000). It also includes a systematic reflection on the Gibbons–Nowotny notion of "Mode 2" knowledge production (Hessels and Van Lente, 2008), and a critical assessment of the main approaches in the sociology of science and technology (Shinn, 2002).

The most cited references consist of several contributions on the role of universities in the knowledge economy and contemporary society (Etzkowitz and Leydesdorff, 2000; Etzkowitz, 1998, 2003; Gibbons et al., 1994; Nowotny et al., 2001; Clark, 1998). Other sources discuss the influence of public research on industrial R&D (Cohen et al., 2002), a "new economics of science" (Partha and David, 1994), patenting as a measure of the influence of university research (Agrawal and Henderson, 2002), and the different channels through which academic researchers interact with industry (D'Este and Patel, 2007). *Higher Education* and *Scientometrics* appear as the most central journals.

4.4. Development of coherence in IS as a field of research

Delineating the field of IS research and identifying its distinct areas of research, while informative, is by nature a descriptive exercise. Yet, after setting the boundaries, further insights on the development of IS can be gained by analyzing its internal dynamics.

Fig. 6 depicts the development of annual publications in the field's research areas. While we observe a somewhat steady increase in the annual number of publications across all the research areas (upper figure), after 2010, a stagnation or even decline is evident for all except INTERNATIONAL BUSINESS and TRANSITIONS. In relative terms (lower figure), the composition reveals the evolving research agenda originating from EVOLUTIONARY ECONOMICS. Around the mid-1980*s*, the emergence of ECONOMIC GEOGRAPHY suggests an interest in the territorial aspects of technological change and economic growth. The field splits further in the early 1990*s*, into IS, with a focus on the link between the technological dynamics and social, institutional, and political factors on the one hand, and GEOGRAPHY OF INNOVATION, with an interest in combining territorial and institutional aspects with systemic aspects of innovation and regional development on the other. In the late 1990*s*, the field specialized further into NETWORKS, INTERNATIONAL BUSINESS, STS, and TRANSITIONS. While the two research areas most associated with the field's initial topics and theoretical foundations, namely EVOLUTIONARY ECONOMICS and IS, represented the most popular research areas in the late 1990*s*, they recently became the ones with the lowest share of annual contributions. Among the field's early knowledge bases, only ECONOMIC GEOGRAPHY has maintained a certain level of relevance. In contrast, TRANSITIONS and INTERNATIONAL BUSINESS now occupy the top positions, reflecting that topics of transition toward sustainability and globalization have lately enjoyed increased attention from academics, policymakers, and practitioners.

In summary, the field's internal dynamics, which could already be observed in our previous analysis of the development of its knowledge bases, also manifests when observing its active research areas, leading to a much broader and more diverse field at present. The growing number of distinct research areas may either have developed from within or entered IS as a result of broadening research agendas from outside the field. How has this growing diversity influenced the field's coherence? While research areas can be expected to specialize somewhat in terms of methods, topics, and theories, is there enough common ground left to collectively pursue a larger research agenda, or has fragmentation and isolation in knowledge silos taken place? In a first attempt to provide answers to these questions, it is helpful to apply a network perspective and inspect the development of bibliographic coupling strength between the research areas in Fig. 7 (cf. Table A3 for numerical values), measuring the extent to which they draw from a common pool of references and knowledge.

Fig. 7a depicts the IS field's research areas in the 1980*s*, up to now only EVOLUTIONARY ECONOMICS and ECONOMIC GEOGRAPHY. The two areas are connected during this period, possibly due to the increasing popularity of research on the relationship between R&D, innovation, and productivity growth among economic geography scholars and their shared body of references to the early contributions in the economics of technical change. This is associated with knowledge spillover and the extent to which they are geographically localized (Breschi and Lissoni, 2001).

In the 1990*s* (Fig. 7b), all research areas display an overall high level of coupling strength, indicating a high consensus in the core literature and dominant theories. This is unsurprising, since a major share of the field's seminal contributions now forming its core literature (e.g. Cohen and Levinthal, 1990; Nelson, 1993; Lundvall, 1992; Edquist, 1997) were published at this time. This demonstrates the influence of core contributions (in this case, mostly in the form of books) to inspire diverse lines of work and form a coherent higher level field of research. EVOLUTIONARY ECONOMICS and IS stand in the center of this development.

In the 2000*s*, we observe a similar pattern, but with decreased strength. Interestingly, the coupling of EVOLUTIONARY ECONOMICS decreases with all research areas except TRANSITIONS, hinting at the challenges to further advance the field's overall theoretical evolutionary foundations. Likewise, INTERNATIONAL BUSINESS moves further toward the most peripheral position, hinting at an up to now unsuccessful integration. This configuration remains somewhat stable in the post-2010 period.

Overall, after a formative stage of "groundwork" in the 1980*s* and 1990*s*, we see the field evolve in a diverse and coherent manner. While the initial pattern established in this period remains somewhat stable, the field's overall coherence decreases and settles below its initial level (cf. Table A3 for numerical values). This development may be explained by the diminishing interest in—and reference to—the field's original core contributions (Fagerberg and Sapprasert, 2011). From a different point of view, it could also be interpreted as the unsuccessful integration of emerging areas, such as INTERNATIONAL BUSINESS and TRANSITIONS, into the field's theoretical foundations.

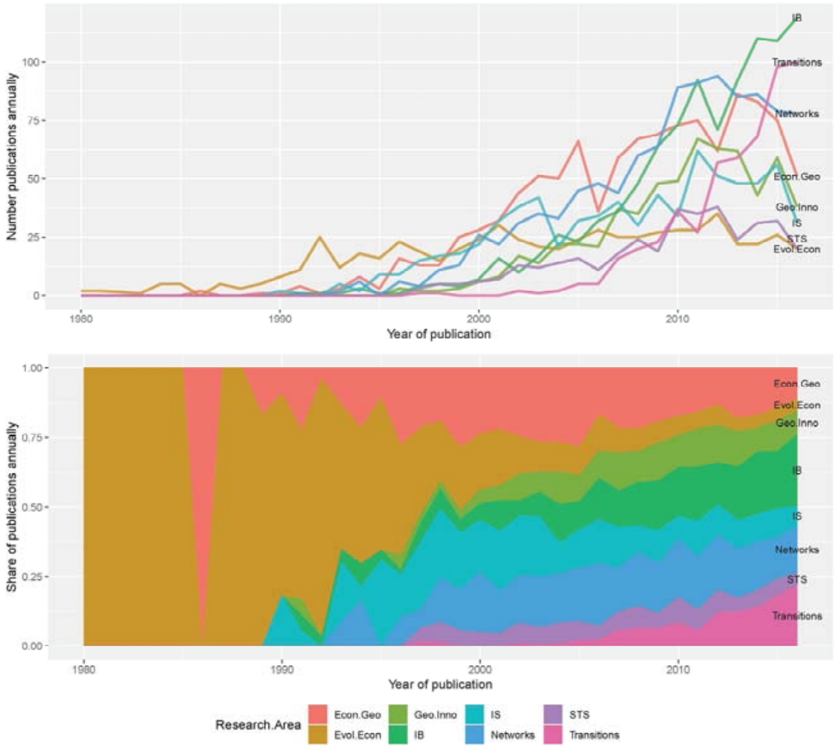

Fig. 6. Developments in annual publications in the research areas. *Note.* Absolute (upper) and relative (lower) numbers of publications per year in the research areas.

4.5. Development of coherence and diversity in research areas

Considering the one-mode bibliographic-coupling network between research areas gives us a good general overview on the field's development in terms of overall coherence, yet many questions remain unanswered in this type of analysis. What are the field's unifying theoretical building blocks? How did these foundations develop over time? Were they strengthened and developed further, neglected, or even substituted, and are these patterns homogeneous across the research areas?

In an attempt to provide first answers, considering the full information contained in the multimodal structure of bibliographic networks appears to be a promising way forward (Opsahl, 2013; Newman, 2004b, 2001). Thus, in Fig. 8, we present the two-mode network (research area → knowledge base), providing insight into the pattern of how the field's research areas draw from (as measured by citations) and integrate the knowledge bases over time.

Fig. 8a depicts the field in the 1980*s*, when we see that EVOLUTIONARY ECONOMICS first mainly drew from the literature associated with the knowledge bases *Organizational Learning* and *Territorial Innovation*, and to a lesser extent, almost all knowledge bases. This pattern is in line with the early attempts of the creators of an evolutionary program in economics and management research to develop and integrate a coherent theory of the firm into analysis of the large systems (Winter, 2017). Initially, ECONOMIC GEOGRAPHY mainly drew from *Territorial Innovation*, and to a lesser extent, from several other knowledge bases. This connection of ECONOMIC GEOGRAPHY corresponds with the beginnings of the regional endogenous development approach (Moulaert and Sekia, 2003).

EVOLUTIONARY ECONOMICS in the 1990*s* (Fig. 8b) maintains the strong connection to its original knowledge bases while additionally integrating *Institutions* to further increase the richness of its theoretical foundation. IS developed in a similar fashion, broadening its knowledge bases over time while decreasing the focus on its original foundation. In contrast, ECONOMIC GEOGRAPHY maintained and even strengthened its association with *Territorial Innovation* over time while integrating a relatively large number of knowledge bases. Similarly, NETWORKS shows an overall tendency of increasing diversity of knowledge bases while growing a strong connection to its main knowledge base *Organizational Learning*. Both GEOGRAPHY OF INNOVATION and TRANSITIONS mainly draw from literature associated with *Territorial Innovation* and *Transitions*, respectively. While continuously strengthening these connections over time, both become increasingly connected to diverse knowledge bases, such as *Organizational Learning* and *Knowledge Production*, after 2010.

A somewhat different tendency is observed for INTERNATIONAL BUSINESS, which mainly drew from literature associated with *Internationalization* in the 1990*s*, and only to some extent from *HR Management*, *Entrepreneurship*, and *Organizational Learning*. The later periods (Fig. 8c and 8 d) show a growing connection to several knowledge bases, such as *Institutions* and *Territorial Innovation*. Interestingly, we also observe a shift from the focus on *HR Management* in the 2000*s* to *Entrepreneurship*, reflecting a refocusing away from global MNE activity to global entrepreneurship.

In summary, over time, we observe heterogeneous processes of knowledge integration across the research. Most research areas were initially relatively focused but expanded their sources of knowledge while maintaining their initial specialty (namely ECONOMIC GEOGRAPHY, GEOGRAPHY OF INNOVATION, STS, or NETWORKS). In contrast, IS and EVOLUTIONARY

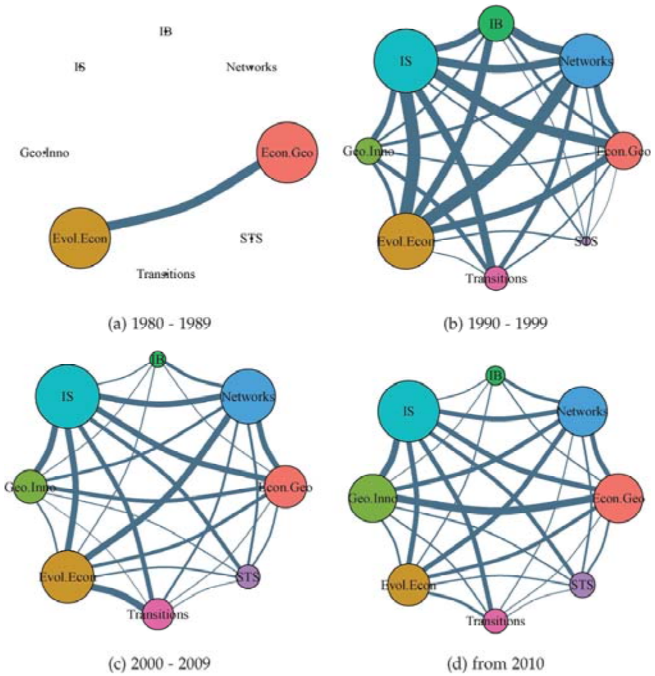

Fig. 7. Development of coherence between research areas. *Note.* Bibliographic coupling network between research areas by time periods. Node-size reflects the research area's degree. Edge-width reflects the (Jaccard-weighted) coupling strength.

ECONOMICS were always rather diverse, and this diversity even increased but at the cost of losing their initial focus. INTERNATIONAL BUSINESS is the only research area that shows changes in the importance given to distinct knowledge bases over time, indicating their ability to pivot toward timely strands of research.

As discussed in section 2, to assess the process of knowledge

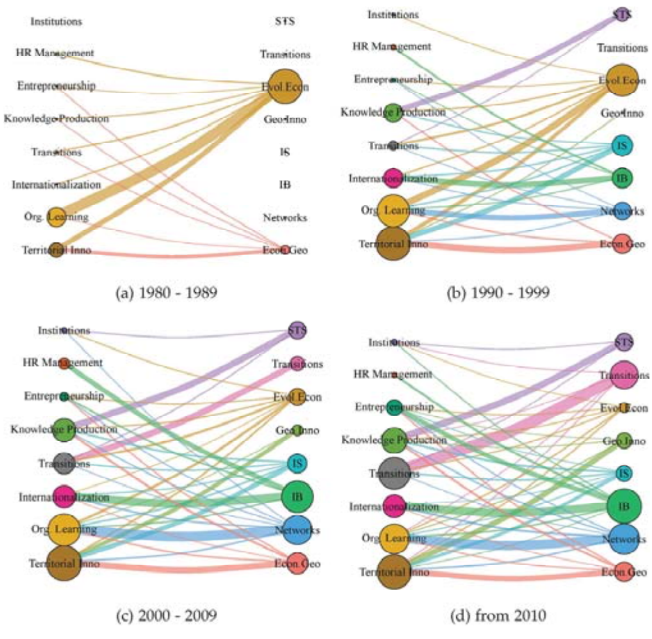

Fig. 8. Network of knowledge bases and research areas over time. Node-size reflects the degree of the research area/knowledge base. Edge-weight corresponds to the (Jaccard weighted) number of citations a knowledge base receives from a research area. The corresponding numerical values can be found in table A4 in the Appendix.

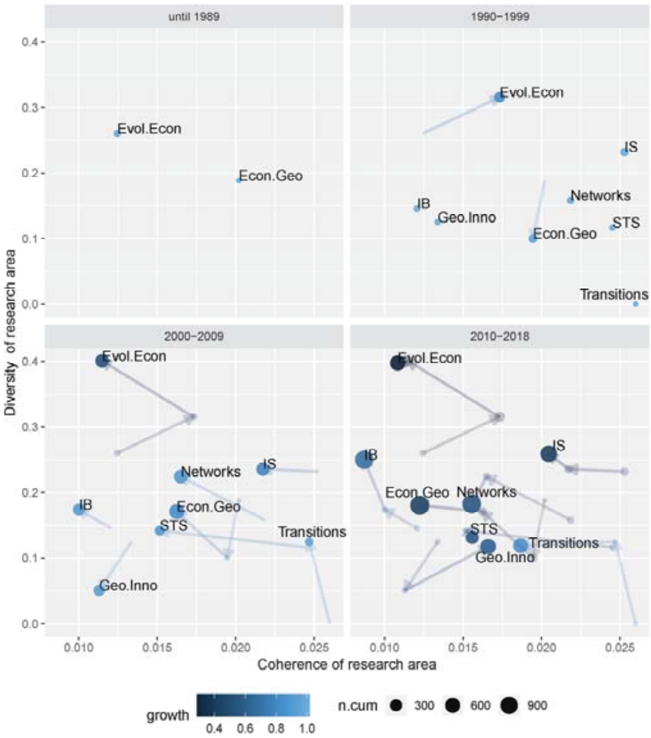

Fig. 9. Developments in the research areas' coherence and diversity. **Note:** (Internal) *Diversity* represents the (Leydesdorff, 2018) diversity measure of the corresponding research area for the cited knowledge bases ($Div = V * B * D$). *Coherence* is measured by the (internal) density of the (Jaccard-weighted) bibliographic-coupling network among publications in the research area. *Growth* represents the research area's growth rate in terms of the number of publications. Node size reflects the area's cumulative number of publications.

integration within the research field, it is useful to trace the research areas' diversity and coherence trajectories (cf. Fig. 1) over time, thereby illustrating heterogeneous processes of knowledge integration. Fig. 9 depicts the joint developments of coherence–diversity dynamics at the research area level (cf. Table A4 for numerical values).

In the 1980*s*, EVOLUTIONARY ECONOMICS emerged around the seminal contribution of Nelson and Winter (1982) in a comparably incoherent way, while ECONOMIC GEOGRAPHY started advancing a less diverse and more coherent line of inquiry related to the issues around "localized knowledge spillovers". While ECONOMIC GEOGRAPHY first maintained its level of coherence while decreasing in diversity during the 1990*s*, it then started to decrease in coherence and increase in diversity, which may be a sign of theoretical expansion (mid-left in Fig. 9). EVOLUTIONARY ECONOMICS first exhibits joint increases in diversity and coherence in the 1990*s*, and over time, further decreases in coherence while maintaining the high level of diversity (upper left in Fig. 9). As suggested by Hodgson and Lamberg (2018), our results for EVOLUTIONARY ECONOMICS point to the combination of growth, diversification, and deepening theoretical fragmentation, leading to a situation where this research area draws from diverse knowledge bases, yet makes relatively few common references to its core theoretical works (with the exception of its foundation by Nelson and Winter (1982)). In contrast, the results for ECONOMIC GEOGRAPHY display tendencies toward not only specialization but also diversification and reintegration, in line with the attitudes expressed by Bathelt and Glückler (2018). Especially, the trend toward diversification and reintegration may be due to the launch of the *Journal of Economic Geography* in 2000, with the specific purpose of stimulating debate across research traditions converging around the common research interest (Bathelt and Glückler, 2018).

INTERNATIONAL BUSINESS changed its position in the process of knowledge integration from fragmented specialization in the 1990*s* and 2000*s* to the position of fragmented diversification after 2010. A possible explanation for this finding may be a lack of substantial integration of the diverse theoretical perspectives applied in the context of international business, as suggested by Buckley et al. (2017). Starting in the 1990*s*, the research area NETWORKS draws from somewhat distinct knowledge bases; in the 2000*s*, it shows a further increase in diversity while slightly decreasing in coherence, indicating the successful integration of new knowledge bases. The change in position after 2010 points to some integration around the core literature. These results suggest the continuing tradition of this research area to engage with concepts across a spectrum of knowledge bases, and reconfigure its knowledge bases in response to current practical challenges.

IS and STS emerged in the 1990*s* as theoretically cohesive research areas while exhibiting different levels of diversification. IS's starting position confirms earlier studies that claim that this strand of literature emerged at the intercept of disciplines and schools of thoughts. Although IS remains connected to diverse knowledge bases over time, its decrease in coherence suggests a lack of advancements in its theoretical core. In contrast, STS is an example of a trajectory moving from the position of more to less coherent diversification. One possible interpretation is the progression from the influential "Mode 2" concept of 1990*s* to successive interest in the alternative approaches for studying changes in the science system, such as "Triple Helix" and "strategic science" through the 2000*s* and to a post-2010s refocus on university–industry linkages and academic entrepreneurship. Yet, no successful integrative development can be observed. GEOGRAPHY OF INNOVATION displays a rather different trajectory. The starting point in the 1990*s* signals a rather specialized research area but loosely integrated theoretical basis. Interestingly, in the 2000*s*, it shows further specialization and fragmentation, while the post-2010s witness a process of coherent diversification, where diversity and coherence increase.

While starting from the position of a highly coherent and specialized research area in the 1990*s*, TRANSITIONS in the 2000*s* displays a sharp increase in diversity and slight decrease in coherence, which may be attributed to a reliance on insights from new knowledge bases while focusing on a narrow research interest. This trend changes after 2010, where research becomes more fragmented, probably as a result of an increasing interest in sustainability issues from researchers in other research areas, as indicated by Markard et al. (2012).

4.6. Some reflections: how did the field develop—and why?

So far, our analysis has illustrated the current state and evolving nature of the IS field, overlapping with the results of previous studies on the whole field (e.g., Martin, 2012a; Fagerberg et al., 2013), as well as its distinct research areas (e.g., Hodgson and Lamberg, 2018; Bathelt and Glückler, 2018; Buckley et al., 2017; Markard et al., 2012), thereby validating our methodology and corpus selection techniques. However, while attempting to exploit the full richness of bibliographic data, ultimately, we face limitations in terms of what the data at hand can explain in relation to why the field developed in this manner. For this—arguably more interesting—question, in the following, we provide some tentative answers going beyond the inferences based on our analysis.

To start, what provided the initial spark for IS as a field of research on its own right? While systemic approaches to the economy, and specifically innovation, can be traced throughout the history of economic thought (e.g., List, 1909), there exists a consensus that the research on IS was launched in reference to the seminal book by Nelson and Winter (1982), *An Evolutionary Theory of Economic Change*, aiming at establishing a more realistic evolutionary foundation in economics that is useful for policy and management alike.

Along these lines, IS can be seen as one of the specializations of the broadly defined evolutionary agenda, focused on informing science and technology policy. Since, at that point, such policy was largely formulated at the national level, it is not surprising that the development of the "National Innovation System" concept around the seminal contributions by Nelson (1993), Lundvall (1992), Freeman (1987) was the initial focus. It should be noted that the seminal contributions so far have in common that they attempted to theoretically bridge several disciplines while being practically relevant. Consequently, it is unsurprising that all the contributions listed so far come in the form of books, a format that enables the formulation of complex and interdisciplinary concepts in sufficient detail while being shielded from the selection environment of established journals. We also observe that the publication of these books was associated with a sharp increase of coherence in the overall IS field and the formation of a stable pattern that persisted over time. According to their share of citations, the research areas where books appear the most relevant part of the knowledge base are IS (45%) and EVOLUTIONARY ECONOMICS (45%). This indicates the strong role that books and book chapters had on the central research areas in IS. Furthermore, in both research areas, the contributions to be found in books have an especially high within-area, as well as between-area, centrality, again demonstrating the crucial importance of these seminal contributions to unifying this field of research and stratifying its future development.

Notably, many seminal and formative contributions to the field of IS research—and research on innovation, R&D and technological change generally—were enabled and driven by the public policy needs of the time. Well-known examples are Christopher Freeman and Dick Nelson's early involvements with public policy institutions, such as the OECD and RAND. Therefore, it is also reasonable to assume that forces external to the academic community shape its development as much as interactions within academia do. Indeed, many historical accounts of IS as a research field pronounce that external engagements with governmental and intergovernmental organizations were instrumental for the formation of the field of IS and continue to shape its development (Fagerberg et al., 2013). A notable example is the concept of NIS. As explained by Sharif (2006), this concept emerged simultaneously in academic and policy arenas, while its development has been facilitated by the intercept of academics working at the OECD. Taking a closer look at whether traces of such engagements between policy and academia can also be found in our bibliometric data, we do not see this manifested in academic publications by actors from the policy space.[15] However, we do see intergovernmental organizations appearing among the cited references, suggesting they are less involved in academic knowledge production but nevertheless present as a source of knowledge. The most cited organization by far is the OECD (597 citations, making it the 43*rd* most cited author), followed by the European Commission (EC) (149 citations, rank 266). Especially, the number of citations of OECD references steadily increased over time, with a sharp increase after 2008 (18 citations) to 2016 (58 citations). Most of the cited references of OECD documents (50%) are located in the knowledge base *Territorial Innovation*, followed by *Knowledge Production* (19%), and they receive the highest numbers of citations from the research areas IS (31%) and GEOGRAPHY OF INNOVATION (22%). Both research areas aspire—at least by internal claims—to inform policy. While a wide range of OECD reports receive few citations in our corpus, two stand out, namely the "Oslo Manual" (OECD, 1997,][65 citations) and "OECD Main Science and Technology Indicators" (OECD, 1988,][63 citations across different volumes). When considering the topic distribution (result of the LDA analysis) in the publications citing OECD documents, we see that especially the topic `R&D, Patents & Productivity` is strongly overrepresented, followed by `Regional Performance & RIS` and `Empirical Evaluations`, suggesting that the OECD mainly serves as a provider of data—and guidance on how to gather and compose such data—for empirical work. However, the third most cited OECD publication in our corpus is the project white paper on "National Innovation Systems" (OECD, 1999,][46 combined citations), a compilation of work on *NIS* geared toward explaining and promoting the concept to policymakers. It appears plausible that the importance given to the concept of IS by the OECD, as evident by the volume of policy-related documents, had and continues to have an effect on boosting research on IS by providing it with greater legitimacy. Others (Godin, 2009) have even claimed that most of the main building blocks of the NIS framework can be traced back to—and are built on—previous efforts at the OECD. While the jury is still out on this claim, it appears evident that the systemic approach to innovation fell on fertile ground at the OECD, which undertook substantial efforts to promote and diffuse it among policymakers across the globe.

Likewise, many innovation scholars collaborated in various OECD studies, using concepts and indicators in their academic research; this suggests a mutual legitimization between academics and the OECD (Albert and Laberge, 2007). Moreover, the close cooperation between the OECD and EC on the design of innovation survey instruments and the commitment of resources for collecting firm-level innovation survey data in Europe and elsewhere, made this type of data more widely available and used by researchers. It is the new evidence stemming from these surveys that significantly influenced the evolution of the research agenda, including the emergence of new research frameworks and the importance given to specific issues like *dynamic capabilities* (Fagerberg et al., 2013, 2006). At the same time, the conceptual foundations of science, technology, and innovation indicators reflect the ideas, more or less informed by the innovation research, that have been taken up by data gatherers and indicator developers. Consequently, one would expect the field not only to continue to be shaped by the demands but also, to some extent, driven by the work of policymakers and intergovernmental organizations. This type of analysis, while limited in our approach, would certainly provide valuable

[15] We only find two publications with a first author directly affiliated with the OECD and one for the European Commission (EC).

insights on the societal role of different research areas. In summary, it can be speculated that the OECD and other intergovernmental organizations influenced the field as "producers of knowledge" from the supply (of data) side, as well as "user of knowledge" from the demand (of policy) side.

5. Conclusion

In this article, we delineated and mapped the field of recent IS research. We identified consistent research areas and knowledge bases, thereby enhancing our understanding of the diversity of research efforts that have contributed to the field's collective advances. Further, we established a conceptual and analytical link between the research areas and knowledge bases. By doing this, we developed and demonstrated a sound methodology for delineating an interdisciplinary academic field with blurry boundaries within a bibliometric corpus. We provided an inductive "bottom up" approach to identifying meaningful clusters of publications without relying on predefined classifications. We demonstrate the usefulness of this approach, especially for capturing the variety of research areas and knowledge bases of a research field that has undergone expansion and reconfiguration in terms of the issues it addresses, its users, and its theoretical foundations.

In an analysis of the resulting co-citation and bibliographic coupling network, we illustrated how the multidimensional structure of bibliometric data can be exploited for identifying and disentangling the structure of knowledge production, as well as the underlying knowledge bases utilized. By deploying methods from NLP, we added a further qualitative layer of information, thereby exploiting the full richness of bibliometric data to create insightful summaries of distinct research areas and their content. This is useful for verifying such a data-driven analysis, as well as giving the identified research areas meaning and context. In addition to the ability to provide an accurate and informative snapshot of a given research field, our method enabled us to unveil a persistent heterogeneity of knowledge integration across research areas and over time; this cannot be captured by commonly used methods for literature summary solely based on aggregated citation numbers. It also proved useful to derive temporal metrics and visualizations that provide insights into the process of knowledge integration, as well as some guidance and implications for its future development. We believe the presented methodology will prove useful for mapping and understanding other academic fields with similar characteristics.The present analysis also inspired the development of a bibliometrics package for the statistical programming environment R, which aims at easing its reconstruction and application in different settings. The current version of this package can be found at https://github.com/daniel-hain/TidyScientometrix. We hope other researchers will apply it to further enhance our knowledge on the development of research fields.

We provided what is, to the best of our knowledge, the most comprehensive bibliographic overview of the current state of IS research, its intellectual contours, and its heterogeneous internal dynamics of coherence and diversity at present. Thus, we contribute to the discussion on what constitutes the IS field now and how it evolved over time. We find the field in the 1980*s* centered on seminal works in EVOLUTIONARY ECONOMICS, and slightly later, IS, which served as the main unifying area of research. After the initial dominance of IS (1990*s* and 2000*s*) we witness a growing importance of other streams of research, especially INTERNATIONAL BUSINESS and SUSTAINABILITY TRANSITIONS. The composition and changes in the field's research areas reveal the evolving research agenda, originating from the influential works in the 1980*s* and 1990*s* and inspiring subsequent development of research specialties. We illustrated how literature on IS has expanded its audience and contributors and the resulting diversity of issues addressed by the growing number of research areas. Despite the initial success of diverse streams of literature to form a coherent higher level field of research, IS has become less coherent, where diverse but fragmented research areas pursue narrower lines of inquiry.

Furthermore, the field's knowledge bases have changed over time, as has the way the research areas use them. Across research areas, we identified distinct development patterns that include starting from a narrow knowledge base and including new ones over time while maintaining the strong connection to a single source (e.g., ECONOMIC GEOGRAPHY, GEOGRAPHY OF INNOVATION, and TRANSITIONS), as well as starting from a diverse knowledge base with subsequent movement to even higher levels of diversity (e.g., IS and EVOLUTIONARY ECONOMICS) while decreasing connections to its theoretical core. From the joint perspective of developments in coherence and diversity, we again illustrate how identified research areas follow different trajectories in the knowledge integration process. EVOLUTIONARY ECONOMICS appears to follow a trajectory of fragmented diversification, while ECONOMIC GEOGRAPHY suggests a disposition toward both diversified specialization and continuous reintegration. In turn, GEOGRAPHY OF INNOVATION and TRANSITIONS research areas move from the position of coherent and specialized lines of inquiry and only lately started to broaden its knowledge bases.

Our analysis of coherence-diversity dynamics provides insights beyond the context of IS, especially on how research fields develop and what promising development paths may be. We showed that research areas commonly associated with IS follow rather different trajectories in terms of coherence and diversity in their knowledge integration process. Thus, as the field grows larger in size as well as more diverse in thematic orientation, there is a danger of fragmented specialization to take place, where different specialties of IS pursue a narrow line of research interest without further enhancement of the common research agenda. There is a general consensus that a diversity of knowledge bases is integral for addressing complex phenomena and responding to the changing "grand challenges" posed by policy and society. Yet, we illustrated that the thriving toward higher diversity can also harm the collective alignment of research efforts if not accompanied by a maintenance of internal coherence.

How can such a coherence be maintained? While not being able to make a strong empirical case, anecdotal evidence hints at the key role of institutions. These can take the form of intergovernmental organizations, such as the OECD in our case, which supports the research and data-gathering infrastructure, compiling a diverse set of results and simplifying them for—and promoting them to—the relevant audience, such as policymakers. Our results also hint at the role joint interdisciplinary journal outlets play in shaping a joint research agenda, in our case mainly *Research Policy*, as the only journal significant in almost all the research areas (and scoring highest on our measure of diversity at the journal level). However, we also illustrate that such integration attempts are not always successful, as in the case for INTERNATIONAL BUSINESS, which remains peripheral despite the evolutionary overlap in intellectual origins and the growing importance of analyzing IS on a global scale.

While we consider that we have done some substantial groundwork for a more nuanced discussion on the state of IS research, we are far from providing conclusive answers. To eventually do this, we suggest the following avenues for future research, which seem promising and fruitful. First, we suggest the importance of books as an outlet for establishing the basis of a interdisciplinary and diverse theoretical foundation and research agenda, yet fall short of thoroughly analyzing this process. The reasons for this are the limitations in the available data, since up to now, there is no comprehensive collection of bibliographic meta-data for books reaching far enough back in time. However, such shortcomings may be overcome by utilizing modern document-processing tools for efficiently creating such data for books; we consider the books central to our identified knowledge bases a natural point to start such an effort. This would also address one of our main limitations in providing a comprehensive overview over the development of a research field and enable a less biased analysis throughout the whole lifecycle of a research field, where the importance of certain types of publication outlets varies over time. Likewise, a similar exercise could be done for policy reports to shed light on the pattern whereby intergovernmental organizations collect, compile, and promote a field's bodies of research, and the effect thereof.

In the IS field or elsewhere, another promising issue to address relates to the different mechanisms of diversification and knowledge integration at the author level. Until now, we have only observed the effect of diversification in terms of knowledge production embodied in publications, but not if these publications originate from authors historically associated with the focal or adjacent fields. Consequently, integrating author level publication histories in such a bibliometric exercise would show us if a diversification process is internally or externally driven. Finally, we demonstrate the usefulness of techniques from NLP to “make sense” of text corpora that are too large for human comprehension, but the potentials of such methods are strongly underutilized. More thorough applications could, for instance, shed light on the unanswered question of directionality, meaning whether new directions of research are emerging from the academic community (and if so, where), policymakers, or intergovernmental “transfer institutions”. Here, the application of semantic lead-lag models (e.g., Ramage et al., 2010) appears especially promising.

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Appendix A

Tables A1–A5

Table A1
List of seed articles.

Publications	TC	TC_year
Etzkowitz &Leydesdorff, 2000, “The Dynamics of Innovation: From National Systems and Mode 2 to...”, *Res. Policy*	1.788	94
Geels, 2004, “From Sectoral Systems of Innovation to Socio-Technical Systems...”, *Res. Policy*	828	55
Malerba, 2002, “Sectoral Systems of Innovation and Production”, *Res. Policy*	764	45
Freeman, 1995, “The National System of Innovation in Historical-Perspective”, *Cambr. J. Econ.*	763	32
Cooke et al., 1997, “Regional Innovation Systems: Institutional and Organisational Dimensions”, *Res. Policy*	741	34
Furman et al., 2002, “The Determinants of National Innovative Capacity”, *Res. Policy*	636	37
Hekkert et al., 2007, “Functions of Innovation Systems: A New Approach for Anal. Tech. Ch.”, *Tech. Forecast. Soc. Ch.*	622	52
Carlsson &Stankiewicz, 1991, “On the Nature, Function and Composition of TS”, *J. Evol. Econ.*	574	20
Freeman, 1991, “Networks of Innovators - A Synthesis of Research Issues”, *Res. Policy*	556	20
Acs et al., 2002, “Patents and Innovation Counts as Measures of Regional Production of New Knowledge...”, *Res. Policy*	518	30
Bergek et al., 2008, “Analyzing the Functional Dynamics of Tech. Inn. Systems: A Scheme of Analysis”, *Res. Policy*	514	47
Markard et al., 2012, “Sustainability Transitions: An Emerging Field of Research...”, *Res. Policy*	508	73
Jensen et al., 2007, “Forms of Knowledge and Modes of Innovation”, *Res. Policy*	505	42
Asheim &Coenen, 2005, “Knowledge Bases and Regional Innovation Systems: Comparing...”, *Res. Policy*	494	35
Lundvall et al., 2002, “National Systems of Production, Innovation and Competence Building”, *Res. Policy*	445	26
Carlsson et al., 2002, “Innovation Systems: Analytical and Methodological Issues”, *Res. Policy*	374	22
Jacobsson &Johnson, 2000, “The Diffusion of Renewable Energy Technology: An Analytical Frwk...”, *Energy Policy*	370	19
Meyer-Krahmer &Meyer-Krahmer, 1998, “Science-Based Technologies: University-Industry Interactions...”, *Res. Policy*	360	17
Markard &Truffer, 2008, “Technological Innovation Systems and the Multi-Level Perspective...”, *Res. Policy*	357	32
Smith &Raven, 2012, “What Is Protective Space? Reconsidering Niches in Transitions to Sustainability”, *Res. Policy*	337	48
Muller &Zenker, 2001, “Business Services as Actors of Knowledge Transformation: the Role of KIBS...”, *Res. Policy*	337	19
Morgan, 2004, “The Exaggerated Death of Geography: Learning, Proximity and Territorial IS”, *J. Econ. Geogr.*	334	22
Cooke P, 1992, “Regional Innovation Systems - Competitive Regulation in the New Europe”, *Geoforum*	301	11
Asheim et al., 2011, “Constructing Regional Advantage: Platform Policies Based on Related Variety and...”, *Reg. Stud.*	286	36
Liu &White, 2001, “Comparing Innovation Systems: A Framework and Application to China's Trans. Cntxt”, *Res. Policy*	276	15
Berry et al., 2010, “An Institutional Approach to Cross-National Distance”, *J. Int. Bus. Stud.*	274	30
Gilsing et al., 2008, “Network Embeddedness and the Exploration of Novel Technologies...”, *Res. Policy*	264	24
Coenen et al., 2012, “Toward a Spatial Perspective on Sustainability Transitions”, *Res. Policy*	258	37
Boschma &Iammarino, 2009, “Related Variety, Trade Linkages, and Regional Growth in Italy”, *Econ. Geogr.*	248	25
Hessels &Van Lente, 2008, “Re-Thinking New Knowledge Production: A Lit. Review and a Res. Agenda”, *Res. Policy*	245	22
Wolfe &Gertler, 2004, “Clusters From the Inside and Out: Local Dynamics and Global Linkages”, *Urban Stud.*	241	16
Christensen et al., 2005, “The Industrial Dynamics of Open Innovation - Evidence From...”, *Res. Policy*	239	17
Schartinger et al., 2002, “Knowledge Interactions Between Universities and Industry in Austria: Sectoral...”, *Res. Policy*	233	14
Owen-Smith et al., 2002, “A Comparison of US and European University-Industry Relations in the Life Sci.”, *Mng. Sci.*	228	13
Phene et al., 2006, “Breakthrough Innovations in the US Biotechnology Industry: The Effects of...”, *Strg. Mng. J.*	227	17
Rodriguez-Pose &Crescenzi, 2008, “Research and Development, Spillovers, Innovation Systems, and...”, *Reg. Stud.*	223	20
Cantwell et al., 2010, “An Evolutionary Approach to Understanding International Business Activity...”, *J. Int. Bus. Stud.*	222	25
Acs et al., 2014, “National Systems of Entrepreneurship: Measurement Issues and Policy Implications”, *Res. Policy*	126	25

Note. This table reports the 38 initial seed articles. They represent the top 1% publications in terms of total plus top 1% in terms of average annual citations received in the WoS corpus which contain the terms “Innovation System(-s)” or “System(-s) of Innovation” in title, abstract, or keywords (total 2.885).

Table A2
Clusters of research areas, summary.

Publications		*References*	
Publication	C_{int}	Reference	Cit
Research Area 1: Economic Geography: Externalities, Growth, Urban Economics, N: 1146 (18%)			
Audretsch D (2003) "Innovation and Spatial Externalities", *Int. Reg. Sci. Rev.*	1.000	Audretsch D, 1996	426
Andersson et al. (2004) "University Decentralization as Regional Policy: the Swedish Experiment", *J. Econ. Geogr.*	0.987	Jaffe A, 1993	279
Greunz (2003) "Geographically and Technologically Mediated Knowledge Spillovers Between European Regions", *Ann. Reg. Sci.*	0.949	Jaffe A, 1989	243
Andersson et al. (2005) "Agglomeration and the Spatial Distribution of Creativity", *Pap. Reg. Sci.*	0.925	Anselin L, 1997	239
Smith P (1999) "Do Knowledge Spillovers Contribute to US State Output and Growth", *J. Urban Econ.*	0.923	Glaeser E, 1992	175
Feldman &Audretsch (1999) "Innovation in Cities: Science-based Diversity, Specialization and Localized Competition", *Eur. Econ. Rev.*	0.888	Marshall A, 1920	161
Acs et al. (2002) "Hightechnology Employment and R&D in Cities: Heterogeneity vs Specialization", *Ann. Reg. Sci.*	0.836	Griliches Z, 1979	153
Del Rey (2001) "Teaching Versus Research: A Model of State University Competition", *J. Urban Econ.*	0.830	Griliches Z 1990	150
Audretsch D (2002) "The Innovative Advantage of US Cities", *Eur. Plan. Stud.*	0.828	Jacobs J, 1969	150
Audretsch D (1998) "Agglomeration and the Location of Innovative Activity", *Oxf. Rev. Econ. Policy*	0.818	Romer P, 1990	149
Research Area 2: Networks: Strategic Alliances, Inter-firm Relations, Open Innovation, N: 1103 (17%)			
Gilsing et al. (2008) "Network Embeddedness and the Exploration of Novel Technologies: Technological Distance, Betweenness Centrality and Density", *Res. Policy*	1.000	Cohen W, 1990	608
Karamanos A (2012) "Leveraging Micro and Macrostructures of Embeddedness in Alliance Networks for Exploratory Innovation in Biotechnology", *R&D Manage.*	0.934	Powell W, 1996	306
Tzabbar et al. (2013) "When Does Tapping External Sources of Knowledge Result in Knowledge Integration", *Res. Policy*	0.922	Burt R, 1992	286
Phelps C (2010) "A Longitudinal Study of the Influence of Alliance Network Structure and Composition on Firm Exploratory Innovation", *Acad. Manage. J.*	0.909	Ahuja G, 2000	262
Paruchuri (2010) "Intraorganizational Networks, Interorganizational Networks, and the Impact of Central Inventors: A Longitudinal Study...", *Organ. Sci.*	0.904	Nelson R, 1982	248
Vanhaverbeke et al. (2015) "Technological Performance and Alliances Over the Industry Life Cycle: Evidence From the ASIC Industry", *J. Prod. Innov. Manage.*	0.904	Barney J, 1991	225
Schoenmakers &Duysters (2006) "Learning in Strategic Technology Alliances", *Technol. Anal. Strateg. Manage.*	0.904	Kogut B, 1992	225
Baum et al. (2010) "Networkindependent Partner Selection and the Evolution of Innovation Networks", *Manage. Sci.*	0.897	March J, 1991	224
Lavie (2006) "The Competitive Advantage of Interconnected Firms: An Extension of the Resource-Based View", *Acad. Manage. Rev.*	0.896	Granovetter M, 1985	192
Soh P (2003) "The Role of Networking Alliances in Information Acquisition and Its Implications for New Product Performance", *J. Bus. Ventur.*	0.890	Baum J, 2000	190
Research Area 3: International Business: Distance Studies, Institutions, N: 1041 (16%)			
Bailey &Li (2015) "Crossnational Distance and FDI: the Moderating Role of Host Country Local Demand", *J. Int. Manag.*	1.000	Hofstede G, 1980	280
Dow &Larimo (2009) "Challenging the Conceptualization and Measurement of Distance and International Experience in Entry Mode...", *J. Int. Market.*	0.992	Kogut B, 1988	242
Slangen &Hennart (2008) "Do Multinationals Really Prefer to Enter Culturally Distant Countries Through Greenfields...", *J. Int. Bus. Stud.*	0.991	DiMaggio P, 1983	186
Salomon &Wu (2012) "Institutional Distance and Local Isomorphism Strategy", *J. Int. Bus. Stud.*	0.976	North D, 1990	184
Chang et al. (2012) "How Cultural Distance Influences Entry Mode Choice: The Contingent Role of Host Countrys Governance Quality", *J. Bus. Res.*	0.951	Johanson J, 1977	176
Ang et al. (2015) "The Interactions of Institutions on Foreign Market Entry Mode", *Strateg. Manage. J.*	0.919	Kostova T, 1999	157
Hutzschenreuter et al. (2011) "The Impact of Added Cultural Distance and Cultural Diversity on International Expansion Patterns...", *J. Manage. Stud.*	0.917	Shenkar O, 2001	129
Ando (2011) "Isomorphism and Foreign Subsidiary Staffing Policies", *Cross Cult. Manage.*	0.912	Barkema H, 1996	117
Kim &Gray (2008) "The Impact of Entry Mode Choice on Foreign Affiliate Performance: the Case of Foreign MNEs in South Korea", *Manag. Int. Rev.*	0.907	Scott W, 1995	113
Wang &Schaan(2008) "How Much Distance Do We Need Revisiting the National Cultural Distance Paradox", *Manage. Int. Rev.*	0.898	Barney J, 1991	107
Research Area 4: Innovation Systems: National, Regional &Sectoral Approaches, N: 783 (12%)			
Danell &Persson (2003) "Regional R&D Activities and Interactions in the Swedish Triple Helix", *Scientometrics*	1.000	Lundvall B, 1992	499
Edquist et al. (2002) "Characteristics of Collaboration in Product Innovation in the Regional System of Innovation of East Gothia", *Eur. Plan. Stud.*	0.998	Nelson R, 1993	365
Woolthuis et al. (2005) "A System Failure Framework for Innovation Policy Design", *Technovation*	0.945	Edquist C, 1997	320
Islam &Miyazaki (2010) "an Empirical Analysis of Nanotechnology Research Domains", *Technovation*	0.920	Freeman C, 1987	208
Weber &Hoogma (1998) "Beyond National and Technological Styles of Innovation Diffusion: A Dynamic Perspective...", *Technol. Anal. Strateg. Manage.*	0.871	Nelson R, 1982	144
Baba &Walsh (2010) "Embeddedness, Social Epistemology and Breakthrough Innovation: The Case of the Development of Statins", *Res. Policy*	0.868	Freeman C, 1995	104
Chung (2002) "Building a National Innovation System Through Regional Innovation Systems", *Technovation*	0.855	Lundvall B, 1988	95
De La Mothe &Paquet (1998) "National Innovation Systems, 'Real Economies' and Instituted Processes", *Small Bus. Econ. Group*	0.841	Porter M, 1990	94
Lundvall B (1998) "Why Study National Systems and National Styles of Innovation", *Technol. Anal. Strateg. Manage.*	0.827	Cooke P, 1997	93
Fischer M (2001) "Innovation, Knowledge Creation and Systems of Innovation", *Ann. Reg. Sci.*	0.818	Cohen W, 1990	90
Research Area 5: Geography of Innovation: Knowledge Sourcing, Flows, &Bases, N: 669 (11%)			
Blazek &Zizalova (2010) "The Biotechnology Industry in the... Region: A Cluster Within a Fragmented Innovation System", *Environ. Plan. C-Gov. Policy*	1.000	Bathelt H, 2004	283
Doloreux &Shearmur (2012) "Collaboration, Information and the Geography of Innovation in Knowledge Intensive Business Services", *J. Econ. Geogr.*	0.999	Boschma R, 2005	181
Uyarra &Flanagan (2010) "From Regional Systems of Innovation to Regions as Innovation Policy Spaces", *Environ. Plan. C-Gov. Policy*	0.975	Asheim B, 2005	140
Fitjar &Rodriguez-Pose (2013) "Firm Collaboration and Modes of Innovation in Norway", *Res. Policy*	0.963	Cooke P, 2004	102
Sternberg (2007) "Entrepreneurship, Proximity and Regional Innovation Systems", *Tijdschr. Econ. Soc. Geogr.*	0.962	Asheim B, 2002	87
Grillitsch et al. (2015) "Variety in Knowledge Sourcing, Geography and Innovation: Evidence From the Ict Sector in Austria", *Pap. Reg. Sci.*	0.957	Amin A, 2004	85
Blazek et al. (2013) "Emerging Regional Innovation Strategies in...: Institutions and Regional Leadership in Generating Strategic Outcomes", *Eur. Urban Reg. Stud.*	0.904	Asheim B 2005	85
Martin (2012) "Measuring Knowledge Bases in Swedish Regions", *Eur. Plan. Stud.*	0.898	Cohen W, 1990	82
Chaminade (2011) "Are Knowledge Bases Enough? A Comparative Study of the Geography of Knowledge Sources in China...", *Eur. Plan. Stud.*	0.869	Gertler M, 2003	82

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Table A2 (*continued*)

Publications		*References*	
Publication	C_{int}	Reference	Cit
Moodysson &Jonsson (2007) "Knowledge Collaboration and Proximity the Spatial Organization of Biotech Innovation Projects", *Eur. Urban Reg. Stud.*	0.844	Cooke P, 1998	75
Research Area 6: Technological Change &Evolutionary Economics, N: 635 (10%)			
Wonglimpiyarat (2005) "The Nano-revolution of Schumpeters Kondratieff Cycle", *Technovation*	1.000	Nelson R, 1982	275
Breschi et al. (2000) "Technological Regimes and Schumpeterian Patterns of Innovation", *Econ. J.*	0.961	Dosi G, 1982	140
Kemp &Soete (1992) "The Greening of Technological Progress: An Evolutionary Perspective", *Futures*	0.950	Freeman C, 1982	103
Marsili (2002) "Technological Regimes and Sources of Entrepreneurship", *Small Bus. Econ. Group*	0.944	Dosi G 1988	97
Henderson &Clark (1990) "Architectural Innovation the Reconfiguration of Existing Product Technologies and the Failure of Established Firms", *Adm. Sci. Q.*	0.919	Abernathy W, 1978	95
Levitas et al. (2006) "Survival and the Introduction of New Technology: A Patent Analysis in the Integrated Circuit Industry", *J. Eng. Technol. Manage.*	0.876	Schumpeter J, 1942	89
Freeman (1991) "Innovation, Changes of Techno-Economic Paradigm and Biological Analogies in Economics", *Rev. Econ.*	0.818	Pavitt K, 1984	88
Adner &Levinthal (2001) "Demand Heterogeneity and Technology Evolution: Implications for Product and Process Innovation", *Manage. Sci.*	0.811	Dosi G, 1988	85
Banbury &Mitchell (1995) "The Effect of Introducing Important Incremental Innovations on Market Share and Business Survival", *Strateg. Manage. J.*	0.809	Rosenberg N, 1982	78
Dosi (1997) "Opportunities, Incentives and the Collective Patterns of Technological Change", *Econ. J.*	0.798	Arthur W, 1989	72
Research Area 7: Sustainability Transitions: TIS, MLP, Regimes, Niches &Systainability, N: 605 (10%)			
Meelen &Farla (2013) "Towards an Integrated Framework for Analysing Sustainable Innovation Policy", *Tech. Anal. Strateg. Mng.*	1.000	Geels F, 2002	239
Markard &Truffer (2008) "Technological Innovation Systems and the Multilevel Perspective: Towards an Integrated Framework", *Res. Policy*	0.994	Geels F, 2007	191
Ingram (2015) "Framing Niche-Regime Linkage as Adaptation: An Analysis of Learning and Innovation Networks…", *J. Rural Stud.*	0.939	Kemp R 1998	185
Walrave &Raven (2016) "Modelling the Dynamics of Technological Innovation Systems", *Res. Policy*	0.929	Bergek A, 2008	131
Fuenfschilling &Truffer (2014) "The Structuration of Socio-Technical Regimes-Conceptual Foundations From Institutional Theory", *Res. Policy*	0.928	Geels F, 2004	129
Lovio &Kivimaa (2012) "Comparing Alternative Path Creation Frameworks in the Context of Emerging Biofuel Fields in the Netherlands…", *Eur. Plan. Stud.*	0.881	Hekkert M, 2007	125
Farla et al. (2012) "Sustainability Transitions in the Making: A Closer Look at Actors, Strategies and Resources", *Tech. Forecast. Soc. Ch.*	0.849	Rip A, 1998	122
Genus &Coles (2008) "Rethinking the Multilevel Perspective of Technological Transitions", *Res. Policy*	0.847	Smith A, 2005	110
Kern (2012) "Using the Multi-Level Perspective on Socio-Technical Transitions to Assess Innovation Policy", *Tech. Forecast. Soc. Ch.*	0.841	Schot J 2008	92
Raven et al. (2011) "Translation Mechanisms in Socio-Technical Niches: A Case Study of Dutch River Management", *Tech. Anal. Strg. Mng.*	0.834	Markard J, 2008	91
Research Area 8: Science Technology Studies: Modes of Knowledge Production, N: 386 (6%)			
Shinn &Lamy (2006) "Paths of Commercial Knowledge: Forms and Consequences of University-Enterprise Synergy in Scientist-Sponsored Firms", *Res. Policy*	1.000	Gibbons M, 1994	171
Sun &Negishi (2010) "Measuring the Relationships Among University, Industry and Other Sectors in Japans National Innovation System:…", *Scientometrics*	0.880	Etzkowitz H, 2000	142
Wehrens et al. (2014) "Hybrid Management Configurations in Joint Research", *Sci. Technol. Hum. Values*	0.837	Etzkowitz H, 1998	61
Shinn (2002) "The Triple Helix and New Production of Knowledge: Prepackaged Thinking on Science and Technology", *Soc. Stud. Sci.*	0.792	Nowotny H, 2001	59
Merz &Biniok (2010) "How Technological Platforms Reconfigure Science-Industry Relations: the Case of Micro- and Nanotechnology", *Minerva*	0.772	Agrawal A, 2002	46
Hessels &Van Lente (2008) "Rethinking New Knowledge Production: A Literature Review and a Research Agenda", *Res. Policy*	0.763	Cohen W, 2002	46
Tuunainen (2005) "Contesting a Hybrid Firm at a Traditional University", *Soc. Stud. Sci.*	0.708	Clark B, 1998	44
Ramosvielba &Fernandezesquinas (2012) "Beneath the Tip of the Iceberg: Exploring the Multiple Forms of University-Industry Linkages", *High. Educ.*	0.695	Dasgupta P, 1994	43
Valimaa &Hoffman (2008) "Knowledge Society Discourse and Higher Education", *High. Educ.*	0.687	Etzkowitz H, 2003	41
Godin &Gingras (2000) "The Place of Universities in the System of Knowledge Production", *Res. Policy*	0.683	Slaughter S, 1997	40

Note. This table reports the most central publications and the most cited references for the identified research areas in the bibliographic coupling network. All calculated centralities are Jaccard-weighted.

Table A3
Research area network (1-mode, external): density and diversity.

	1980-1989		1990-1999		2000-2009		from 2010		All Periods	
Research Area	$\mathrm{Dens}^{1m}_{\mathrm{ext}}$	$\mathrm{Div}^{1m}_{\mathrm{ext}}$	$\mathrm{Dens}^{1m}_{\mathrm{ext}}$	$\mathrm{Div}^{1m}_{\mathrm{ext}}$	$\mathrm{Dens}^{1m}_{\mathrm{ext}}$	$\mathrm{Div}^{1m}_{\mathrm{ext}}$	$\mathrm{Dens}^{1m}_{\mathrm{ext}}$	$\mathrm{Div}^{1m}_{\mathrm{ext}}$	$\mathrm{Dens}^{1m}_{\mathrm{ext}}$	$\mathrm{Div}^{1m}_{\mathrm{ext}}$
Econ.Geo	0.365	0.000	0.043	0.218	0.031	0.223	0.036	0.229	0.065	0.172
Networks	–	–	0.063	0.179	0.040	0.146	0.037	0.139	0.073	0.121
IB	–	–	0.042	0.150	0.012	0.236	0.014	0.197	0.035	0.170
IS	–	–	0.075	0.141	0.047	0.125	0.046	0.115	0.087	0.093
Geo.Inno	–	–	0.031	0.161	0.025	0.267	0.036	0.251	0.048	0.144
Evol.Econ	0.365	0.000	0.066	0.221	0.039	0.213	0.031	0.175	0.078	0.150
Transitions	–	–	0.028	0.092	0.023	0.317	0.018	0.237	0.036	0.181
STS	–	–	0.010	0.095	0.017	0.216	0.019	0.183	0.023	0.117
all	0.729	0.000	0.357	0.404	0.235	0.395	0.237	0.360	0.446	0.372

Note. This table reports the development of the research area's external degree density ($\mathrm{Dens}^{1m}_{\mathrm{ext}}$, based on the bibliographic coupling network between research areas), and their diversity ($\mathrm{Div}^{1m}_{\mathrm{ext}}$, Leydesdorff diversity of edge-weights to other research areas).

Table A4
Research area - knowledge base (2-mode) network: coherence and diversity.

Research Area	1980-1989		1990-1999		2000-2009		from 2010		All Periods	
	Coh^{2m}_{int}	Div^{2m}_{int}	Coh^{2m}_{int}	Div^{2m}_{int}	Coh^{2m}_{int}	Div^{2m}_{int}	Coh^{2m}_{int}	Div^{2m}_{int}	Coh^{2-m}_{int}	Div^{2m}_{int}
Econ.Geo	0.020	0.188	0.019	0.100	0.016	0.171	0.012	0.181	0.013	0.190
Networks	–	–	0.022	0.158	0.017	0.224	0.016	0.183	0.015	0.211
IB	–	–	0.012	0.146	0.010	0.174	0.009	0.250	0.008	0.238
IS	–	–	0.025	0.232	0.022	0.236	0.020	0.259	0.020	0.242
Geo.Inno	–	–	0.013	0.125	0.011	0.051	0.017	0.118	0.013	0.101
Evol.Econ	0.012	0.260	0.017	0.316	0.011	0.401	0.011	0.398	0.011	0.300
Transitions	–	–	0.111	0.000	0.025	0.125	0.019	0.119	0.018	0.108
STS	–	–	0.025	0.117	0.015	0.142	0.016	0.132	0.014	0.134
all	0.010	0.181	0.005	0.197	0.002	0.225	0.002	0.215	0.002	0.211

Note. This table reports the development of the research area's internal coherence (Coh^{2m}_{int}, based on internal bibliographic coupling network) measured by internal degree density, and their diversity (Div^{2m}_{int}, measured by their Leydesdorff diversity of cited knowledge bases).

Table A5
Community detection algorithm benchmark.

Algorithm	Bibliographic			Co-citation		
	M	N_{com}	G_{size}	M	N_{com}	G_{size}
Louvain (Blondel et al., 2008)	0.36	8.00	0.24	0.42	8.00	0.22
Infomap (Rosvall and Bergstrom, 2007)	0.21	23.00	0.85	0.40	114.00	0.83
Fast Greedy (Newman, 2004a)	0.27	6.00	0.62	0.35	4.00	0.28
Label Propagation (Raghavan et al., 2007)	0.00	2.00	0.50	0.00	1.00	0.00
Walktrap (Pons and Latapy, 2005)	0.27	21.00	0.79	0.37	35.00	0.77

Note. This table compares the achieved modularity (M), number of detected communities (N_{com}), and GINI coefficient (G_{size}) of community size between popular algorithms to detect communities in weighted networks.

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CHAPTER 3

III Assessing Weaknesses in National Innovation Systems

Marija Rakas (rakas@business.aau.dk)

Department of Business and Management

Aalborg University, Denmark

Abstract

This paper presents an empirical analysis of national innovation systems' weaknesses or problems, including broad patterns of weaknesses, mainly in European Union countries' national innovation systems (NIS) and trends therein. The study primarily uses Community Innovation Survey (CIS) data, developed for mapping innovation activity and the factors that affect it in Europe, for this purpose. The starting point for the analysis is the activities approach to analysing innovation systems dynamics, pioneered by Carlsson and Stankiewicz (1991) and later adapted to the national level (Edquist, 2005; Fagerberg, 2017; Liu & White, 2001). The emphasis is on identifying weaknesses or problems in five processes or activities that define NIS in a range of policy-relevant areas that potentially obstruct the system's dynamics as a whole and, thus, raise the need for political intervention. The resulting dataset includes 26 European Union (EU) member states, plus Iceland, Norway, and Turkey. The systems' weaknesses that are identified empirically in this paper concern knowledge, skills, demand, finance and institutional processes. The analysis describes broad patterns in NISs' weaknesses that divide countries into six different groups, and how these weaknesses have changed during the 2002-2010 period. The results indicate the existence of heterogeneity in patterns of weaknesses in countries' innovation systems and that despite some exceptions, the countries' positions remained rather stable over time.

1. Introduction

Since the emergence of National Innovation System (NIS) literature, the systemic approach to innovation policy has attracted the attention of various scholars working on different policy areas, as reflected in the number of published papers in journals associated with policy-related matters (Fagerberg & Sapprasert, 2011). The approach also has gained popularity among policymakers in various national governments and international organisations, such as the Organisation for Economic Co-operation and Development (OECD) and World Bank (Sharif, 2006). One of the core arguments in extant NIS literature has been that partial understanding of the innovation process and the factors that influence it can result in a narrow focus on technological inputs at the expense of a more extensive set of activities and factors that affect development and diffusion of all innovation types. Early NIS literature (Freeman, 1987; B.-A. Lundvall, 1992; Nelson, 1993) has been praised for broadening the discussion on innovation, and for providing some particularly useful insights on the prominent role of non-R&D-based sources and innovation types, the interactive nature of innovation processes that involve firms and their external environments, and the non-market nature of institutions that govern these interactions (Soete, Verspagen & ter Weel, 2010). Recent theoretical advances in this approach (Edquist, 1997, 2005; Fagerberg, 2017; Liu & White, 2001) have changed the focus of the analysis from the particular actors, institutions or their interactions to a set of activities or processes that influence firms' innovation processes and, thus, a system's innovation performance as a whole, and that can be shaped by policymakers' coordinated actions.

The paper sets out to identify, empirically, innovation systems' weaknesses or problems across a range of policy-relevant areas or activities that define NIS and map broad patterns in systems' weaknesses in different NIS, guided by the proposed activities-based framework for analysing the determinants of a country's technological dynamics. I employ the theoretical framework that has been developed with innovation policy in mind (Fagerberg, 2017), and that can be applied usefully in the analysis of activities and, thus, the weaknesses or problems in innovation systems at national levels. In this framework, the public policies and programmes are the starting point for the analysis, and only these activities and institutions in the NIS that can be influenced by public intervention are examined. More specifically, the emphasis is on five generic processes or activities in the NIS that concern knowledge, skills, demand, finance and institutions and that influence firms' innovation and, thus, shape the country's technological dynamics.

The starting point of this paper's analysis is the activities-based approach to analysing the dynamics of the technological innovation systems pioneered by Carlsson and Stankiewicz (1991) and later adapted to the national level (Edquist, 1997, 2005; Fagerberg, 2017; Liu & White, 2001). From the activities approach to national innovation systems, an innovation system's technological dynamics or output is influenced by activities carried out partly by private and public organisations, and, thus, is shaped by their strategies and policies, respectively. Examples of activities include knowledge creation through R&D activities, financing of innovation development and the formation of skills and demand-side activities. In this perspective, public organisations' actions (innovation policy) at the national level are viewed as an aspect of the innovation system's wider setting, as these actions are intended to shape the context in which firms innovate and operate positively. Furthermore, the list of activities is viewed as useful in identifying and analysing weaknesses or problems that might occur in innovation systems and that should guide policy analysis and design. More specifically, problems in innovation systems are conceived as inefficiencies, bottlenecks or weaknesses in the systems' activities that tend to hinder innovation processes and might explain a system's poor innovation performance (Borrás & Edquist, 2016). Thus, each activity in the innovation system has been associated with a list of potential problems that might require policy intervention. Examples of some policy-relevant problems along different innovation-system activities include insufficient R&D investment levels, insufficient levels and types of skills, unsophisticated demand and a lack of seed capital, among others. The list of policy-relevant problems also includes problems generated by policy initiatives themselves.

The paper mainly draws on aggregate innovation statistics from three rounds of the Community Innovation Survey (CIS), i.e., three time periods – 2002-2004 (CIS2004), 2004-2006 (CIS2006) and 2008-2010 (CIS2010) – as these rounds contain information on various external factors that hinder firms' innovation activities and are comparable over time. Additional country-level data on activities' institutional dimension in NIS come from sources such as the Heritage Foundation and Transparency International. The data set covers 26 EU member countries (Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Germany, Denmark, Estonia, Greece, Spain, Finland, France, Croatia, Hungary, Ireland, Italy, Lithuania, Luxembourg, Latvia, Malta, the Netherlands, Poland, Portugal, Romania, Slovenia and Sweden) and three non-EU member states (Iceland, Norway and Turkey). To provide empirical identification of the generic processes or activities within NIS and the weaknesses or problems therein, as specified in the analytical framework, a principal component analysis is conducted on smaller subsets of indicators. A clustering of countries then is conducted based on the countries' scores on each of the considered indicators of systems' activities that might hinder firms' innovation activities to identify a set of specific profiles of weaknesses or problems that afflict different national innovation systems. As the paper uses aggregate data referring to three time periods, the analysis goes beyond mapping the innovation systems' weaknesses in a static manner.

While several proposed frameworks exist for analysing NIS activities and for diagnosing systemic problems in extant literature, as well as theoretical contributions on potential types of system problems, empirical contributions are somewhat limited. In addition, while previous research has used case study methods to analyse this for more narrowly defined technologies, such an approach may be too demanding in the case of entire countries, not to mention the European Union as a whole. Therefore, a need exists to develop new empirical methodologies that can be used to identify systems' weaknesses at more aggregate levels. However, this study's ambitions are more modest than that based on the discussion in extant literature on identifying systemic NIS problems along various dimensions.

The paper is organised in the following manner: Section 2 provides a brief overview of analytical frameworks for the analysis of innovation systems' activities at the national level for policy purposes. Section 3 provides an overall account of the study's principal data sources and methodology, and Section 4 presents the results. Section 5 concludes the paper, discussing the study's limitations and suggesting future avenues for research.

2. Varieties of analytical frameworks for identifying systems' activities and problems

As pointed out in the introduction, the starting point of the analysis is the activities approach to national innovation systems, developed for understanding the relationship between innovation system performances or output and activities within the system that influence the innovation processes and, thus, performances or output of the system as a whole. While all proponents of the approach argue for the need to address NISs' activities systematically, no single universally accepted approach exists for defining and analysing activities. Chaminade and Edquist (2005) distinguish between four approaches based on the approaches' principal focus on activities related to innovation process (Edquist, 2005; Fagerberg, 2017; Liu & White, 2001), the knowledge-production process (David & Foray, 1995; Johnson & Jacobsson, 2003), the organisations that impact NIS (Borrás, 2004) and the approach that focuses on the activities and organisations that policy interventions can stimulate (OECD, 2002). In what follows, I focus on the version of the approach that emphasises activities related to innovation processes (Edquist, 2005; Fagerberg, 2017; Liu & White, 2001). A brief overview of the analytical frameworks is presented to provide a theoretical and conceptual basis for this paper's empirical analysis.

In the analytical framework put forth by Edquist (2005), the focus is on four broad categories of NIS *activities*, defined as determinants of innovation processes, i.e., the development, use and diffusion of innovation. These four broad categories are: i) provision of knowledge inputs to the innovation process (provision of R&D and competence building); ii) demand-side activities (formation of new product markets and articulation of new product-quality requirements); iii) provision of NIS constituents (creating and changing organisations needed for developing new fields of innovation, networking through markets and other mechanisms, and creating and changing institutions); and iv) support services for innovative firms (incubation activities, financing innovation processes and providing consultancy services). In turn, the activities included in each of the broad categories are described as partly performed by private and public organisations, whereas the latter's actions comprise innovation policy. The suggested approach to empirical analysis entails comparing innovation systems' relative performance with regard to intensities of different kinds of innovation to determine how well the systems perform. In the next step, the identified problem, in terms of innovation performances, is related to the previously listed system's broad activity categories to identify the main activities behind a low propensity to innovate in an innovation system. Furthermore, a list of analytical and related policy questions with regard to the division of labour in these activities, as well as the character of the existing public intervention, is proposed to carry out the analysis as a basis for innovation policy making.

In the framework developed by Liu and White (2001), the emphasis is on five fundamental activities: i) research (basic, developmental, engineering); ii) implementation of innovations (manufacturing); iii) end-use (customers of product and process outputs); iv) linkage (bringing together complementary knowledge); and v) education. In this contribution, the emphasis is on system-level characteristics, i.e., both structure and dynamics associated with a varying organisation of fundamental activities and implications for the system's performances, including efficiency and efficacy (or lack thereof) in producing, diffusing and exploiting innovations. The approach is viewed as particularly useful for comparing relative performances of national innovation systems associated with alternative systems' structure and dynamics.

Finally, the analytical framework developed by Fagerberg (2017) largely is in line with previous contributions. The main difference is that the system's technological dynamics or output is presented as being influenced by five activities viewed as generic NIS processes: i) knowledge; ii) skills; iii) demand; iv) finance; and v) institutions. Because of the focus on innovation policy, the generic[1] processes are described in terms of how public organisations can influence these processes.

While the presented approaches indicate differences in the number and definitions of activities, terms used and how activities are grouped into broader categories, considerable overlap exists between them[2]. In this paper, I use the proposed classification of processes suggested by Fagerberg (2017). The choice of the framework is based mainly on the understanding that differences between the alternative lists of activities are minor and that generally accepted framework among researchers has yet to emerge. Although this paper's analytical framework is organised according to the specification of NIS activities proposed by Fagerberg (2017), insights from Edquist (2005) and related contributions also are incorporated.

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[1] While Fagerberg (2017) does not provide an explicit explanation for using the term *generic* when referring to NIS processes, it is reasonable to assume that the term is used to refer to basic activities that are fundamental for many or all innovation processes, and that can be analysed in different NISs.

[2] The frameworks have the following systems' activities in common: First, Edquist's (2006) 'provision of R&D' (mainly in science and engineering fields) corresponds to Fagerberg's (2017) 'knowledge' and to Liu and White's (2001) 'research'. Second, Edquist's (2006) 'competence building' resembles, but is much broader than, Fagerberg's (2017) 'skills' and Liu and White's (2001) 'education'. Third, Edquist's (2006) thematic category 'demand-side activities' corresponds to Fagerberg's (2017) 'demand' and to Liu and White's (2001) 'end-use'. Fourth, Edquist's (2006) broader category 'provision of constituents' parallels Fagerberg's (2017) 'institutions' concerning the creation of and changes in formal institutions, such as laws and regulations, and matches Liu and White's (2001) 'linkage' activities. Finally, Edquist's (2006) 'support services for innovative firms' subcategories on financing innovation processes and provision of consultancy services and incubation activities are viewed as separate 'finance' activities in Fagerberg (2017) and as 'linkage' activities (which include interactions between actors and activities) in Liu and White (2001).

2.1. Activities and problems in NIS

In what follows, each of the five processes emphasised by Fagerberg (2017) is described in more detail, followed by a brief illustration of potential problems or weaknesses in the innovation system. While each process and potential related problems are described in isolation, it is important to keep in mind that these are interrelated and interact with each other, and that the way in which this happens depends on the specific national context.

First, **knowledge** refers to knowledge production and R&D activities (basic and applied research) in innovation systems as a means of developing economically relevant knowledge that can provide the impetus for innovations (Edquist, 2011). The emphasis, in particular, is on research-based activities and the generation of new scientific-technological knowledge. Knowledge production and R&D activities are viewed as an important NIS activity because the results of R&D activities represent inputs not only in the innovation process, but also on furthering the knowledge-production process. Extant NIS literature also stresses that considerable differences exist between countries in the provision of R&D by public and private organisations. More specifically, in countries at lower levels of development, investment in R&D is relatively low and mainly is conducted in public organisations, whereas in countries at higher levels of development, R&D investment is high, and most of it comes from the private sector (Edquist, 2011). When it comes to empirical evidence, a recent study by Wirkierman, Ciarli and Savona (2018) shows that most countries that are ranked low on innovation inputs (measured as R&D expenditures, demand and firm organisation) also rank low in terms of innovation output. For countries in the middle and at the top of distribution, input/output rankings are stable, with a few exceptions. Examples of public policy initiatives that influence research activities include direct public funding of R&D in public organisations, such as universities and public research institutes; schemes that support collaborative R&D; tax incentives; and intellectual property rights. Borrás and Edquist (2019a) suggest four issues that might impede innovation systems and may require policy action, such as: inadequate levels of private investment in R&D; weak complementarity between R&D funding sources; high uncertainty and long lags between investment and private returns; and poor social rates of return.

While some innovations originate from R&D activities, including ones provided by or conducted in cooperation with other private and public actors in the system, a significant number of innovations originates from ongoing learning processes by doing and using associated with other activities (e.g., industrial engineering and design), informal and formal processes of diffusion of information and technological competencies (e.g., publications, technical associations, labour etc.) and through markets (e.g., licencing, consultancy deals, knowledge embodied in capital equipment and intermediate inputs) (Dosi, 1988). These other processes are relevant to the use and recombination of already-existing and economically useful information and knowledge that firms rely on to develop new products or processes. The discussion above suggests that knowledge-related processes that are relevant to innovation processes are broader than R&D. Thus, the concept of knowledge is used in this paper to refer to R&D and other activities needed for the use and recombination of already-existing and economically useful information and knowledge. The example of public policy initiatives influencing these activities includes the provision of support services in cases of certain SMEs and mature sectors (Edquist, 2011). From this, it follows that a system's weaknesses may concern limited quantity and quality of services available to SMEs, or limited access to providers of technology and business-support services (Shapira & Youtie, 2014).

Second, **skills**[3] refer to the processes or activities in innovation systems as a means of creating both specialised and general skills that are essential to firms' abilities to generate technological dynamics (Fagerberg, 2017). Public innovation policy's role in this area concerns supporting the creation, maintenance and development of relevant skills in the innovation system. More specifically, the principal areas of public policy intervention include the organisation, regulation and funding of formalised education processes in educational organisations, as well as vocational training and continuous processing of skills development in the workplace. Other relevant areas of

[3] In Edquist (2011), a competence-building activity is classified as part of the broader thematic category described as 'provision of knowledge inputs to the innovation process'. It refers to activities and processes related to individuals and organisations' capacity to create, absorb and exploit knowledge. Liu and White (2001) use the term 'education' to refer to education at universities and in vocational and training schools.

public intervention include migration policy (Borrás & Edquist, 2015). On a general level, the high academic standards within a country for the largest population of school students is viewed as supporting participation in further education and training, as well as creating a workforce that can engage in innovation productively. Extant literature also suggests that the quantity and quality of skills at higher education and vocational levels directly affect firms' capacity to implement innovations, and that considerable differences exist between countries' skills-formation systems (Toner, 2011). General agreement exists in extant innovation-studies literature on the comprehensive set of activities related to innovation and the variety of skills required for their fulfilment (Toner, 2011). The workforce skill base is related to every function within the firm, from R&D and manufacturing to management, finance, marketing and distribution. It follows that skills are related to formal education and training in the scientific and engineering fields, as well as in law, management, finance, marketing, etc. Also, the level and type of vocational qualifications in the workforce are viewed as playing a central role in technology generation, diffusion and incremental innovation (Toner, 2011). However, the exact ways in which levels and types of formal education affect innovation performances in an innovation system remain an open research question (Borrás & Edquist, 2015; Toner, 2011). Furthermore, it is important to note that even when formal education and training systems are functioning well, the workplace remains the central location for skills development. More specifically, the extent to which firms' workforces actively engage with innovation depends strongly on organisations' practices (Arundel, Lorenz, Lundvall & Valeyre, 2007; Toner, 2011). Following the previous discussion and from existing literature, possible weaknesses in the innovation system include insufficient skill levels due to low levels of education or vocational training and/or brain drain. System weaknesses or imbalances also have been related in extant literature to the time lag between supply and demand for specific skills and competencies, as well as the imbalance between internal and/or external sources of competencies that firms rely on in their innovation processes (Borrás & Edquist, 2015). The imbalance between internal and/or external sources of competencies is related to problems tied to lost opportunities or weak absorptive capacity, i.e., firms' ability to absorb and use knowledge and skills developed by other organisations in the system through, for example, collaborations that depend highly on human resource development (Borrás & Edquist, 2015).

Third, **demand** processes are involved in the creation of new product markets and the articulation of quality requirements from households, public-sector organisations and other end-users that are important to maintaining and fostering innovations (Edquist, 2011). System problems or weaknesses, in turn, may exist if the demand for new products or services does not exist or is highly uncertain (especially in the early development stages), or when the sophistication level of users of goods and services is not sufficient to provide the required feedback or impetus for innovation activities. Extant literature emphasises three principal issues from a public policy perspective: i) lack of innovation dynamics in the economy and public sector; ii) potential innovation lock-in in some industries; and iii) the opportunity costs of not developing technologies and innovative solutions needed to solve complex social and economic challenges (Borrás & Edquist, 2019b). In this area, governments can use public procurement instruments, as well as other instruments, such as changing standards and regulations (Edquist, 2005; Fagerberg, 2017).

Fourth, **finance** refers to the financing of innovation processes that may facilitate the commercialisation of technological knowledge and its diffusion (Edquist, 2011; Fagerberg, 2017). Given that innovative projects usually require a substantial financial investment and are characterised by high uncertainty, firms may face a lack of financial means to sustain their efforts and/or difficulty in mobilising financial resources from sources outside the organisation, which may lead to low investment levels and, consequently, failure to introduce innovative products or processes in the system. The problem is particularly prominent in the early stages of innovative projects due to high levels of uncertainty and risk in terms of their outputs (Deligia, 2006). Moreover, it is well-established in extant literature that funding sources and availabilities depend on both innovative projects' development stages and firms' characteristics. Large and established companies mainly rely on internal sources (e.g., retained profits) and generally have greater access to different sources of external financing. However, small firms and entrepreneurs' innovative projects, to a large extent, rely on external funds for innovation and face particular challenges in accessing financing from ordinary financial markets. Early NIS literature illustrated that important differences exist in the functioning and institutional set-up of financial systems between countries, and that these matter for financing innovation. In particular, different financial systems may be more or less supportive of countries' innovation capabilities (B. Lundvall, 2010). What is essential, from a policy perspective, is to assess the conditions for funding innovation projects at different development stages, as well as establish new innovative enterprises. An example of public policy initiative in this area entails the provision of seed capital (Edquist, 2005; Fagerberg, 2017). The system weakness, from a policy perspective, can be related to unsatisfactory development and/or activity within, regarding a) the financial market in general; b) alternative private finance sources for innovation, such as venture capital and business angels (i.e., a lack of or low levels of private funding); and c) the demand for private finance sources for innovation (i.e., weak entrepreneurship).

Fifth, the **institutions** themselves are defined broadly as the 'rules of the game' that influence entrepreneurial actions (Fagerberg, 2017) or affect innovative organisations and innovation processes (Edquist, 2011), whereas the processes (and, thus, the role of public innovation policy) related to institutions concern creation of and changes to these rules to facilitate innovation processes. Examples of institutions and entities relevant to innovation processes are numerous and include intellectual property rights (IPR) laws, requirements concerning setting up or closing down businesses, regulations for hiring and firing personnel, environmental and safety regulations, corruption, patent and tax laws, cultural and informal norms, and rules concerning the collaboration and sharing of knowledge and information. These institutions influence innovative organisations and firms' innovation processes by providing incentives for and obstacles to organisations and individuals to innovate or engage in entrepreneurial activities (Edquist, 2011; Fagerberg, 2017). For example, IPR laws are viewed as a means of providing incentives for firms to invest in knowledge production and innovation through the provision of legal protection of knowledge and its exploitation. In turn, a system's institutional problems refer to ill-developed institutional frameworks or missing institutions that firms rely on in their innovation processes. For example, an institutional setting may be characterised as incomplete or ineffective, for example, with respect to legal mechanisms for enforcing contracts, exercising and protecting intellectual property rights and resolving conflicts, while also being unfavourable in terms of social norms of collaboration and entrepreneurship culture that can hinder the development of innovations. From a policy perspective, it is critical to assess whether existing institutions are inappropriate or ineffective at fulfilling the function of supporting innovation and entrepreneurship actions in a system.

3. Data and method

This paper analyses countries as units of observation, and most of the indicators used to map problems in NISs are based on aggregate Community Innovation Survey (CIS) innovation statistics available on the Eurostat website. The CIS is a survey of enterprises' innovation activities and is conducted every two years[4] across the European Union, some European Free Trade Association (EFTA) countries and EU candidate countries. To ensure comparability across countries, Eurostat, in close cooperation with the countries, has developed a standard core questionnaire, starting with CIS3 (for 2000/2001 with most participating countries) data collection, along with an accompanying set of definitions and methodological recommendations. The concepts and methodology of the CIS also are based on various editions of the Oslo Manual (OECD/Eurostat/EC, 1997; OECD/Eurostat, 2005; OECD, 2019), the international reference used to collect and report innovation data. The aggregated data are checked and corrected for detected inconsistencies and quality at the national level, while Eurostat also carries out quality checks (Eurostat, 2014).

To construct composite indicators on system weaknesses or problems along different dimensions or factors, as specified in the analytical framework, I rely on aggregate statistics in the CIS questionnaire's section on perceived barriers hindering firms' innovation activities. In this section of the CIS questionnaire, firms are asked to assess the importance of various factors hindering their innovation activities or projects, or influencing a decision not to innovate, as experienced during the three-year period that the survey covers. The list of hindering factors that correspond to the same question in more than one wave of the CIS includes: i) lack of funds within the enterprise or group; ii) lack of finance from sources outside the enterprise; iii) too high innovation costs; iv) lack of qualified personnel; v) lack of information on technology; vi) lack of information on markets; vii) difficulty finding collaboration partners for innovations; viii) markets dominated by established enterprises; ix) uncertain demand for innovative goods or services; x) prior innovations; and xi) no innovation demand. The

[4] The survey has been carried out every two years from 2004 onwards (Eurostat, 2014).

available aggregate indicators are all expressed as percentages of innovative enterprises for which a specific factor is perceived as a highly important factor in hindering their innovation activities[5].

The list of available data for the relevant indicators is shown in Table 1 for all three time periods applied in the analysis. The choice of countries to include in the analysis, to a large extent, was driven by CIS data availability. Complete data on indicators of interest were available for only 13 countries (Bulgaria, the Czech Republic, Estonia, Spain, Hungary, Ireland, Italy, Lithuania, Luxembourg, Latvia, Portugal, Romania and Norway) for all three time periods (2002-2004, 2004-2006 and 2008-2010). For the rest of the countries, data either from two time periods (2002-2004 and 2004-2006, 2002-2004 and 2008-2010 or 2004-2006 and 2008-2010) or only one period were available due to non-coverage or large amounts of missing data points for countries by years on selected variables of interest. CIS rounds conducted prior to or after the time periods examined in this paper either contain or do not contain a modified version of the questions of interest in this study and, for this reason, were not considered here.

Table 1: CIS data availability

2002-2004 (CIS2004)	2004-2006 (CIS2006)	2008-2010 (CIS2010)
Austria	Austria	-
Belgium	-	Belgium
Bulgaria	**Bulgaria**	**Bulgaria**
Cyprus	-	-
Czech Republic	**Czech Republic**	**Czech Republic**
Germany	-	-
Denmark	-	-
Estonia	**Estonia**	**Estonia**
Greece	Greece	-
Spain	**Spain**	**Spain**
Finland	-	Finland
France	-	France
-	Croatia	Croatia
Hungary	**Hungary**	**Hungary**
Ireland	**Ireland**	**Ireland**
-	-	Iceland

[5] The aggregate statistics for the subset of non-innovative enterprises are not available for all three time periods.

Italy	-	Italy
Lithuania	**Lithuania**	**Lithuania**
Luxembourg	**Luxembourg**	**Luxembourg**
Latvia	**Latvia**	**Latvia**
Malta	-	Malta
The Netherlands	The Netherlands	-
-	Poland	Poland
Portugal	**Portugal**	**Portugal**
Romania	**Romania**	**Romania**
Sweden	-	Sweden
Slovenia	-	Slovenia
Norway	**Norway**	**Norway**
-	Turkey	-
25	18	22

Note: In bold are countries for which data are available for all three reference periods.

In addition to CIS, two additional sources of mainly survey-based indicators are used to account for an institutional dimension of activities in NIS: Heritage Foundation and Transparency International. The Heritage Foundation's Index of Economic Freedom provides country-level composite indices on 10 economic freedoms on an annual basis (as of 1995) for a large number of countries (Miller et al., 2010). I include two indices: i) property rights (to measure the degree to which a country's laws protect private property rights and the degree to which its government enforces those laws) and ii) business freedom (to measure the ability to start, operate and close a business that represents the overall regulatory burden, as well as government efficiency in the regulatory process). Each index is a number on a scale from 0 to 100, with 100 equalling the highest score. Property-rights index scores for each country are derived based on a qualitative assessment according to the criteria. Business-freedom scores are derived by averaging scores on various sub-factors, which are all given equal weight. The main source of data for the property rights index is the Economist Intelligence Unit's *Country Profile, Country Report* and *Country Commerce* (various editions), whereas the business freedom index mainly uses data from the World Bank's *Doing Business* study (various editions). The year's indices primarily are based on data for the period between the second half through the first half of the two previous years (e.g., 2010 indices mainly are based on data covering the period from July 2008 to June 2009) (Miller et al., 2010).

As for corruption prevalence, Transparency International's Corruption Perceptions Index (CPI) is used. A CPI score relates to perceptions of the degree of corruption as perceived by businesspeople and a nation's analysts, ranging between 10 (very little corruption) and 0 (highly corrupt). Raw CPI data are converted to a scale of 0 to 100. The CPI 2004 is a three-year average, whereas the CPI 2006 and 2010 combine data from the past two years. All institutional indicators take one value for each country-year combination.

More information on definitions and data sources is provided in Table 2. The selection of indicators was driven by the analytical framework adopted in the paper, as well as pragmatic considerations due to limited data availability from countries and year combinations examined in this paper. The included indicators are used commonly in extant literature as measures of governance quality with respect to innovation and economic life more generally. These indicators reflect institutional rules' efficacy in generating incentives or removing barriers affecting innovation efforts or firms' entrepreneurial action.

Table 2: Sources and definitions of indicators: Institutional dimension

Indicator and definition	Scale	Reference years	Data sources
Property rights index: the degree to which a country's laws protect private property rights and the extent to which these laws are enforced by the government.	Index (0=low; 100=high)	2004*, 2006 and 2010	**Heritage Foundation database:** based on the following third-party sources in order of priority: Economist Intelligence Unit – *Country Profile, Country Report* and *Country Commerce*; U.S. Department of Commerce – *Country Commercial Guide*; U.S. Department of Commerce, *Country Commercial Guide*; U.S. Department of State, *Country Reports on Human Rights Practices;* and various news and magazine articles.

Business freedom index: overall burden of regulations and the efficiency of government in the regulatory process.	Index (0=low; 100=high)	2004*, 2006 and 2010	**Heritage Foundation database**: based on the following sources in order of priority: World Bank – *Doing Business*; Economist Intelligence Unit – *Country Profile, Country Report* and *Country Commerce*; and official government publications in each country.
Corruption Perceptions Index (CPI): the degree to which corruption is perceived to exist among public officials/politicians.	Index (0=high; 10=low).	2004, 2006 and 2010	**Transparency International database**: based on corruption-related data in expert surveys carried out by a variety of reputable institutions.

Source: For detailed information on the information sources for property rights and the business freedom index for the 2004, 2006 and 2010 editions, please see Miller et al. (2010). For detailed information on the information sources for the 2004, 2006 and 2010 CPI editions, see Graf Lambsdorff (2004, 2006) and Transparency International (2010).
* For the 2004 edition, the business freedom index methodology is based on a subjective assessment, using a score of 1-5. The 2004 scores have been converted to a scale of 1-100 based on a simple formula to make them comparable with the new editions (Miller et al., 2010).

3.1. Identification of national innovation systems' weaknesses

The selection of relevant indicators and the methodology applied in the analysis of NISs' weaknesses are driven by the adopted analytical framework, which includes the following steps:

1. The selected indicators are preliminarily grouped into five subsets referring to specific NIS dimensions specified in the analytical framework: knowledge; skills; demand; finance; and institutions. The principal reason for doing so was to quantify, empirically, the dimensions in a more theoretically focussed and conceptually transparent way, as well as to facilitate interpretation.
2. A PCA analysis then is performed on each sub-set of indicators to derive a set of composite indicators, each corresponding to a specific dimension. The exception is sub-set skills, in which only one indicator

was available. Following Fagerberg et al. (2008), the variables are standardised by deducting the mean and dividing by the pooled data's standard deviation. This procedure allows for using as much information as possible, and ensures that the change in the composite variable over time reflects both changes in each country's position *vis-à-vis* other countries, as well as in the relative importance of the underlying indicators over time *vis-à-vis* other indicators.

3. Finally, a cluster analysis of countries is performed based on the countries' scores using a set of composite and single indicators.

As discussed in the previous section and mentioned in Step 1 above, systems' possible weaknesses or problems can be identified in relation to five generic processes or activities within the system. The selection of CIS-based aggregate indicators (which are consistent over time) and the preliminary groupings of indicators corresponding to the same dimensions are listed below:

- Knowledge: i) lack of information on technology; ii) lack of information on markets; and iii) difficulty in finding collaboration partners for innovations.
- Skills: lack of qualified personnel.
- Demand: i) markets dominated by established enterprises; ii) uncertain demand for innovative goods or services; and iii) no innovation demand.
- Finance: i) lack of funds within the enterprise or group; ii) lack of finance from sources outside the enterprise; and iii) too high innovation costs.
- Institutions: i) property rights index; ii) business freedom index; and iii) Corruption Perceptions Index.

The first process, **knowledge**, is operationalised as the provision of science and technological knowledge, as well as the provision of information and other knowledge inputs that innovative firms draw from when searching for innovative solutions. Due to the questionnaire's structure, no information is available on the knowledge-generation processes based on R&D and any weaknesses or problems therein. Thus, the operationalisation here is limited to the processes of knowledge/information diffusion and usage in the system, rather than its creation. However, the diffusion and use of existing knowledge is certainly important to creating new knowledge. To provide insight into possible weaknesses in this process, three indicators are used: i) the share of innovative enterprises for which the lack of information on technology is a highly significant factor; ii) the share of innovative enterprises for which the lack of information on markets is a highly important factor; and iii) the share of innovative enterprises for which difficulty in finding collaboration partners for innovations is a highly significant factor in hindering firms' innovation activities. The high perceived importance of a lack of information on market, technology and partnership opportunities may reflect a system's weakness in terms of insufficient knowledge diffusion and use due to, for example, limited provision of or access to consultancy services for innovation processes. Previous research on identifying and measuring systemic problems based on firm-level survey data shows that innovation systems can be ineffective when firms in the system lack information on technological opportunities, markets and potential knowledge sources (Chaminade, Intarakumnerd & Sapprasert, 2012).

To gain insight into relative weaknesses in **skills** provision, which affect firms' ability to engage in innovation-related activities of various types and to be successful in innovation, I considered: i) the share of innovative enterprises for which a lack of qualified personnel is a highly important factor in hindering innovation activities. The strong emphasis on skills as factor-hindering innovation activities may reflect both skill shortages in the economy and difficulty in mobilising skilled workers for innovative enterprises. Access to skilled human capital also depends on well-functioning labour markets. While relevance issues concerning skills' role in the innovation system are much broader, the limited information available from innovation surveys does not allow for covering them here.

When it comes to aspects of **demand processes,** such as, for example, formation of new product markets and articulation of quality requirements in terms of demand, which may affect firms' innovation activities, I take three indicators into account: i) share of innovative enterprises for which markets dominated by established enterprises are a highly important factor; ii) share of innovative enterprises for which uncertain demand for innovative goods or services is a highly important factor; and iii) share of innovative enterprises, in which no need to innovate exists due to no demand for innovations – a highly important factor in hindering innovation activities. The weakness in the formation of new product markets due to limited uptake of innovative products may be reflected in a greater emphasis on uncertain demand as a hindering factor. On a related matter, poor articulation of the requirements for novel solutions due to, for example, weak sophistication in users, which negatively affects production and commercialisation of innovations, may be reflected in a greater emphasis on non-existent demand for innovative solutions as a hindering factor. The heavy emphasis on a market dominated by established enterprises as a hindering factor is not related directly to weakness in articulation of demand for innovation or the formation of new product markets. However, it may reflect weakness in product markets' functioning due to the competitive context's nature. In the context of limited openness to competition, incumbent firms may be less incentivised to pursue innovation to improve their competitive position. Moreover, the entry of new firms that embody more productive technologies, as well as the uptake of new solutions by small firms, may be limited (Furman, Porter & Stern, 2002; Veugelers, 2017). Chaminade et al. (2012) show that based on firm-level data, the hindered-market-conditions component of the Thai innovation system depends highly on both a lack of domestic competition and a lack of customer interest in innovation, at least for innovative firms.

In providing insight into potential system weaknesses in terms of generating **financing** that is necessary for the production and commercialisation of innovative products I consider three indicators: i) share of innovative enterprises, for which a lack of funds within the enterprise or group is a highly important factor; ii) share of innovative enterprises, for which a lack of financing from sources outside the enterprise is a highly important factor; and iii) share of innovative enterprises, for which too high innovation costs are a highly important factor in hindering innovation activities. The list of indicators includes both internal and external factors related to financing innovation processes, but both indicate weaknesses or problems related to finances. More specifically, the emphasis on a lack of funding from external sources may reflect difficulties in obtaining funding from external sources due to an underdeveloped capital market supply or due to high uncertainty and risk levels. Moreover, the emphasis on a lack of funding from internal sources or high innovation costs may reflect high costs and difficulties in obtaining funding from external sources, even when the capital market supply is developed sufficiently. Table 3 provides descriptive statistics for selected CIS-based indicators.

Finally, when it comes to **institutions** and weaknesses therein, I take three indicators into account. As mentioned in the previous section, these three indicators are used commonly in extant literature as general measures of governance quality. Weakness in an institution's related processes may reflect institutional rules' limited efficacy to generate sufficient incentives and/or remove barriers, such as high regulatory burdens and/or high corruption levels affecting firms' innovation efforts or entrepreneurial actions. Again, relevance issues concerning the role of institutions' related processes in the innovation system are much broader than what the limited information available from innovation surveys allows me to cover here.

Table 3: CIS-based Indicators: Descriptive statistics (percentage of innovative enterprises indicating highly important factors that hinder their innovation activities)

		CIS (2002-2004)		CIS (2004-2006)		CIS (2008-2010)	
Dimension	Variables	Mean	Std.	Mean	Std.	Mean	Std.
Knowledge	Lack of information on technology	0.07	0.09	0.07	0.07	0.04	0.02
	Lack of information on market	0.08	0.09	0.07	0.07	0.05	0.02
	Difficulty in finding collaboration partners for innovation	0.09	0.07	0.09	0.04	0.08	0.04
Skills	Lack of qualified personnel	0.13	0.06	0.16	0.06	0.11	0.03
Demand	Market dominated by established enterprises	0.15	0.05	0.15	0.05	0.14	0.05
	Uncertain demand for innovative goods or services	0.13	0.04	0.12	0.05	0.15	0.06
	No innovation demand	0.06	0.09	0.06	0.06	0.05	0.02
Finance	Lack of finance from sources outside your enterprise	0.16	0.07	0.18	0.07	0.19	0.08
	Lack of funds within your enterprise or group	0.21	0.07	0.23	0.07	0.25	0.09
	Innovation costs too high	0.21	0.08	0.23	0.09	0.24	0.09
	Number of observations	25		18		22	

Source: Eurostat Database, Results of the CIS2004, CIS2006 and CIS2010.

In the next step, a principal component analysis (PCA) is performed on subsets of indicators to confirm preliminary grouping of selected variables. As common procedure in a PCA, all indicators are standardised. For some institutional indicators, the scale is reversed while keeping the original range to put indicators in increasing order (with low values signalling low levels and vice versa). The PCA's principal aim is to reveal how different variables are associated. The resulting new variables, or principal components, are linear combinations of the original variables, accounting for most variance in the dataset. The method has been used commonly in innovation research (Crescenzi, Rodriguez-Pose & Storper, 2007; Fagerberg & Srholec, 2008; Fagerberg, Srholec & Knell, 2007).

4. Empirical analysis

4.1. PCA results

The following section presents the results of the principal component analysis. Table 4 shows the principal component loadings for the first group of variables, which are related to *knowledge*. These loadings are the correlation coefficients between the variables (rows) and the principal components (columns), providing the basis for interpreting the principal components. Indicators of limited information on market, technology and difficulty in finding collaboration partners all load highly (> 0.50) on the first principal component, labelled *knowledge*, accounting for 88.24% of the variance in the dataset. Higher scores on this principal component indicate greater perception of constraints in the knowledge domain, whereas lower scores point in the opposite direction.

Table 4: Knowledge – Principal component analysis

Variable	Component loadings
Lack of information on technology (percentage of innovative enterprises)	0.98
Lack of information on the market (percentage of innovative enterprises)	0.95
Difficulty in finding collaboration partners for innovation (percentage of innovative enterprises)	0.89

Note: The number of observations is 65; one principal component with an eigenvalue >1 was detected, which explains 88.24% of total variance; extraction method: principal component analysis; based on pooled data.

Table 5 shows the principal component loadings for the second group of variables, comprising demand-related factors. The first principal component accounts for 70.37% of the variance in the dataset, and all included variables satisfy a criterion of having a primary factor loading of 0.5 or above. Higher scores on this principal component indicate greater perception of barriers in the domain of market-related factors.

Table 5: Demand – Principal component analysis

Variable	Component loadings
A market dominated by established enterprises (percentage of innovative enterprises)	0.85
Uncertain demand for innovative goods or services (percentage of innovative enterprises)	0.88
No innovation demand (percentage of innovative enterprises)	0.78

Note: The number of observations is 65; one principal component with an eigenvalue >1 was detected, which explains 70.37% of total variance; extraction method: principal component analysis; based on pooled data.

Table 6 shows component loadings for the third grouping of original variables on the first principal component, comprising finance-related factors. The very high loadings (> 0.50) of all three variables are found in the first principal component, which accounts for 87.19% of the variance in the dataset. The first principal component, labelled *finance*, has a strong positive association with a lack of funds within the enterprises or enterprise group, a lack of sources outside the enterprise and high innovation costs (as higher values indicate higher perceived financial barriers). In countries with high scores on this principal component, the perception of obstacles in the finance domain is greater, whereas in countries with low scores, financial constraints are perceived to a lesser extent.

Table 6: Finance – Principal component analysis

Variable	Component loadings
Lack of finance from sources outside an enterprise (percentage of innovative enterprises)	0.92
Lack of funds within an enterprise or group (percentage of innovative enterprises)	0.94
Innovation costs too high (percentage of innovative enterprises)	0.94

Note: The number of observations is 65; one principal component with an eigenvalue >1 was detected, which explains 87.19% of total variance; extraction method: principal component analysis; based on pooled data.

Table 7 presents principal component loadings for the fourth group of variables, which are related to institutional factors. All selected variables load highly on the first principal component, which accounts for 79.27% of variance in the dataset. Countries with high scores on this principal component perceive greater constraints in the domain of institutions that are considered in this paper.

Table 7: Institutions – Principal component analysis

Variable	Component loadings
Property rights index (country scores)	0.93
Business freedom index (country scores)	0.79
CPI (country scores)	0.94

Note: Number of observations is 65; one principal component with an eigenvalue >1 was detected, which explains 79.27% of total variance; extraction method: principal component analysis; based on pooled data.

4.2. Results of the clustering analysis

This section presents the results of the clustering analysis based on the countries' scores on each principal component and one additional indicator. As stated earlier, the skills-related factor is expressed with a single indicator (the share of innovative companies for which a lack of qualified personnel is a highly significant factor hindering innovation activities). The composite score for a given country for a principal component is based on the sum of products of the country's standardised values on each variable and the corresponding loading of the variable for the given principal component. For an overview of the factor scores by countries and over time, see Table A1 in the appendix.

The hierarchical agglomerative cluster analysis (Ward method using Euclidian distance) detected potential groupings of countries' observations into three, four or six clusters. While no clear-cut test statistic for clustering results exists, several rules and validation techniques can be used to determine the number of clusters present in the data (Aldenderfer & Blashfield, 1984). The obtained cluster solutions were inspected based on several criteria. First, the inspection of the curve in the scree plot, which is analogous to the 'screen test' of factor analysis, is used.[6] Second, the value of the fusion coefficient is inspected to discover a significant increase in the value of the factor, in which an increase suggests that two relatively different clusters have been merged. These criteria suggested that a four- or six-cluster solution might be appropriate. Third, the consensus among

[6] A scree plot shows the semi-partial R squared on the y-axis and the number of clusters on the x-axis.

the three statistics, i.e., the peaks of the cubic clustering criterion (CCC) and pseudo F statistic, in combination with a small value of the pseudo t2 statistic, suggests that a six-cluster solution is more suitable. Finally, the four- and six-cluster solutions are inspected qualitatively for plausibility, revealing that the six-cluster solution improves the representation of distinct profiles of country groupings (see Table A3 in the appendix). Given the small size of the sample and the limited number of variables included in the analysis, it was necessary to rely on qualitative assessment in cluster formation to a large extent.

As a robustness check, the six-cluster solution obtained from the hierarchical procedure is tested with the help of k-means clustering analysis. The results showed that the six-cluster solution resulted in groups of very similar size and that the profiles corresponded well with the ones obtained from hierarchical clustering. This consistency is an indicator of stability. As k-means clustering usually is used to test validity, as well as improve on the results obtained from the hierarchical procedure. The results of k-means cluster analysis are reported in Table 8.

Table 8: Identification of clusters (K-means clusters)

	Cluster 1 *Finance,* ***institutions*** *and skills*	Cluster 2 *Finance and institutions*	Cluster 3 ***Knowledge****,* ***demand*** *and* ***skills***	Cluster 4 *None*	Cluster 5 ***Finance****, knowledge, demand and skills*	Cluster 6 *None*
Knowledge	0.27	-0.18	**6.98**	-1.06	**1.57**	-0.57
Skills	**0.63**	-0.42	**2.08**	-0.98	**0.64**	0.18
Demand	0.45	0.31	**5.02**	-2.00	**2.35**	-0.30
Finance	**2.19**	**0.83**	-1.09	-1.65	**2.87**	-0.83
Institutions	**0.98**	**0.66**	**0.68**	-1.15	0.38	-0.73
Cluster size	8	19	3	11	6	17

Note: The cluster analysis relies on the results of the principal component analysis and one additional indicator (skills). Table A.1 in the appendix shows the factor scores by country and over time. Columns represent the six profiles of the national innovation system that have been detected by the cluster analysis, while rows show average principal component scores (with the exception of the skills row, which shows mean values) on the five main constraints. The principal component scores and skills indicator have a mean of zero and a standard deviation of one, from which follows that the average principal component scores above (or below zero) indicate a higher perception of constraints. Numbers in bold indicate the highest scores/means on each of the five principal constraints.

On one hand, Clusters 3 and 5 represent highly constrained, but distinct profiles. Cluster 3 combines high scores on four dimensions (particularly knowledge/information, skills and demand), except for finance, whereas Cluster 5 has high positive scores on four dimensions, but especially finance. On the other hand, Clusters 4 and 6 score low on all dimensions, particularly for Cluster 4. Finally, Clusters 1 and 2 are more distinct in terms of constraining factors. Both clusters have high scores on finance and institutions, whereas Cluster 1 also scores high on skills.

In summary, the cluster analysis provides six different profiles of weakness patterns in national systems of innovation in terms of perceived barriers' extent and scope. The following subsection characterises the detected clusters of countries.

4.3. Characterising clusters

In what follows, the clusters (in Table 9) are characterised based on the 13 original variables. Columns represent the six clusters that have been delineated by the cluster analysis, while rows present average values on the variables associated with each cluster. Finally, the changes in the countries' membership in relation to the specific cluster at different points in time are provided in Table 10.

A high level of perceived barriers characterises the countries in **Cluster 1** with respect to a lack of financial resources and high innovation costs, and in regard to a weak institutional setting. At the core of the latter are weak and ineffective property rights systems, a very strong perception of corruption and a business environment that generally is not supportive of innovation and entrepreneurship. Also, the countries in this cluster, relatively speaking, strongly perceive a lack of qualified personnel. This cluster is joined only by Slovenia during the initial period (2002-2004). However, Slovenia moves to Cluster 4 during the final period (2008-2010), and Croatia and Romania appear during the middle period (2004-2006) and remain there during the subsequent period (2008-2010)[7]. This cluster also is

[7] Data for Croatia and Romania are available for the 2004-2006 and 2008-2010 periods.

joined by Lithuania, Portugal and Turkey[8] during the middle period (2004-2006).

The countries in **Cluster 2** are characterised by a strong perception of barriers to financial resources (especially from sources within the enterprise or enterprise group), as well as overly high innovation costs, though relatively lower than in Cluster 1. Simultaneously, this cluster is characterised by a relatively strong perception of corruption and a business environment that is the least conducive to innovation and entrepreneurship. This cluster brings together Bulgaria, Cyprus[9], the Czech Republic, France, Hungary, Italy and Lithuania during the initial period (2002-2004). Bulgaria and Hungary remain in this cluster during the middle period (2004-2006) and are joined by Poland, whereas during the final time period (2008-2010), the Czech Republic, France, Hungary, Italy, Lithuania, Latvia and Malta appear in the cluster. The membership in this cluster remains stable over time for France, Hungary and Italy. As previously presented, Lithuania moved to Cluster 1 during the middle period (2004-2006), whereas Bulgaria changed its membership to Cluster 5 during the final time period (2008-2010). At the same time, the Czech Republic moves to Cluster 6 during the middle period. However, it is worth noting that only from the Czech Republic, Hungary, Bulgaria and Lithuania, from the group of countries joining this cluster at any point of time, are data available for all three time periods, whereas for the remaining countries, France and Italy, data are available only for two time periods. In addition, although the moves between Clusters 1 and 2 reflect changes in countries' positions, these are small shifts that did not significantly alter countries' positions.

[8] Data for Turkey are only available for the 2004-2006 period.
[9] Data for Cyprus are only available for the 2002-2004 period.

Table 9: Original variables' mean values (over period) for the six-cluster solution (K-means analysis)

		Cluster 1 *Finance **inst.** and skills*	Cluster 2 *Finance and inst.*	Cluster 3 ***Knowl.. demand,** inst., and **skills***	Cluster 4 *None*	Cluster 5 ***Finance** knowl., **demand,** and skills*	Cluster 6 *None*	Total
Knowledge	Lack of info. on technology	0.05	0.05	**0.34**	0.03	0.09	0.05	0.05
	Lack of info. on market	0.06	0.09	**0.23**	0.03	0.15	0.06	0.06
	Difficulty in finding collaboration partners	0.11	0.11	**0.24**	0.08	0.17	0.14	0.08
Skills	Lack of qualified personnel	0.16	0.04	**0.35**	0.03	0.11	0.03	0.13
Demand	Market dominated by established enterprises	0.18	0.16	**0.22**	0.07	0.20	0.14	0.14
	Uncertain demand	0.04	0.04	**0.32**	0.03	0.08	0.05	0.13
	No innovation demand	0.13	0.14	**0,22**	0.07	**0.22**	0.11	0.06
Finance	Lack of funds within	**0.32**	0.25	0.16	0.15	**0.32**	0.19	0.22
	Lack of finance from outside sources	0.25	0.19	0.17	0.10	**0.29**	0.13	0.17
	Innovation costs too high	0.32	0.27	0.12	0.13	**0.38**	0.17	0.21
Institutions	Property rights index	**55.00**	40.00	43.33	12.27	41.43	14.71	30.85
	Business freedom index	28.34	**29.66**	28.93	14.48	24.60	19.12	23.59
	Corruption Perceptions Index (CPI)	**5.56**	5.21	5.10	1.29	4.49	2.44	3.78
	Cluster size	8	19	3	11	7	17	65

Note: In bold are the highest means for each variable.

With respect to **Cluster 3**, the perception of barriers is highest in all aspects, except for lack of finance and high innovation costs, which are at levels similar to those in Cluster 4, characterised by the lowest values on all determinants and potentially affecting firms and countries' innovation activities negatively. It indicates a very strong perception of knowledge- and information-related barriers, as well as demand-related constraints. At the core of the latter is a highly uncertain demand for innovative goods and services, and no reason to innovate due to no demand for innovation. Similar to Clusters 1 and 2, it also has a relatively weak and ineffective property rights system, as well as a business environment that generally is less supportive of innovation and entrepreneurship. This cluster brings together Latvia and Portugal during the initial time period and Greece during the middle period. Greece initially is found to be a member of Cluster 1. During the middle period (2004-2006), Latvia joins Cluster 2, while Portugal moves to Cluster 1. No country remains in or joins this cluster during the final time period (2008-2010).

The perception of barriers in countries grouped in **Cluster 4** is the lowest on all factors that hinder the firm's innovation activities. This cluster includes Scandinavian and Northern European countries such as Denmark, Finland, Germany, Iceland, the Netherlands, Norway and Sweden[10], except for Slovenia. While data availability for country-year combinations differs, only two countries changed their membership for the whole period examined in this study. In the case of Norway, cluster membership changes to Cluster 6 during the final time period, while Sweden joins this cluster during the middle time period by moving from Cluster 6. As both Clusters 4 and 6 score relatively low on all barriers, the changes in countries' positions can be viewed as rather small. Interestingly, the only relatively new EU member country, Slovenia, joins this cluster during the 2008-2010 period by moving from Cluster 1, which points toward higher barriers.

Cluster 5 is characterised by the highest perception of finance-related barriers (primarily a lack of external funding sources for innovation) – and to some extent, knowledge – as well as demand-related barriers. Regarding knowledge factors, a lack of information on markets and difficulties in finding collaboration partners for innovation seem to be the most

[10] Data for Denmark and Germany are only available for the 2002-2004 period, and for Iceland, only for the 2008-2010 period.

prominent ones. When it comes to demand-related barriers, a market dominated by established enterprises, with no reason to innovate due to having no demand for innovation, appears to be more pronounced than in other clusters. At the same time, in terms of institutional set-up, this cluster seems to be more effective on all dimensions compared with Clusters 1, 2 and 3, but less so compared with the less-constrained Clusters 4 and 6. Cluster 5 includes Spain during all three time periods, while Greece, Latvia and Bulgaria show up in this cluster during the initial (2002-2004), middle (2004-2006) and final (2008-2010) time periods, respectively.

Like Cluster 4, the perception of barriers on all examined factors negatively affecting firms' innovation activities in **Cluster 6** is relatively low, but higher than in Cluster 4. This cluster brings together Austria, Belgium, Estonia, Ireland, Luxembourg, Malta and Sweden during the first time period. Countries for which data are available for all three or two time periods – such as Austria, Belgium, Estonia, Ireland and Luxembourg – express stable membership in this cluster over time. Only one relatively new EU member, the Czech Republic, joins the cluster during the 2006-2008 period, moving from and back to Cluster 2, which is characterised mainly by financial and institutional constraints. As previously indicated, Norway joins this cluster during the final time period (2008-2010) by moving from Cluster 4, which points toward the lowest barriers.

Overall, the switches from one cluster to another are rather low for countries that initially are found in relatively low-constrained systems, such as Clusters 2, 4 and 6. However, the switches are more pronounced for countries initially found in more constrained systems of innovation. And yet, these shifts did not move countries' initial position in a positive direction significantly and/or are less consistent over time, with a few exceptions, such as Slovenia and Estonia.

Table 10: Countries' membership in identified clusters over time

Cluster	2002-2004	2004-2006	2008-2010
Cluster 1 Finance, **institutions** and skills	**Slovenia**	Croatia, **Portugal,** Romania, Turkey, **Lithuania**	Croatia, Romania
Cluster 2 Finance and Institutions	Bulgaria, Cyprus, **Czech Republic,** France, Hungary, Italy, **Lithuania, Romania**	**Bulgaria,** Hungary, Poland	Czech Republic, France, Hungary, Italy, Lithuania, Latvia, Malta, Poland
Cluster 3 **Knowledge, demand**, institutions and **skills**	**Latvia, Portugal**	Greece	
Cluster 4 None	Germany, Denmark, Finland, the Netherlands, Norway	The Netherlands, **Norway**	Finland, Iceland, Sweden, Slovenia
Cluster 5 **Finance**, knowledge, **demand** and skills	**Greece,** Spain	Spain**, Latvia**	Bulgaria, Spain, Portugal
Cluster 6 None	Austria, Belgium, Estonia, Ireland, Luxembourg, **Malta, Sweden**	Austria, **Czech Republic,** Estonia, Ireland, Luxembourg	Belgium, Estonia, Ireland, Luxembourg, Norway
Number of observations	25	18	22

Note: In bold are countries that changed their membership in the cluster during the following period.

This paper's clustering results reveal a divide among EU countries when examining the 2008-2010 period (based on overall EC' IUS2010[11] scoring).

[11] The European Commission's Innovation Union Scoreboard (IUS) 2010 provides the summary innovation index for 27 EU member states. Based on the index, the member states are grouped as innovation leaders, innovation followers, moderate innovators and modest innovators (European Commission, 2011).

The EU15 countries that are innovation leaders are all in Cluster 4: Finland and Sweden. Most other EU15 countries that are Innovation followers – including Austria, Belgium, Ireland and Luxembourg – are in Cluster 6. One exception to this is France, which is in Cluster 2. Finally, the EU15 countries that are moderate innovators are found in Clusters 2 (Italy) and 5 (Spain, Portugal). Within the group of EU13 countries, most countries are either modest or moderate innovators, and mostly are found in Clusters 1 and 2. The exception is Bulgaria, which joins Cluster 5 with Spain and Portugal. Two of the EU13 countries that stand out as innovation followers (Estonia and Slovenia) are found in the less-constrained Clusters 4 and 6, respectively.

The observed patterns are highly plausible in light of empirical evidence of stable heterogeneity and a lack of convergence in innovation capacity, as well as in innovation enablers in EU28[12] countries (Veugelers, 2017). With respect to enablers of innovation capacity, Veugelers (2017) shows substantial heterogeneity in public R&D spending (as a percentage of GDP) across EU countries and over time (2008-2015), as well as a growing divide between EU member states. The divide is prominent between EU15[13] and EU13[14] member countries, as well as within these two groups. More specifically, EU15 North[15] countries, the leading countries in terms of innovation performance, are spending the most on R&D and continue to do so, whereas EU13 countries, and especially the EU15 South,[16] continue to lag behind. These results are contrary to expectations in extant literature about the relationship between public spending in R&D and levels of initial conditions and countries' economic development of countries, indicating that public spending on R&D (as a percentage of GDP) is more prominent in catching-up countries. When it comes to the second enabler of innovation capacity, i.e., skill levels (as measured by tertiary education levels), the picture that emerges is a continuous improvement in all EU countries, but

[12] As of 1 February 2020, the UK is no longer part of the EU; therefore, the number is reduced to 27.

[13] EU15 includes Austria (AT), Belgium (BG), Cyprus (CY), Denmark (DK), Germany (DE), Greece (EL), Spain (ES), Finland (FI), France (FR), Italy (IT), Malta (MT), Portugal (PT), the Netherlands (NL), Sweden (SE) and the United Kingdom (UK).

[14] EU13 includes the Czech Republic (CZ), Estonia (EE), Hungary (HU), Slovenia (SI), Slovakia (SK), Bulgaria (BG), Croatia (HR), Ireland (IE), Lithuania (LT), Latvia (LV), Luxembourg (LU), Poland (PO) and Romania (RO).

[15] EU15 North includes AT, BE, DK, DE, FI, FR, NL, SE and the UK.

[16] EU15 South includes CY, EL, ES, IT, MT and PT.

especially EU13. Based on these results, Veugelers (2017) concluded that the size of public R&D spending in EU countries does not support the convergence to support catching up in innovation capacity.

Although considerable heterogeneity exists in innovation performances and in the amounts of public funds spent on research and development, the evidence on national innovation policy mixes or programmes across EU countries and their changes over time shows signs of too much convergence and remarkable stability (Izsak, Markianidou & Radošević, 2015; Veugelers, 2015). In other words, the convergence in innovation policy mixes in EU member countries suggests that these policy mixes do not in sufficiently take countries' specific challenges and circumstances into account. The high similarity in the mix of innovation policy instruments adopted by EU countries (1990-2013), as reported in Veugelers (2015), is not in line with the heterogeneity in the relative importance of various hindering factors found in this paper.

On a similar note, Izsak et al. (2015) raise concerns about too much convergence among innovation policy mixes across EU countries that might limit policies' efficacy. Based on the clustering analysis of research and innovation policy measures[17] adopted by EU27 countries during the 2004-2012 period, Izsak et al. (2015) identified five different groupings of countries based on their policy-mix profiles. Their analysis reveals that countries at different levels of development and maturity, as reflected in their distance to the technological frontier,[18] have similar policy-mix profiles, suggesting potential mismatches between policy mixes adopted and specific challenges and situations faced in the countries' respective NISs. On a related matter, no one-to-one relationship was found between the groupings of countries in terms of innovation performances and membership in the specific policy-mix group. Moreover, their results show

[17] The types of policy instruments included in the analysis of policy mixes are: 1) Public R&D, including competitive research and centres of excellence; 2) industry-science collaboration, including collaborative research, cluster policies and competence centres in which both industrial and academic sectors are involved; 3) knowledge and technology transfer, including technology transfer and spin-off measures; 4) business RDI, including direct support to business R&D and business innovation; 5) tax incentives; and 6) venture capital funds (state-backed) (Izsak et al., 2015).

[18] Technology distance is provided by the Innovation Union Scoreboard's (IUS) 2013 ranking of countries based on their innovation performances.

the stability of countries' policy-mix profiles over the examined time period. Some of the interpretations put forth for observed stability in countries' policy approaches include long-lasting structural features and persistent policy philosophies.

In summary, the observed patterns and their relative stability over time among the country groupings can be interpreted in terms of relative heterogeneity and stability in national innovation environments, including innovation policy mixes, as well as interactions between the two. However, the aforementioned interpretations' validity requires further research.

5. Summary and concluding discussion

The present paper has explored the possibility of using primarily CIS-based indicators on factors that hinder firms' innovation activities to identify the innovation systems' weaknesses or problems along a range of policy-relevant areas or activities that define NIS, as well as map broad patterns and trends in systems' NIS weaknesses mainly in EU countries. These indicators have been complemented with a few indicators on NISs' institutional characteristics. The paper has focussed on five processes, or aspects, in the innovation system – knowledge, skills, market, finance and institutions – which are viewed as crucial to supporting innovative firms' innovation processes.

To this end, six different profiles of national innovation systems have been identified, with some having features of highly constrained systems along several dimensions (Clusters 3 and 5), others being more specialised in terms of the main system's problems (Clusters 1 and 2) and those that are the least-constrained along all dimensions (Clusters 4 and 6). Overall, the results show that heterogeneity exists in weakness patterns along generic processes in countries' national innovation systems. The results point to differences in weakness patterns between new and old EU member states, as well as within these two groups of countries. These findings, to a large extent, are in line with the view that there are large heterogeneity and limited convergence in innovation performances and enablers among EU countries (Veugelers, 2017). In addition, a descriptive analysis of changes in the countries' cluster membership at different points in time provides some insights into the efficacy (or lack of) of countries' innovation policies in maintaining and/or improving the initial system's conditions in which firms operate and innovate. More specifically, countries that are positioned initially in the clusters, where the perception of barriers is relatively weak, tend to remain in the same cluster, whereas only a few countries, such as the Czech Republic and Slovenia, show changes in their initial positions in a positive direction. The observed patterns in systems' NIS weaknesses and their relative stability correspond with findings obtained by Izsak et al. (2015) on similarity and stability in EU member states' national innovation policy mixes. Izsak et al. (2015) raise question regarding the efficacy of adopting similar innovation policy mixes or practices in EU member countries that face different technological and policy challenges and situations. The issue is that such innovation policy mixes may be ineffective when they are not matched with objective challenges or challenges that stem from each member state's innovation position. This view also is shared by Borrás and Edquist (2013), who point out that the efficacy of innovation policy depends on the extent to which innovation policy instruments address real NIS weaknesses or problems and take into account public actors' capacities and the institutional context's nature, as well as the extent to which innovation policy instruments are customised to the system's changing needs. Thus, the analysis presented here provides additional insight on the inconsistency between countries' choice of policy instruments and the identified weaknesses or problems in their respective NIS.

This paper's aim has not been to provide a comprehensive study of NISs, but to point out some weaknesses in generic processes and varieties of NISs in Europe and over time, as perceived by innovative firms. Thus, it is an exploratory attempt to provide a general description of cross-country similarities and differences in terms of weaknesses in NISs' generic processes based on innovative firms' perception of the relevance and impact of external influences on their innovation activities. While the analysis maps the relation between different NIS dimensions and finds distinct weakness patterns among countries' innovation systems, it does not provide explanations for the observed patterns, and more importantly, how and whether these differences are reflected in how well the systems perform. Furthermore, while country groupings along the selected NIS dimension seem plausible, the issues at hand require much more in-depth exploration of each specific country's NIS to provide valuable insight for policy purposes. However, the findings support the view that no single favoured innovation policy exists that countries can follow by adopting overly narrow or generic innovation policies (‘one size fit all’) or by copying policies developed elsewhere. As a result, the adoption of more differentiated and flexible policies that match systems’ specific problems in different national systems of innovation, at different points in time, is needed. The findings also support the view that weaknesses in terms of different countries’ innovation environments are systemic. In other words, addressing one problem such as, for example, access to finance in isolation without examining other barriers to innovation may not result in improved innovation performances in countries.

This paper contains several other limitations that deserve to be acknowledged and that point out related challenges and opportunities for future research in this area. First, the CIS aggregate dataset includes only information up to 2010, and the information is not available for a considerable number of EU countries, limiting the scope of the analysis. Second, the relevance issues concerning each of the generic processes in the innovation system are much broader, and the limited information on the external factors that influence firms’ innovation processes that is available from aggregate CIS data does not allow for covering all of them in sufficient detail. For these reasons, CISs are useful only to a limited extent for mapping heterogeneous environments in which firms operate and innovate. Consequently, the provided picture of NISs’ heterogeneity in terms of weaknesses in generic processes based on business perceptions might be viewed as overly simplistic given national innovation systems’ complexity. Alternatively, other data sources that are better placed to provide information on these issues could have been used. However, the information that can be obtained from other sources is not always readily available for a large number of countries and time periods, or comparable with innovation survey data. Thus, future research that aims to identify innovation systems’ weaknesses by enlarging the number of countries and types of dimensions and indicators to be examined in the analysis is crucially important for empirical analysis in this field. Finally, this paper’s objective is rather descriptive, and the empirical analysis has been simple. A promising avenue for future research includes examining the degree of complementarities and interactions among the various dimensions of a national system of innovation, determining firms’ innovation activities, as well as the complex processes that link them together.

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Appendix

Appendix Table A1. Factor scores by country

TIME	2002-2004				2004-2006				2008-2010			
GEO	KNW	SKL	DEM	FIN	KNW	SKL	DEM	FIN	KNW	SKL	DEM	FIN
AT	-0.31	-0.47	-0.94	- 0.48	-0.53	0.64	-0.78	- 0.40	-	-	-	-
BE	-0.49	0.06	-0.56	- 0.81	-	-	-	-	-0.65	0.05	-0.63	- 1.21
BG	0.41	-0.80	0.27	0.82	0.14	-0.49	-0.63	- 0.14	**1.84**	**0.61**	**2.96**	3.18
CY	-0.20	0.36	-1.27	**1.60**					-	-	-	-
CZ	-1.13	-0.61	0.27	- 0.61	-1.19	0.39	-0.59	- 0.56	-1.15	-0.47	0.27	0.90
DE	-1.17	-1.63	-1.88	- 1.32	-	-	-	-	-	-	-	-
DK	-1.10	-1.23	-0.88	- 1.25	-	-	-	-	-	-	-	-
EE	-0.70	**1.85**	0.06	0.72	-0.49	1.83	-1.50	- 0.36	-0.73	0.13	-0.85	- 0.62
EL	**4.01**	**1.90**	**2.64**	**3.26**	**6.35**	**2.41**	**5.22**	- 1.08	-	-	-	-
ES	1.26	0.53	2.33	**2.63**	1.17	0.62	**1.89**	1.74	**0.93**	-0.50	**2.64**	**3.79**
FI	-0.31	-0.73	-1.47	- 1.82	-	-	-	-	-0.92	-0.62	-1.56	- 1.24
FR	0.05	0.30	0.56	0.52	-	-	-	-	0.00	0.14	0.74	1.46
HR	-	-	-	-	0.34	**1.37**	-0.22	**2.94**	0.06	0.13	0.30	**3.78**
HU	-0.95	-1.10	0.07	1.03	-0.55	0.14	0.18	1.23	-0.58	-0.51	1.31	1.03
IE	0.14	0.93	-0.71	- 0.27	-0.41	-0.60	0.33	- 0.94	-0.61	-0.97	0.39	0.11
IS	-	-	-	-	-	-		-	-1.25	-1.11	-2.50	- 0.93
IT	-0.02	-0.50	-0.35	0.27	-	-	-	-	0.02	-0.88	1.19	1.95
LT	0.27	0.06	0.01	0.44	-0.27	**2.23**	-0.64	1.06	0.03	-0.20	-0.55	0.26
LU	-1.12	-0.23	-0.10	- 2.44	-0.40	1.34	0.22	- 1.94	-0.42	-0.16	1.27	- 2.36
LV	**8.21**	1.70	**6.05**	- 0.61	0.90	1.41	**1.90**	2.09	0.11	-0.34	0.49	0.64
MT	-0.33	-0.80	0.29	- 1.35	-	-	-	-	-0.16	-1.23	0.86	0.18
NL	-0.96	-1.21	-2.27	- 1.56	-1.26	-1.18	-2.86	- 2.94	-	-	-	-
PL	-	-	-	-	-0.20	-1.12	0.44	1.79	0.11	-1.00	0.86	1.88
PT	**6.37**	**2.13**	**3.79**	- 1.57	0.58	0.00	0.63	**2.18**	**0.89**	-0.08	**2.11**	**3.40**
RO	0.47	0.17	1.25	0.55	**0.63**	0.04	0.34	**2.35**	-0.31	-0.75	1.78	2.36

SE	-0.80	-0.78	0.32	-0.81	-	-	-	-	-1.27	-0.34	-1.45	-1.64
SI	0.48	1.23	1.06	1.50	-	-	-	-	-1.33	-1.42	-2.88	-2.46
NO	-1.22	-1.37	-2.18	-1.38	-0.89	0.09	-2.04	-1.62	-0.65	-0.20	-1.40	-0.35
TR	-	-	-	-	**0.64**	0.80	0.33	1.34	-	-	-	-

Note: KNW: Knowledge, SKL: Skills, DEM: Demand and FIN: Finance. The principal component scores and skills variables have means of zero and standard deviations of one, from which follows that the average principal component scores above (or below zero) indicate greater perceptions of constraints. Numbers in bold indicate the three highest scores on each of the four main constraints.

Appendix Table A2. **Original variables' mean values for the four-cluster solution (Ward method)**

		Cluster 1	Cluster 2	Cluster 3	Cluster 4	**Total**
Knowledge	Lack of info. on technology	0.03	0.05	0.10	**0.35**	0.05
	Lack of info. on market	0.04	0.05	0.09	**0.34**	0.06
	Difficulty in finding collaboration partners for innovation	0.05	0.09	0.15	**0.23**	0.08
Skills	Lack of qualified personnel	0.11	0.13	0.17	**0.24**	0.13
Demand	Market dominated by established enterprises	0.11	0.16	0.21	**0.22**	0.14
	Uncertain demand for innovative goods or services	0.04	0.04	0.08	**0.32**	0.13
	No innovation demand	0.10	0.14	0.21	**0.22**	0.06
Finance	Lack of funds within the enterprise or group	0.17	0.27	**0.32**	0.16	0.22
	Lack of finance from sources outside the enterprise	0.11	0.21	**0.28**	0.17	0.17
	Innovation costs too high	0.15	0.28	**0.36**	0.12	0.21
Institutions	Property rights index	12.50	43.21	42.50	**43.33**	30.85
	Business freedom index	16.43	**29.73**	23.40	28.93	23.59
	Corruption Perceptions Index (CPI)	1.78	**5.31**	4.43	5.10	3.78
	Cluster size	26	28	8	3	65

Note: The table shows, for each cluster, the average percentage share (over period) of innovative enterprises for which a specific factor is perceived as a highly important hindering factor. For example, in Cluster 2, factor lack of finance within the enterprise is a highly important hindering factor for 27% of the innovative firms. The table also shows, for each cluster, average scores (over period) on three indices (property rights, business freedom and CPI). For definitions, see Table 3. Bold-face numbers indicate the highest mean for each variable.

Appendix Table A3. **Original variables' mean values for the four- and six-cluster solutions (Ward method)**

		Four-cluster solution				Six-cluster solution					
		1	2	3	4	1	2	3	4	5	6
Knowledge	Lack of info. on technology	0.03	0.05	0.10	0.35	0.03	0.05	0.05	0.05	0.09	0.34
	Lack of info. on markets	0.04	0.05	0.09	0.34	0.03	0.08	0.11	0.06	0.15	0.23
	Collaboration difficulties	0.05	0.09	0.15	0.23	0.08	0.13	0.12	0.14	0.17	0.24
Skills	Lack of qualified personnel	0.11	0.13	0.17	0.24	0.03	0.04	0.06	0.03	0.10	0.35
Demand	Market dominated	**0.11**	0.16	0.21	0.22	**0.07**	0.16	0.17	**0.14**	0.21	0.22
	Uncertain demand	0.04	0.04	0.08	0.32	0.03	0.04	0.05	0.04	0.08	0.32
	No demand	0.10	**0.14**	0.21	0.22	**0.07**	0.13	0.15	**0.12**	0.21	0.22
Finance	Lack of finance within	**0.17**	**0.27**	0.32	0.16	**0.15**	**0.25**	**0.29**	**0.19**	0.32	0.16
	Lack of finance outside	**0.11**	**0.21**	**0.28**	0.17	**0.10**	**0.18**	**0.26**	**0.12**	0.28	0.17
	Innovation costs too high	**0.15**	**0.28**	0.36	0.12	**0.13**	**0.26**	**0.31**	**0.16**	0.36	0.12
Institutions	Property rights index	12.50	**43.21**	42.50	43.33	12.27	**34.44**	**59.00**	12.67	42.50	43.33
	Business freedom index	16.43	**29.73**	23.40	28.93	14.48	**26.05**	**36.36**	17.85	23.40	28.93
	CPI	1.78	**5.31**	4.43	5.10	**1.29**	4.82	**6.20**	**2.15**	4.43	5.10
	Cluster size	26	28	8	3	11	18	10	15	8	3

Note: The table shows, for each cluster, the average percentage share (over period) of innovative enterprises for which a specific factor is perceived as a highly important hindering factor. For example, in Cluster 2 (four-cluster solution), factor lack of finance within the enterprise is a highly important hindering factor for 27% of the innovative firms. The table also shows, for each cluster, average scores (over period) on three indices (property rights, business freedom and CPI). For definitions, see Table 3. The different shades of grey show how the second cluster in the four-cluster solution splits into two separate clusters in the six-cluster solution. Numbers in bold indicate values of the original variables in which the split is most notable.

Appendix Table A4. Countries' membership in identified clusters (2008-2010 period); innovation performance groups as measured by the Innovation Union Scoreboard (IUS), 2010 and 2011; and EU groups based on distinctions between the EU12, EU15 and European Economic Area (EEA)

Clusters	Country (2008-2010)	Performance groups (based on IUS 2010)*	Performance groups (based on IUS 2011)**	EU groups
Cluster 1 Finance, **institutions** and skills	Croatia	Moderate innovator	Moderate innovator	EU12
	Romania	Modest innovator	Modest innovator	EU12
Cluster 2 Finance and Institutions	Czech Republic	Moderate innovator	Moderate innovator	EU12
	France	Innovation follower	Innovation follower	**EU15**
	Hungary	Moderate innovator	Moderate innovator	EU12
	Italy	Moderate innovator	Moderate innovator	**EU15**
	Lithuania	Modest innovator	Modest innovator	EU12
	Latvia	Modest innovator	Modest innovator	EU12
	Malta	Moderate innovator	Moderate innovator	EU12
	Poland	Moderate innovator	Moderate innovator	EU12
Cluster 3 **Knowledge**, demand, institutions and **skills**				
Cluster 4 None	Finland	Innovation leader	Innovation leader	**EU15**
	Iceland	Innovation follower	Innovation follower	EEA
	Sweden	Innovation leader	Innovation leader	**EU15**
	Slovenia	Innovation follower	Innovation follower	EU12
Cluster 5 **Finance**, knowledge,	Bulgaria	Modest innovator	Modest innovator	EU12
	Spain	Moderate innovator	Moderate innovator	**EU15**

demand and skills	Portugal	Moderate innovator	Moderate innovator	**EU15**
Cluster 6 None	Belgium	Innovation follower	Innovation follower	**EU15**
	Estonia	Innovation follower	Innovation follower	EU12
	Ireland	Innovation follower	Innovation follower	**EU15**
	Luxembourg	Innovation follower	Innovation follower	**EU15**
	Norway	Moderate innovator	Moderate innovator	EEA

Note: *Average performance in 2010 reflects performances in 2008/2009. ** Average performance in 2011 reflects performances in 2009/2010.

CHAPTER 4

IV Institutional Context and Modes of Innovation in National Systems of Innovation: A Study of Six Small European Countries

Marija Rakas (rakas@business.aau.dk)

Ina Drejer (id@business.aau.dk)

Department of Business and Management

Aalborg University, Denmark

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Abstract

This paper aims to develop a broader understanding of the role played by institutions in the functioning of national innovation systems, as reflected in the behaviour of innovative firms. The extent to which national institutional settings are reflected in firms' innovation behaviour, as expressed in their modes of innovation, is empirically explored in relation to six small European countries (Bulgaria, Estonia, Lithuania, Hungary, Portugal and Norway). A range of primarily survey-based data are used to cluster the countries based on the characteristics of their national institutional settings, whereas the modes of innovation of the six countries are identified through the use of exploratory factor and cluster analysis on micro-aggregated data obtained from the Community Innovation Survey 2012. The association between institutional settings and modes of innovation is investigated by linking the patterns observed in the two cluster analyses. Due to the relatively low number of countries included in the analysis, the association is explored by observing patterns rather than by statistically testing for associations across country groups. The analysis finds some support for the notion of national institutional settings being reflected in firms' modes of innovation. However, the analysis also points to the need for better data in order to conduct more comprehensive analyses of the relations between institutional settings and modes of innovation.

1. Introduction

The literature concerning national innovation systems (NIS) has emphasised the importance of national institutions, as well as the overall structures of production, in characterising national systems of innovation and explaining the different rates and directions of knowledge accumulation in different countries (e.g. Lundvall, 1992; Edquist, 1997). The role played by national institutional arrangements in relation to the structuring of economic behaviour, including innovation, has also been the subject of research into the varieties of capitalism (VoC) (e.g. Hollingsworth & Boyer, 1997; Soskice & Hall, 2001). The most recent literature regarding the role that institutions may play in innovation activity has focused on the relation between the quality of institutions and the level of innovation activity (e.g. Barasa et al., 2017; Fischer & Tello-Gamarra, 2017). However, very few studies have analysed the direct role that institutions can play in firms' innovation behaviour. Accordingly, this paper presents an empirical analysis intended to broaden the understanding of the role played by institutions in the functioning of NIS, as reflected in the innovation behaviour of firms.

The long tradition of studying firms' innovation behaviour in terms of the observable patterns of innovation at the sectoral level started with Pavitt's (1984) taxonomy of technological trajectories. Yet, national differences in innovation modes remain relatively underexplored. The present paper thus contributes to the innovation literature by exploring whether different types of national institutional settings are associated with particular modes of innovation. More specifically, it seeks to answer the following research question: *How, and to what extent, are national institutional settings reflected in firms' modes of innovation?* The analysis explicitly addresses whether particular modes of innovation are more dominant, as measured by their frequency of occurrence, in specific institutional settings.

To identify the innovation modes, this paper uses micro-aggregated Community Innovation Survey data, which refer to the period 2010–2012. The formal and informal institutional settings are identified through a variety of mainly survey-based data. The data set covers six relatively small countries in Europe: Norway and five European Union (EU) countries, namely Bulgaria, Hungary, Estonia, Lithuania and Portugal. As the first step in the analysis, the six countries are clustered into subgroups based on the commonalities in their institutional settings. As the second step, through a combination of exploratory factor analysis and clustering methods, the innovative firms in the six analysed countries are clustered according to different types of innovation behaviour. The firm-level clusters are interpreted as modes of innovation. Finally, a range of propositions derived from the literature regarding the association between the countries' institutional settings and the identified modes of innovation are explored by linking the findings from steps one and two. Due to the relatively low number of countries included in the analysis, the propositions are explored by observing patterns rather than by statistically testing for associations across country groups.

Although generally consistent patterns can be observed across the country groups in terms of the modes of innovation that are most dominant, the association with the characteristics of their institutional settings is not as straightforward as initially proposed. The most convincing results are found for the most 'extreme' countries included in the analysis, that is, Norway and Bulgaria, where the innovation modes identified as being dominant represent a relatively good reflection of the countries' institutional settings. The findings concerning the four remaining countries are mixed, suggesting a more complex association between institutional traits and firms' modes of innovation, which possibly reflects the need to take the broader, country-specific context into account. Despite the limitations of the analysis, the insights provided with regards to the role played by the institutional setting in incentivising firms to adopt specific orientations in relation to innovation behaviour illustrate the policy-related evidence that could be gained through the development of better quality data and by analysing a larger number of countries.

The remainder of this paper is structured as follows. Section 2 briefly reviews how institutions have previously been conceptualised in the innovation literature, including how institutions are considered to affect firms' innovation mechanisms. This section also reviews previous studies concerning modes of innovation that are of relevance to the present study, and it sets out propositions regarding how specific institutions may influence innovation behaviour. Section 3 describes the data and methods used to identify the countries' institutional settings and the firms' modes of innovation. Section 4 presents the empirical analysis, while section 5 offers a conclusion based on the findings, discusses the limitations of the analysis and suggests future avenues for research.

2. Theoretical starting points: An overview of the literature on institutions and modes of innovation

2.1. The conceptualisation of institutions in the innovation literature

The prior literature concerning NIS has emphasised the importance of both national institutions and the overall structure of production in characterising innovation systems and explaining the different rates and directions of knowledge accumulation in different countries. In the NIS literature (e.g. Lundvall, 1992; Edquist, 1997), a firm's behaviour is assumed to be shaped by the institutions that constitute barriers and incentives for innovation. Accordingly, scholars in the field of innovation systems (IS) studies have sought to explain the differences in firms' innovation behaviour by exploring differences across sectors and countries (Pavitt, 1984; Lundvall, 1992; Nelson, 1993; Malerba & Orsenigo, 1995), arguing that national, sectoral and firm patterns of innovation are all influenced by local institutional factors.

However, despite institutions and the ways in which they influence innovation being central elements of the definition of an innovation system, the various contributors to the development of the NIS concept have not shared a common understanding of the term 'institution'. This was first noted by Edquist (1997), although Grønning (2008) also emphasises the differences among leading innovation systems scholars in terms of their perceptions of the meaning of institutions. Grønning (2008) divides the innovation systems scholars' understandings of institutions into three groups. (1) In what is characterised as a predominantly <u>regulative through cognitive understanding of institutions</u>, institutions are perceived as the 'rules of the game' and, although norms and actions are also included in this understanding, they are included in a way that stresses how institutions regulate and shape behaviour. Grønning (2008) includes the work of Charles Edquist and Bengt-Åke Lundvall as being representative of this understanding (e.g. Lundvall, 1992; Edquist, 1997; Lundvall, 1997). (2) The second approach, which Grønning (2008) associates with, for example, Bo Carlsson and Rikard Stankiewicz, focuses on the <u>institutional infrastructure, as expressed through regimes and organisations</u>, implying that institutions can be both abstract and manifest. According to this approach, the institutional infrastructure includes the political system, the educational system and patent legislation as well as those institutions regulating labour relations (e.g. Carlsson & Stankiewicz, 1991; Carlsson, 2004). (3) Finally, in what Grønning (2008) describes as a <u>predominantly habitual/cognitive perspective on institutions</u>, institutions are conceptualised according to 'habits of action', that is, expected patterns of behaviour (drawing on Veblen, 1899), and 'ways of playing the game', which, with reference to game theory, are associated with sustaining cooperation or solving coordination problems in a repeated game context (drawing on Schotter, 1981). Grønning (2008) associates this approach, which features a move towards a more cognitive focus on the social construction of institutions, with the later work of Richard R. Nelson. Nelson and Sampat (2001) separate their perception of institutions from the regulative through cognitive understanding mentioned above by stressing that they are not talking about '"the rules of the game" (interpreted as broad constraints), "governing structures" (embodied in particular organizational forms) or "cultural beliefs and norms"' (p. 41). They perceive institutions as 'social technologies' tied directly to standardised patterns of behaviour in a theory-of-production setting, rather than to factors 'that constrain and shape that behavior' (Nelson & Sampat, 2001, p. 40). In this sense, institutions may be related to routines, which are defined as 'regular and predictable' behaviour (Nelson & Winter, 1982, p. 15).

The lack of consensus as to what constitute institutions within the NIS framework may explain why, despite the emphasis on institutions being core elements of innovation systems, empirical NIS studies of the direct role played by institutions in influencing firms' innovation behaviour are largely missing.

The role of national institutional arrangements in relation to the structuring of economic behaviour has also been addressed in the VoC literature (e.g. Hollingsworth & Boyer, 1997; Soskice & Hall, 2001). The main argument here is that different institutional arrangements encourage particular innovation strategies and capabilities that are manifested in specific patterns of technological change and sectoral specialisation. Such patterns are generalised as being mainly related to radical or incremental innovation, respectively.

The NIS and VoC literature share a conception of firms as being relational, although firms play a much more pivotal role in the VoC literature than in the NIS literature, where the emphasis is on the relations between the different types of actors within the system. The development of the VoC literature belongs to the comparative political economy, while the NIS and IS literature have largely been unified in terms of their adherence to both evolutionary economics and systemic perspectives on innovation. Although both the VoC and NIS/IS literature draw on the work of North (1990) in relation to the conceptualisation of institutions, they do not necessarily have a shared understanding of the phenomena when using the concept of institutions, as the two strands of literature have generally been developed in isolation, with some very few exceptions (Akkermans et al., 2009; Herrmann & Peine, 2011; Meelen et al., 2017), and, as discussed above, the understanding of institutions varies among innovation systems scholars. Furthermore, the VoC literature has a clear national focus, while the systems of innovation literature also emphasises the role of sectoral, technological and regional systems. The national focus within the VoC approach is rooted in a perception of labour market regulation, education and training, and corporate governance being some of the most important institutional structures; hence, these types of institutions are viewed as being highly dependent on national regulatory regimes (Soskice & Hall, 2001).

The VoC literature distinguishes between two different types of political economies, namely liberal market economies (LMEs) and coordinated market economies (CMEs), with reference to the way in which firms resolve the coordination problem in different institutional spheres. The literature assumes that because CMEs provide more institutional support for strategic interactions (e.g. collaborative research and development [R&D]), the actors involved in these types of economies will be more inclined to invest in specific and co-specific assets (e.g. industry-specific training and collaborative R&D) 'that cannot readily be turned to another purpose' and 'whose returns depend heavily on the active cooperation of others' (Soskice & Hall, 2001, p. 17). As CMEs are characterised by consensus seeking and features such as secure employment and opportunities to influence the decisions of the firm, as well as by collaborations that encourage clients and suppliers to suggest incremental improvements, these types of systems are assumed to be better equipped to support incremental innovation than radical innovation (Soskice & Hall, 2001, pp. 39-41). On the contrary, LMEs have more fluid markets, which are assumed to provide actors with more opportunities to move resources around in the search for high returns and, accordingly, the actors are assumed to be more inclined to invest in switchable assets (e.g. multi-purpose technologies) 'whose value can be realized if diverted to other purposes' (Soskice & Hall, 2001, p. 17). The institutional framework of LMEs is said to be supportive of radical innovation because of assumptions regarding an unrestricted labour market rendering it easy to hire and fire people with specialised skills; dispersed ownership and few restrictions on mergers and acquisitions rendering it easy to acquire new technologies through firm acquisitions; and strong venture capital markets supporting entrepreneurs with regards to bringing new ideas to the market (Soskice & Hall, 2001, p. 40). However, a recent empirical study of 15 Western countries (Meelen et al., 2017) questions the impact that the institutions emphasised within the VoC literature have on innovative specialisation in terms of the 'radicality' of innovation in individual firms. Furthermore, the generalisability of the VoC dichotomy to a broader set of countries than the group of Western Organisation for Economic Co-operation and Development (OECD) countries,[1] which formed the empirical basis of Soskice and Hall's (2001) development of the VoC as a framework for understanding institutional differences and similarities among developed economies, has been questioned (Ahlborn et al., 2014). Ahlborn et al. (2014) focus specifically on Central and Eastern European countries as examples of countries in transition that do not necessarily fall within the two traditional VoC groups and where performance results may be driven by the quality of institutions rather than by differences in the types of institutions. Following a similar line of reasoning, Feldmann (2019) argues for further comparative analyses of economic governance across multiple institutional fields as well as for refining the analyses of the under-theorised varieties of capitalism found outside the Western OECD countries.

The relation between the quality of institutions and innovation has been the primary focus of recent studies that, different from the above-mentioned strands of literature, share an emphasis on developing countries. These studies, which adopt both regional and national perspectives, include perceptions of corruption, the rule of law, regulatory quality, democratic predominance and political rights in their measures of institutional quality. Barasa et al. (2017) apply a resource-based view in their analysis of how regional institutional quality across 16 regions in Kenya, Tanzania and Uganda influences the ability of firms to extract value – as measured by the product innovation output – from their resources. Resources are expressed as internal R&D, human capital and managerial experience, while regional institutional quality is defined as 'a situation in which there is low corruption, a strong rule of law and a high degree of regulatory quality' (Barasa et al., 2017, p. 281). Fischer and Tello-Gamarra (2017) position their study of the extent to which institutional quality affects the performance of R&D, as an innovation input, in 51 developing countries within an innovation systems framework, although they do not enter into a detailed discussion of the systemic features. In their study, institutional quality is measured in terms of corruption, democracy and political rights, while labour productivity and patenting activity are

[1] USA, Great Britain, Australia, Canada, New Zealand, Ireland, Germany, Japan, Switzerland, the Netherlands, Belgium, Sweden, Norway and Denmark.

considered indicators of innovation performance. Both these studies find a relation between institutional quality and innovation output/performance; in the case of Barasa et al. (2017), by applying firm level data, whereas the data applied by Fischer and Tello-Gamarra (2017) are country-level data.

The focus of the present study is on innovation modes rather than on the types or rates of innovation. This implies that the NIS framework is the most relevant point of departure for the analysis. Despite the lack of a common understanding of innovation within the NIS research, this strand of literature is characterised by a relation to the organisational aspects of innovation and, thereby, the innovation modes. This differs from the VoC literature, which focuses on the macro level and on innovation output in terms of radicality. Further, the VoC literature only addresses innovation behaviour through assuming that certain types of innovation behaviours are more likely to lead to radical or incremental innovation than others. The recent literature concerning the quality of institutions, although Fischer and Tello-Gamarra (2017) admittedly refer to a NIS framework, also emphasises the innovation output by focusing on how the quality of institutions affects the effectiveness of innovation resources and, thereby, the innovation output.

2.2. Modes of innovation – Conceptualisation and empirical investigations

The modes of innovation are a synonym for innovation behaviour in the sense that a mode of innovation is a characterisation of how firms innovate regarding the types of investments they make (e.g. R&D or training), the types of sources they use in the innovation process and the aims they pursue. As outlined below, different elements may be emphasised in different studies, although the common assumption in all such studies is that each individual firm can be characterised by one mode of innovation. This does not imply that all innovation processes within a given firm are carried out in the same way, but rather that the modes of innovation should be perceived as characterisations of individual firms' overall approaches to innovation.

A range of empirical studies have explored the heterogeneity of firms' innovation activities or strategies, and they have identified certain patterns or regularities in these activities (or strategies) that might be explained at the firm, sectoral or national level. At the sectoral level, the tradition of identifying modes of innovation began with the taxonomy and theory of sectoral patterns of technological change proposed by Pavitt (1984). According to Pavitt's (1984) famous taxonomy, the differing technological trajectories of firms[2] can be explained by sectoral differences in the sources of technology or innovation, the types of users and the means of appropriation of innovation. Several studies have followed this tradition (e.g. Malerba & Orsenigo, 1996; Marsili, 2001; for reviews, see Archibugi, 2001; Peneder, 2003). Pavitt's (1984) taxonomy, which was initially conceived solely for manufacturing industries, has been further refined, extended and applied in the context of the service industries (Evangelista, 2000; Miozzo & Soete, 2001; Hollenstein, 2003), both the manufacturing and service industries (Castellacci, 2008; Bogliacino & Pianta, 2016), as well as at the firm (Arvanitis & Hollenstein, 1998; Arundel & Hollanders, 2004) and product levels (Guerrieri, 1999). Since the 1990s, the availability of firm-level data from national innovation surveys has resulted in several contributions, which are related to Pavitt's (1984) classification in terms of the basic conceptual categories used for the classification, but which are more critical with respect to sectoral regularities and which argue in favour of focusing directly on the classification of firms (Peneder, 2003). Prior studies that question the usefulness of associating the observed patterns of firms' innovation and innovation activities with sectoral specificities include the work by Leiponen and Drejer (2007) and that by Srholec and Verspagen (2008).

While the literature on NSI suggests that differences in firms' innovation activities are more pronounced between than within countries, cross-country differences in innovation patterns have not commonly been explored empirically in the literature. Exceptions do exist, however, in the work by Arundel et al. (2007), Castellacci (2009), Srholec and Verspagen (2008) and Peneder (2010), who all attempt to identify either the modes of learning for innovation or national differences in sectoral patterns or modes of innovation.

Arundel et al. (2007) provide a typology of innovative firms based on two criteria: i) the level of novelty of the firm's product and process innovations and ii) the extent of the firm's in-house innovative activities. These criteria

[2] The trajectories are characterised in terms of the relative importance of product versus process innovation, the main sources of process technology, the relative size of the firm, as well as the size and pattern of technological diversification (Pavitt, 1984).

classify firms into three mutually exclusive modes, namely either 'lead innovators', 'technology modifiers' or 'technology adopters'. The authors show that the distribution of firms according to the specified innovation modes differs among the 14 EU countries considered in the study, and they try to explain the differences in the relative frequency of innovation modes within a nation by means of the relative prevalence of organisational forms that promote learning. Jensen et al. (2007) use a similar approach, albeit based only on data concerning Danish firms, to define a priori two 'modes of learning', namely a science, technology and innovation (STI) mode and a doing, using and interacting (DUI) mode. They find that a combination of the two different modes is most conducive to innovative performance.

Castellacci (2009) investigates cross-country differences in the sectoral patterns of innovation of 22 manufacturing sectors in ten EU countries and finds significant differences in terms of the technological trajectories across countries, which can be explained by the influence of NIS as well as by the fact that the interaction between national systems and sectoral patterns represents an independent source of variability within the sample. Based on a sample of 13 EU countries (firms involved in manufacturing and most sectors of market services), Srholec and Verspagen (2008) identify five clusters that represent relatively homogenous patterns of firm behaviour with regards to their use of four 'ingredients': research, user, external and production ingredients. The identified clusters are labelled as either 'high profile' (high scores for all four identified ingredients of the innovation process), 'user-driven' (high scores for the user and production ingredients), 'externally sourced' (high scores for the external and production ingredients), 'opportunistic' (high scores for the external ingredient) or 'low profile' (low scores for all four ingredients). Srholec and Verspagen (2008) also assess the heterogeneity of firms' innovative behaviour within and between sectors and countries, and they find that while countries and sectors matter to a certain extent, most of the firm-level heterogeneity remains within both sectors and countries, at least in the static sense. Further, their results show that the most relevant contextual factors shaping the innovation strategies of firms cut across sectors and countries. In contrast, Peneder (2010) provides a set of integrated taxonomies for both firms and industries, which explain sectoral characteristics by means of the systemic differences in the distributions of heterogeneous firms across countries. He demonstrates how distinct technological regimes exhibit systematic differences in terms of the distribution of heterogeneous firm types.

In summary, prior empirical studies seeking to classify firms' innovation activities differ with regards to their focus on one or several dimensions, and the patterns of firms' innovative activities may also differ. Moreover, those studies that consider multiple dimensions of innovation or multiple innovation activities rely on different measures, the selection of which depends on either a theoretical or a data-driven approach. That is, in some studies, the modes of innovation are defined a priori, as informed by the theory, while in others, a more exploratory methodology is applied. Due to these differences, a comparison between the obtained taxonomies cannot be performed in a straightforward manner.

Despite drawing on insights from the above-mentioned studies, the present study goes beyond their principal focus on identifying the modes of innovation by exploring whether different types of institutional settings are associated with the presence/relative dominance of particular modes of innovation.

2.3. How specific institutions may influence innovation behaviour

As discussed in section 2.1, there is a fundamental assumption within the NIS literature that institutions may shape firms' behaviour with regards to innovation. The understanding of institutions that underlies the current analysis is mainly in accordance with the regulative through cognitive understanding, whereby institutions are perceived as the 'rules of the game'. These rules may be either formal in the sense that they are constituted by, for example, laws and intellectual property rights or informal in the sense that they are customs and traditions that regulate interactions between actors and thereby reduce uncertainty and transaction costs (Edquist & Johnson, 1997; Boschma, 2005).

The present analysis is rooted in a NIS-based understanding of the importance of the interplay between formal and informal institutions in shaping actors' behaviour and interactions. The institutions included in this analysis relate to intellectual property rights protections, labour market systems as well as customs and perceptions related to trust. These three types of institutions are chosen due to the way they are able to affect the kinds of innovation efforts undertaken and the ways that firms organise their innovation activities, mainly in terms of internal and external R&D, training regarding innovation activities and the sources used in the innovation process. While the kinds of institutions considered here do not cover all the aspects of the institutional context, they do include some of those that may affect how firms innovate.

2.3.1. Intellectual property rights protections

Intellectual property protections in the form of legally enforceable intellectual property rights (IPR) – patents, copyrights and trademarks – are seen as a means of incentivising innovation, particularly investment-intensive innovation activities, such as R&D-based innovation, by allowing innovative firms appropriation of the benefits of their investments in innovation (e.g. Gilbert & Shapiro, 1990).

If technological change is cumulative, then the IPR concerning an existing technology may actually hinder subsequent innovation when it comes to building on technology applied in prior innovations (Williams, 2013). However, this is more likely to affect the diffusion of innovation and incremental innovations rather than the overall modes of innovation.

Accordingly, we propose the following:

Proposition 1: Strong IPR protection is conducive to R&D-based innovation.

IPR may shape the direction of innovation across sectors, as their importance as an incentive varies across sectors (Moser, 2005). This implies that the industry structure may influence the extent to which investment-intensive innovation modes are identified in individual countries.

2.3.2. Labour market systems

A flexible labour market is assumed to make it easy for firms to hire or fire employees so as to take advantage of new opportunities (Soskice & Hall, 2001). While this type of labour market organisation is, in general, perceived as discouraging firm-specific investment in employee skills, the particular type of flexible labour market system known as flexible security systems, which combine low dismissal protection with extensive unemployment benefits, active labour market policies and well-developed systems of continuing vocational training, may be more geared towards the promotion of on-the-job learning (Holm et al., 2010; Lorenz, 2015). Lorenz (2015) argues that flexible security systems, which combine elements of labour market regulation and deregulation, can promote employee learning and innovation by preventing that firms' freedom to adapt their knowledge base to changes in products and processes by hiring and firing leads to a loss of skills associated with the unemployed leaving the labour market or seeking employment where their skills cannot be used. Although Lorenz's (2015) analysis deals with on-the-job learning in general and empirically links this to process innovation abilities, the argument in the present paper broadens his approach so as to also apply it to the training of employees, which is specifically intended to develop or introduce new or significantly improved products and processes.[3] This is reflected in the following proposition:

Proposition 2a: A high degree of flexible security in the labour market is conducive to employee training for innovation.

Furthermore, Lundvall (2007), also drawing on work by Lorenz (e.g. Lorenz & Valeyre, 2006), argues that a labour market that promoting mobility and (publicly funded) labour market training, when combined with short power distances within organisations, tend to 'support a mode of innovation in firms where there is wide interaction among different categories of employees and among firms' (Lundvall, 2007, p. 106). This finding is supported by Lorenz (2015). Accordingly, the following proposition is offered:

Proposition 2b: A high degree of flexible security in the labour market is conducive to innovation drawing on external firm sources.

2.3.3. Trust

In the literature concerning NIS, one of the most highly emphasised informal institutions assumed to shape innovation activity is trust. A high level of trust is an important factor in relation to an efficient system of innovation because trust is crucial for interactive learning (Lundvall et al., 2002), while high levels of interpersonal trust are considered to be conducive to both collective action and co-operative behaviour (Morrone et al., 2009). This is confirmed in the recent study by de Zubielqui et al. (2019), who not only find a strong association between trust and collaboration with

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[3] Employee learning is in the data applied in Lorenz's (2015) analysis being operationalised as 'learning new things on your own'. In the data applied in the present context, the focus is on training regarding innovation activities, which is defined as 'In-house or contracted out training for your personnel specifically for the development and/or introduction of new or significantly improved products and processes' (question 5.1 in the harmonised survey for The Community Innovation Survey [2012]).

supply chain partners, but also between trust and informal IP protection mechanisms as well as shared IP. On the contrary, a closed approach to innovation – or a strong reliance on contractual regulations governing collaborations – is prevalent when trust is absent. In the present analysis, corruption is included as an expression of a lack of trust, which can undermine collaboration (Anokhin & Schulze, 2009; Barasa et al, 2017).

The above discussion leads to the following proposition:

Proposition 3: High levels of trust are conducive to innovation drawing on several types of external sources.

The following analysis will address the four above-mentioned propositions by assessing the extent to which the institutional settings related to IP, labour market organisation and trust in the six analysed countries are reflected in the dominant modes of innovation across those countries.

3. Data and method

The current analysis is based on two main types of data. One type of data comprise micro-aggregated innovation survey data sets for the period 2010–2012, which are provided by Eurostat. These data are applied in relation to the identification of innovation modes. The other type of data comprise different indicators of institutional settings, which draw on a combination of sources. The data are described in more detail below.

As outlined in section 3.3, the choice of countries included in the analysis is driven by the availability of comparable data.

3.1. Identification of institutional settings

The formal and informal institutional settings are identified through a variety of data. Finding high-quality, internationally comparable data describing a complex phenomenon such as an institutional setting is not an easy task. Therefore, the identification of institutional settings performed in this paper does have certain weaknesses. However, it is an explorative attempt to provide insights into institutional settings, which also aspires to establish the direction for future analyses and data-collection procedures.

The source used to identify variables reflecting the institutional settings related to IPR protection and enforcement is Atkinson et al.'s (2012) Global Innovation Policy Index 2012, which draws on a range of underlying sources. Based on the work of Lorenz (2015), the source for identifying the variables reflecting labour market organisation is Eurostat.[4]

European Social Survey data are used to construct an aggregate index of trust in others, while Transparency International, a global civil society organisation with the declared aim of fighting corruption, is the source of the survey-based corruption perception index. Table 1 provides an overview of the sources for each indicator used in the identification of the institutional setting.

[4] Ideally, we would have considered the OECD indicators concerning the strictness of employment protection legislation. However, these indicators are only available for four of the six countries in our sample.

Table 1: Sources of indicators concerning the institutional setting

	Indicator	Primary source	Reference year	Reported in	Type of measure
IPR	Business executives' rating of IP protection	World Economic Forum: The Executive Opinion Survey	2010	Global Innovation Policy Index 2012	Rating, 7=Best; 1=Worst
	Opinions of the legal and political environment on enforcing IPR	Property Rights Alliance	2011	Global Innovation Policy Index 2012	Rating, 10=Best; 0=Worst
	Assessment of the integrity of the legal system	The PRS Group[5]	2008	Global Innovation Policy Index 2012	Rating,10=Best; 0=Worst
Labour market system	Expenditure on labour market policies per unemployed person*	Eurostat	2010	Labour market policy – expenditure and participants. Data 2010 (2012 edition)	Expenditure per unemployed person (as measured in euros)
	People aged over 15 years whose job started within 3 months prior to survey	Eurostat	2009	Data in Focus 35/2009	Percentage of people
	Passive labour market supports (out-of-work income maintenanc e and	Eurostat	2010	Labour market policy – expenditure and participants. Data 2010 (2012	Percentage of total expenditure

[5] An international company specialising in political risk and country risk forecasts.

	support; early retirement expenditure) *			edition)	
	Active labour market measures (training; job rotation and job sharing; employment incentives; supported employment and rehabilitation; direct job creation; start-up incentives)*	Eurostat	2010	Labour market policy – expenditure and participants. Data 2010 (2012 edition)	Percentage of total expenditure
	Adults aged 24 to 65 involved in training or education (measured over a four-week period prior to the survey)	Eurostat	2010	Eurostat database, Population and social conditions (trng_lfs_01)	Percentage of people
Trust	Corruption perception index	Transparency International	2009 and 2010	Corruption perception index 2010	Rating, 10=Best; 0=Worst
	Trust in others**	European Social Survey	2012	Calculated by the authors	Percentage of people

* Data for Norway are incomplete in the currently available Eurostat publication and, therefore, are based on Lorenz (2015).

** The European Social Survey (ESS) (2012, round 6) relies on the question: 'Generally speaking, would you say that most people can be trusted or that you can't be too careful in dealing with people?' to measure interpersonal trust. It uses an 11-point scale, where 0 means you can't be too careful and 10 means that most people can be trusted. The applied indicator resulting from this question is the percentage of people who answer within the 5 to 10 range.

The patterns of institutional settings are identified by means of a clustering analysis. This method is appropriate because it allows for the grouping of the sample countries based on the similarities in their institutional configurations, at least in relation to those aspects included in the identification of the institutional setting. The basic assumption is that the specific elements are not independent. To find stable solutions, both a hierarchical clustering method (Ward's method and Squared Euclidean distance) and a k-means clustering analysis[6] are applied to the selected indicators of countries' institutional settings in order to group the countries into relatively homogenous institutional profiles.[7] The hierarchical clustering method and the k-means clustering resulted in the same groupings of countries.

3.2. Identification of innovation modes

The innovation modes are identified by applying a combination of principal component and cluster analysis to the innovation survey data for the period 2010–2012. The analysis is carried out on micro-aggregated data obtained from the Community Innovation Survey provided by Eurostat. Micro-aggregation is a procedure used by Eurostat to protect the statistical confidentiality of the data by averaging the data for three similar firms. A study by Mairesse and Mohen (2001), which examines the robustness of the micro-aggregation procedure used by Eurostat, shows that the results are rather similar when firm-level and micro-aggregated data are used. Perhaps a more fundamental criticism, which should be taken into account when interpreting the findings, concerns the use of innovation survey data for international comparisons when the sampling of respondents differs

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[6] Using indications of the appropriate number of clusters derived from applying Ward's method. In terms of deciding on the number of clusters to retain, we plot the number of clusters on the x-axis against the distance at which the cases (countries) are combined on the y-axis to identify the distinctive break (*elbow*).

[7] The variables used in the clustering analysis are standardised. We also ran the clustering analysis on non-standardised data so as to test whether the results differ solely on the basis of this factor (Aldenderfer et al., 1984). When non-standardised data are used, a variable of a relatively large size and standard deviation in our data set (*Trust in others*) swamps the effects of the other variables in terms of the estimation of the cluster solutions. In relation to the selected labour market policy (LMP) indicators, we ran the clustering analysis including the original data and, alternatively, the factor scores calculated based on the original data with the help of a principal component analysis (PCA). An inspection of the results reveals that the solution is robust to data transformation.

across countries and the questionnaires differ in terms of their content, the order of the questions and their formulation (Mairesse & Mohen, 2010). Although the national community innovation surveys take as their point of departure a standardised questionnaire, there are differences across the countries with regards to the ways the questionnaires are structured and the questions are phrased. Countries that deviate too much from the standardised Community Innovation Survey questionnaire, for example, by completely rephrasing or leaving out key questions, changing or leaving out answer categories, or applying different kinds of filters, have been omitted from the current analysis. However, as illustrated in Table 2, the surveys' coverage does differ across the included countries.

In the analysis, firms are classified into four broad sectors, namely 'Low-tech manufacturing & Mining and quarrying', 'Other manufacturing', 'Knowledge intensive services' and 'Other services & Utilities'. Agriculture and fishing, construction, and selected service and semi-public sectors are not included in the analysis due to missing data for some countries.[8] The analysis operates with three size categories – fewer than 50 employees, 50–249 employees, and 250+ employees – for all the countries except Estonia, for which only two size categories (fewer than 50 employees and 50+ employees) are available.

The present analysis is conducted on data weighted by Eurostat/the national statistical offices according to the firm size and industry affiliation. In the case of Estonia, for which the available weights have a value of zero for all the observations, we have replaced the zeros with ones. The reason for this is that reporting all zeros rather than missing information on the unit weights might indicate a sample design with equal selection probabilities. However, it could also mean that the missing weights have been replaced with zeros as part of a basic clearing of the data set by Eurostat/the national statistical office. Due to the differences in the sizes of the populations and samples for the included countries, we adjusted the weights of each of the observations by applying the population and sample size scaled weight, as recommended for a cross-country analysis (Kaminska

[8] The NACE codes for the included sectors are as follows: 'Low-tech manufacturing & Mining and quarrying' (NACE 5-9, 10-18, 31-32), 'Other manufacturing' (NACE 19-30, 33), 'Knowledge intensive services' (NACE 58-66, 69-75), 'Other services & Utilities' (NACE 35-39, 45-47, 49-51 and 52-53), agriculture and fishing (NACE 1-3), construction' (NACE 41-43) and selected service and semi-public sectors (NACE 74, 82).

& Lynn, 2016). In practice, this means that we adjusted the relative contributions of units from the countries in proportion to the size of the population and sample in a given country. Table 2 provides an overview of the included innovation survey data sets for the six countries.

Table 2: Overview of the included innovation survey data sets

	Number of observations (unweighted)*	Survey type	Surveyed industries (NACE rev. 2)	Overall sample rate	Observations omitted as outliers**	% omitted outlier observations
Bulgaria	2,076	Mandatory, census	5–75		366	17.63%
Estonia	694	Mandatory, combination sample/census	5–75	64,4	134	19.31%
Lithuania	583	Mandatory, sample	5–75	24,8	119	20.41%
Hungary	1,090	Mandatory, combination sample/census	5–75	39,8	303	27.8%
Portugal	3,198	Mandatory, combination sample/census	5–75	41	619	19.35%
Norway	1,304	Mandatory, combination sample/census	1–3, 5–75, 82	47	242	18.56%

Source: European Commission, Eurostat, Community Innovation Survey 2012, Short Synthesis of the Quality Reports.
* Only innovative firms (in terms of goods and services innovation, process innovation, abandoned innovation activities and ongoing innovation activities) are included in the analysis. Firms with organisational and/or marketing innovation are not included, as such firms are not asked questions on their activities and sources.
** Outliers are omitted from the cluster analyses – the procedure for doing so is described below.

The procedure for identifying the modes of innovation largely follows the procedures applied in previous studies (e.g. Leiponen & Drejer, 2007; Srholec & Verspagen, 2008). The innovation modes are identified through information concerning internal and external R&D activity, training for innovation activities as well as sources of innovation.[9] The information on the sources of innovation are based on the firms' assessment of the importance of the following sources: sources within the enterprise; suppliers of equipment etc.; clients or customers; competitors; consultants etc.; universities; government, public or private research institutes, conferences etc.; journals etc. and professional organizations.[10] The variables used in identifying modes of innovation are described in detail in appendix Table A1.

The innovation modes for the pooled data set for all the included countries are identified through a two-step analysis. The first step is an exploratory factor analysis, which applies the principal component method to a polychoric correlation input matrix. Polychoric correlations are used because several of the variables are categorical with narrow scales.

As a second step, the factor scores derived from the principal component analyses are used as the input for k-means clustering analyses. Outliers are excluded from the cluster analyses via a procedure in which an initial cluster analysis is run with a large number of clusters, thereby checking for clusters with only one or a very few members. Such outliers are present in all the country data sets. To avoid outliers distorting the clusters, an outlier observation is prevented from being assigned to a cluster if its distance to the nearest cluster seed exceeds a pre-set numeric value.[11] The sensitivity of the results is checked by testing different values in relation to excluding outliers.

As there is no clear-cut test statistic for clustering results, clustering analyses rely heavily on the judgement of the researchers conducting the

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[9] Regrettably, information concerning the objectives of innovation, the effects of innovation and the methods of protection had to be omitted from the analysis due to missing variables for some countries. Consequently, the identified innovation modes do not cover all the aspects of firms' innovative behaviour.

[10] The information on the sources is based on the following question: 'During the three years 2010 to 2012, how important to your enterprise's innovation activities were each of the following information sources*? Include information sources that provided information for new innovation projects or contributed to the completion of existing projects*.'

[11] This value is based on information concerning the maximum distance between any observation in the cluster and the cluster seed, as well as the distance between a current cluster mean and the nearest other cluster mean. See SAS Institute Inc. (1999) for a detailed description of the applied procedure.

analyses (Ketchen & Shook, 1996). In the present analysis, optimising the value of the cubic clustering criterion (CCC) is prioritised while at the same time minimising the number of observations not assigned to a cluster because they are characterised as outliers. Additionally, hierarchical clustering analyses (Ward's method) are also run on the data in order to obtain indications of the appropriate number of clusters since the hierarchical Ward method, as opposed to k-means clustering, does not rely on the number of clusters being specified a priori.

In the analysis, solutions with CCC values below two are deemed to be unacceptable. All the acceptable solutions according to the above criteria are tested in order to identify the most stable clusters. However, in the case of Hungary, the solutions are not very stable in the sense that the dominant cluster changes according to the specification, while this is not the case for the other countries. Furthermore, we seek to disregard solutions where more than 25 percent of the observations from a single country are not assigned to any cluster. Again, in the case of Hungary, the proportion of omitted observations exceeds this limit by 2.8 percentage points. Accordingly, the results concerning Hungary should be interpreted with caution.

3.3. Relating institutional settings to modes of innovation

The analysis of the relation between institutional settings and modes of innovation is carried out in a two-step process. First, the identified patterns of institutional settings are used to formulate assumptions regarding dominant or weakly represented innovation modes in each country. Second, those assumptions are confronted with the identified modes of innovation. To carry out the analysis, a data set that is comprehensive in terms of its country coverage and the relevant aspects of both innovation modes and institutional settings is required. Due to the limited number of countries included in the analysis, the findings concerning whether or not relations between institutional settings and modes of innovation can be detected will be of only an indicative nature.

3.3.1. The implications of data requirements for country selection

Even though Community Innovation Survey (CIS) 2012 micro-aggregated data sets are available for 14 countries,[12] the relatively small sizes of the national samples of innovative firms for some countries, the incomplete or lack of available data on certain relevant aspects of innovation modes, and/or the institutional set-up left us with a data set covering only seven European countries, namely Bulgaria, Estonia, Hungary, Lithuania, Norway, Portugal and Spain. Table A2 in the Appendix presents a detailed overview of the data availability for all 14 countries.

Furthermore, Spain was excluded from the analysis so as to avoid the inclusion of one large country, in terms of population size, in the data set, which otherwise comprises only small countries. There are two main reasons for this. First, larger countries are, in general, associated with more heterogeneity in terms of the cultures, languages and preferences of the population than smaller countries (Alesina, 2003). Tabellini (2010) shows, based on the broader measure of culture (including cultural traits such as trust in others) obtained from the two waves of the World Value Surveys (1990–1991 and 1995–1997), that there is considerable heterogeneity in terms of cultural traits across the regions in countries such as Spain and Italy. However, the relationship between the size and the heterogeneity of the population is not perfect. For instance, some small countries are associated with a high population diversity, for example, Belgium (Alesina, 2003). Second, it is reasonable to assume that regional differences with regards to the labour market organisation tend to be more prominent in larger, more heterogeneous and more decentralised countries. One implication of more heterogeneity across the regions within a country, which is related to both trust and labour market organisation, is that the national averages are likely to be imperfect measures of national characteristics. If that is the case, then the regions within the country represent a more appropriate geographical unit for analysing the proposed relationship between institutional settings and modes of innovation. Unfortunately, due to the limits of the data set, we cannot empirically test whether the character of the institutional setting, as defined in this paper, and relatedly the modes of innovation, differ significantly at the sub-national regional level. Hence, the analysis is confined to six small European

[12] The fourteen countries are Bulgaria, Cyprus, the Czech Republic, Germany, Estonia, Spain, Croatia, Hungary, Lithuania, Norway, Portugal, Romania, Slovenia and Slovakia.

countries for which comprehensive data regarding both the modes of innovation and institutional settings are available and for which the regional variations are expected to be less prominent.

4. Empirical analysis

4.1. Background

As described above, six European countries, namely Bulgaria, Estonia, Hungary, Lithuania, Norway and Portugal, form the empirical basis of the present paper. Table 3 presents an overview of the countries' main characteristics.

Table 3: General country characteristics, 2012

	Population	Land area, sq. km	EU affiliation	GDP per capita, US$ (PPP value in parenthesis)	Annual growth in GDP per. capita, 2011–2012
Bulgaria	7,305,888	108,560	EU member since 2007	7,378 (16,208)	0.6
Estonia	1,322,696	42,930	EU member since 2004	17,422 (26,804)	4.7
Hungary	9,920,362	90,530	EU member since 2004	12,834 (22,998)	-1.1
Lithuania	2,987,773	62,674	EU member since 2004	14,341 (24,568)	5.2
Norway	5,018,573	365,245	Part of the Economic Area Agreement since 1994 (single market)	101,564 (65,380)	1.4
Portugal	10,514,844	91,590	EU member since 1986	20,577 (26,454)	-3.6

Source: World Bank Databank (except for information on EU affiliation, which is based on European Union member data)

The following section provides an overview of the general country characteristics and the features related to innovation performances, as such factors are also likely to be associated with innovation behaviour. Yet, these factors are more likely to influence the amount of resources allocated to innovation activities by firms than the kinds of efforts and the ways in which firms organise their innovation activity in a given country. As the innovation modes are analysed using data referring to the period 2010–2012, the information displayed in Table 3 refers to 2012.

The six included countries are all small European countries. All except for Norway are members of the EU, which they joined at different times: Portugal in 1986, Estonia, Hungary and Lithuania in 2004, and Bulgaria in 2007. Norway has been part of the European Economic Area Agreement since 1994, which includes participation in the European single market.

There are significant differences among the countries in terms of their economic wealth, with Norway being by far the richest country, as measured by the gross domestic product (GDP) per capita. Portugal’s GDP per capita is the second highest, although it is still considerably lower than Norway’s. Estonia’s GDP per capita is slightly lower than Portugal’s, followed by Lithuania and Hungary. Bulgaria's GDP per capita is much lower than all other countries' included in the analysis. Although the level of GDP growth per capita also varies across the countries, there is no clear relation between the level and annual growth rate of the GDP per capita.

As illustrated in Table 4, the structure of economic activity also differs considerably among the six included countries. Norway is relatively less specialised in manufacturing and more specialised in services, including knowledge-intensive services, when compared to the EU average. In terms of specialisation in manufacturing, Lithuania is close to the EU average, while the remaining four countries are above the average. Hungary has the strongest manufacturing specialisation of the six countries, although, together with Norway, it distinguishes itself with a relatively significant orientation towards high and medium-high tech manufacturing.

Table 4: Structure of the economy: Composition of employment, average 2011–2015 (%), and relative turnover by firm size, average 2011–2014 (%)

	Agriculture & Mining	**Manufacturing**	***of which High and Medium-High Tech***	**Utilities and construction**	**Services**	***of which Knowledge-Intensive Services***	**Public administration**	**Micro enterprises (0-9 employees)**	**SMEs (10-249 employees)**	**Large enterprises (250+ employees)**
Bulgaria	7.6	19.9	*18.6*	9.8	55	*45.1*	7.7	21.4	47.1	31.6
Estonia	4.9	18.9	*21*	11.3	58.1	*53.3*	6.8	30.3	47.1	22.6
Hungary	5.1	21.1	*41.2*	8.8	55.9	*53.2*	8.9	20.4	36.6	43.4
Lithuania	9	15.4	*12.1*	9.4	60.2	*50*	6	17	48.2	34.7
Norway	4.8	9	*33.2*	8.8	71.4	*67*	6.1	24.3	35.5	39.3
Portugal	8.6	16.7	*17.3*	8.2	59.8	*53.7*	6.8	24.1	48.1	30.7
EU average	5.1	15.6	*36.4*	8.6	63.6	*58*	7.1	17.3	38	44.1

Source: European Commission, European Innovation Scoreboard 2017.

In terms of firm size, all the included countries have a lower representation of large enterprises than the EU average. Hungary, however, is quite close to the EU average in terms of large enterprises, albeit with an overrepresentation of micro-enterprises.

As illustrated in Table 5, the countries also differ in terms of the features, which are related to the innovation performance and, to some extent, may be associated with the institutional setup, such as R&D and other innovation expenditure and the populations' education levels.

Table 5: Features related to innovation performance, 2012

	Tertiary educational attainment, age group 30–34, %*	R&D expenditure in the public sector, % of GDP**	R&D expenditure in the business sector, % of GDP**	Non-R&D innovation expenditure, relative to the EU average***
Bulgaria	26.9	0.23	0.37	0.50
Estonia	39.5	0.88	1.22	1.83
Lithuania	48.6	0.66	0.24	2.26
Hungary	29.8	0.41	0.83	0.71
Portugal	27.8	0.68	0.68	0.94
Norway	47.6	0.78	0.85	0.24
EU-28	36.0	0.72	1.28	1.00

Sources: * Eurostat (European Union Labour Force Survey). ** Eurostat, Research and development expenditure, by sectors of performance. *** European Union, Innovation Union Scoreboard 2014.

According to the analysis conducted by Ahlborn et al. (2014), the six included countries also show differences with respect to their membership in clusters of economic systems based on the modified VoC approach. Ahlborn et al. (2014) find that Bulgaria, Estonia, Lithuania and Hungary belong to a separate cluster of Central and Eastern European Countries (CEECs), which are characterised as economies in transition. Within the CEECs cluster, Bulgaria, Estonia and Lithuania are distinguished as liberal market economies (CEEC LMEs), whereas Hungary is characterised as a coordinated market economy (CEEC CME) type of capitalism. Norway and Portugal are characterised as belonging to a 'traditional' Western coordinated market economies (CME) type of capitalism. Within the traditional CME cluster, Norway shares the characteristics of the variety labelled Nordic CME, whereas Portugal shares the characteristics of the mixed market economies (MMEs), which mainly comprise Southern European countries. Ahlborn et al.'s (2014) study emphasises the importance of the development component with respect to the innovation variable,[13] which seems to separate the CEEC clusters of countries in

[13] The innovation variable used by Ahlborn et al. (2014) is the World Bank Knowledge Assessment Methodology (KAM) measure of innovation, which is constructed as a simple average of the normalised values of the three variables included in the basic scorecard. The three variables are: researchers in R&D per million of the population, patent applications granted by the United States Patent

transition from the 'traditional' OECD groups of countries. For example, both the CEEC CME and CEEC LME groups are, on average, associated with a rather low innovation capacity when compared to the 'traditional' CMEs and LMEs, although they show large similarities in terms of various other institutional features. However, a low innovation capacity is also characteristic of the 'traditional' MME group (e.g. Portugal), which represents a separate institutional configuration (Ahlborn et al., 2014). Table A6 in the Appendix presents an overview of the countries' memberships of different groups over time, as based on Ahlborn et al. (2014).

Ahlborn et al.'s (2014) clustering of countries is based on macro indicators perceived to relate to both policy (the overall size of government, transfer spending, sectoral regulation in trade, labour and capital markets) and performance (income equality, innovation capacity, fiscal debt). Accordingly, the only overlap with the indicators used in the present analysis to cluster the countries according to the institutional setting relates to the functioning of the labour market system. The following section will illustrate the extent to which these differences lead to differences in the country groupings.

4.2. Institutional settings

The cluster analysis divides the countries into four groups of institutional settings. Table 6 presents an overview of the patterns of institutional settings using colour coding to express the values of the countries' indicators relative to the lower and upper cut-off points, which are determined by the distance to the observed minimum and maximum values (see note below Table 6).

and Trademark Office (USPTO) per million of the population, and scientific and technical journal articles per million of the population.

Table 6: Overview of the institutional settings by country and cluster

		Cluster 1	Cluster 2	Cluster 3			Cluster 4
	Colour coding: *Dark blue: above high cut-off** *Medium blue: within high and low cut-off* *Light blue: below low cut-off ***	Norway	Estonia	Hungary	Lithuania	Portugal	Bulgaria
Intellectual property rights	IP protection rating	5.6	4.6	4	3.5	4.4	2.6
	Legal and political environment	8.5	7.1	6.1	5.8	6.8	5
	Integrity of the legal system	10	6.67	6.67	6.67	8.33	4.17
Labour market system (LMS)	Expenditure per unemployed person	47.451	2025.52	2268.84	696.21	6437.98	599.24
	Passive LMP supports	43.2	79	53.9	61	66.7	77.2
	Active LMP measures	45.5	13.1	39.4	28.7	27.8	16.1
	Training	18.2	11	3	4.4	5.7	1.6
	Labour market	3.8	4.5	2.5	2.4	2.9	2.9
Trust	Corruption perception index	8.6	6.5	4.7	5	6	3.6
	Trust in others	90	72.4	58.8	63.7	37.3	33.5

Note: The high cut-off point is calculated as the minimum value of the indicator + 2x ((maximum value of indicator – minimum value of indicator)/3).
The low cut-off point is calculated as the minimum value of the indicator + ((maximum value of indicator – minimum value of indicator)/3).

The **first cluster includes only Norway**. The country has high scores for all the dimensions of the institutional setting included within the analysis. In particular, Norway distinguishes itself from the other included countries in terms of its labour market system characteristics. The overall expenditure on labour market policies per employed person is considerably higher than for any of the other countries, while the percentage of expenditure on active labour market policies is also very high, with only Hungary having anywhere near a similar percentage.

Norway's strong IPR regime is assumed to be conducive to R&D-based innovation because of the high scores concerning the integrity of the legal system, the legal and political environment and the IPR protection rating.

Furthermore, the high levels of trust, as reflected in a low perception of corruption and a high share of the population expressing trust in others, may encourage innovation drawing on several types of external sources. This is further supported by the high degree of flexible security within the labour market, which may be conducive to both innovation drawing on external firms as well as employee training for innovation activities.

In sum, the institutional settings of Norway (Cluster 1) may be associated with **a combination of R&D-based innovation, employee training for innovation activities and an approach to innovation that draws on several types of external sources**.

The **second cluster** is also a one-country cluster, encompassing only **Estonia**. Considering IP rights, Estonia's scores within the intermediate range are interpreted as being 'neutral' in relation to R&D-based innovation. The scores for the five indicators concerning the labour market system are rather mixed. Estonia places the highest emphasis on passive labour market supports. It also shows a high level of labour market mobility, as well as an intermediate degree of access to life-long learning. However, the total LMS expenditure per unemployed person is rather low in Estonia. Based on this, we would expect an innovation approach oriented towards external sources and employee training for innovation to be more prevalent in Estonia than in the two remaining clusters (3 and 4), albeit in a less dominant innovation mode when compared to Norway in Cluster 1. Finally, the scores concerning informal institutions are also mixed. Estonia scores high in terms of the indicator of interpersonal trust, which is assumed to be conducive to innovation drawing on several types of external sources, and medium in relation to the corruption perception.

In sum, the institutional setting of Estonia (Cluster 2) does **not** point strongly in the direction of a dominate **R&D-based** mode of innovation, although it may be moderately favourable to **employee training for innovation and an innovation approach that draws on several types of external sources,** albeit to a lesser extent than in the case of Norway (Cluster 1).

Cluster 3 includes **Hungary, Lithuania and Portugal**. In terms of the IPR regime, the scores are mixed for the three countries, with Portugal actually having a relatively stronger IPR regime, especially when it comes to the integrity of the legal system. Hungary and Lithuania, on the other hand, score relatively low with regards to the legal and political environment, although they have similar scores to Portugal in relation to IP protection rating, being in the intermediate range. As a whole, the cluster is assessed as having an institutional setting concerning IPR that is similar to that of Cluster 2 (i.e. being ‘neutral’ in relation to R&D-based innovation). In relation to the labour market system indicators, Lithuania and Portugal are in the intermediate range with regards to both active measures and passive protection, and they have a similar balance between the two. Yet, Hungary stands out due to the higher emphasis on the active aspect of policy support. In terms of the overall expenditure on labour market policies per unemployed person, the level of labour mobility and the access to life-long learning, all the countries in the cluster are in the low range. Combined with the low to intermediate scores concerning interpersonal trust and the corruption perception index, the institutional setting is average to weak in all three countries in terms of encouraging the use of external sources and employee training as sources of innovation.

In sum, when compared to Estonia in Cluster 2, the institutional settings of Hungary, Lithuania and Portugal (Cluster 3) appear to be similar in terms of being **neutral in relation to R&D-based innovation** and **less conducive to drawing on external sources and employee training for innovation**.

The final cluster, **Cluster 4**, consists of only one country, namely **Bulgaria**. With the exception of a relatively higher emphasis on passive protection, Bulgaria scores below the lower cut-off point for all the indicators. Therefore, the institutional setting of Bulgaria can be perceived as **discouraging the R&D-based, external-source-based and training-based modes of innovation**.

With the exception of Norway being in a cluster of its own, the above-described groupings of countries exhibit little overlap with Ahlborn et al.’s (2014) clustering according to VoC characteristics. Different groups of countries based on the institutional aspects, as defined in this paper, cut across the split between the CEECs models as well as between the CEEC and MME types of capitalism. For instance, one of the identified clusters brings together Hungary (CEEC CME), Lithuania (CEEC LME) and Portugal (MME). The labour market system features, as proposed in the NIS literature (Lorenz, 2015), seem to be a prominent characteristic that differentiates these clusters of countries. Thus, if the perspective of the VoC approach is widened to include additional countries and additional aspects of the institutional framework, the classification of countries could provide a more complex picture.

4.3. Modes of innovation and their relation to the institutional setting

This section presents the identified modes of innovation and then discusses their frequency of occurrence in the different countries in relation to the identified institutional settings. Table 7 presents an overview of the identified modes of innovation for all the considered countries through the combined factor analysis and the clustering procedure. A solution featuring six clusters – representing six different modes of innovation – was found to be the most appropriate, as based on the criteria discussed in section 3.2. The exploratory factor analysis and k-means clusters solution across all the countries are shown in Appendix Tables A3 and A4. The innovation modes are described in terms of the size (number of firms assigned to each cluster, which represents an innovation mode), the industry characteristics (whether certain industry groups are more dominant in each cluster when compared to the average), the original variables used in the factor analysis, as well as the additional variables expressing the types of innovation outputs (frequencies of the categorical variables for each cluster).

Two of the identified modes of innovation (Modes 1 and 2) are rather similar in terms of their use of internal and external R&D activities and employee training for innovation, although the first mode is more narrowly focused in terms of external sources. Hence, we label Mode 1 'R&D-based and narrow market sources' and Mode 2 'R&D-based and wide sources'.

Mode 3 mainly draws on suppliers and customers as sources. Mode 4 focuses on a wide set of different types of external sources, also assigning high importance to competitors, professional organisations and, in particular, conferences. We label Mode 3 'Internal and narrow market sources', while we label Mode 4 'Internal, market and professional sources'.

The final two modes of innovation are quite distinct in terms of their features. Mode 5, which we label 'Wide sources of information', is characterised by a strong orientation towards all the considered sources of information (i.e. market, science-based and professional sources). Unlike Modes 1 and 2, R&D activities are less frequently used in Mode 5, although they are still practiced more than in the other three modes. Finally, Mode 6 encompasses firms that neither assign much importance to any of the external sources of information nor rely on R&D and employee training for their innovation activities. Accordingly, we label this mode ‘Low profile’.

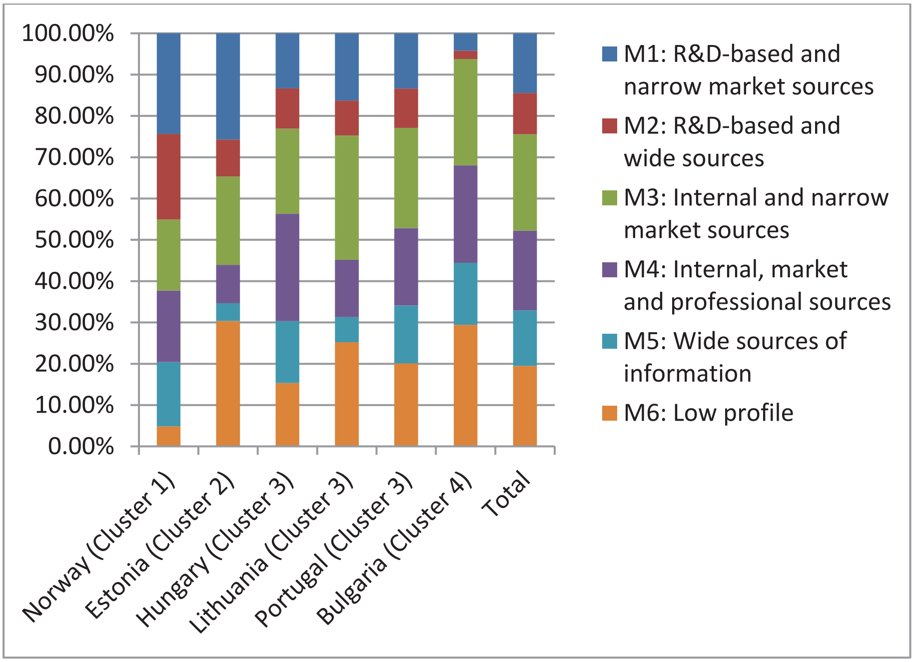
Table 7: Characterisation of the innovation modes across all the countries (Bulgaria, Estonia, Hungary, Lithuania, Norway and Portugal)

	All countries						
	Total incl. non-assigned (8945)	Mode 1 R&D-based and narrow market sources	Mode 2 R&D-based and wide sources	Mode 3 Internal and narrow market sources	Mode 4 Internal, market and professional sources	Mode 5 Wide sources of information	Mode 6 Low profile
# obs., unweighted/weighted		1169/1770	859/1223	1555/2854	1322/2360	959/1643	1298/2383
Overrepresented industry		Other man. and KIBS	Other man. and KIBS	Low-tech and other man.	Low-tech. man.; other services	Low-tech and KIBS	Low-tech. man.; other services
Internal R&D	40.24	**86.10**	**94.01**	29.74	13.86	35.51	13.55
Training for innovation	52.19	**79.28**	**81.63**	50.07	41.96	43.89	33.03
External R&D	22.87	**61.90**	**79.26**	4.13	2.20	13.82	4.61
Sources within enterprise	79.80	**98.99**	**98.41**	**97.06**	**87.74**	**90.24**	40.91
Suppliers of equipment etc.	69.37	**71.28**	**84.08**	**81.81**	**88.60**	**85.11**	33.64
Clients or customers	67.11	**79.76**	**89.54**	**75.97**	**87.25**	**86.42**	23.39
Competitors	49.06	46.87	**70.94**	39.45	**75.98**	**75.99**	11.65
Consultants etc.	30.95	28.27	**72.17**	9.51	28.59	**71.54**	6.99
Universities	22.80	20.87	**80.23**	1.22	6.66	**63.72**	1.48
Government, public and private research institutes	17.72	8.12	**66.36**	0.96	3.48	55.22	1.29
Conferences etc.	47.40	47.65	**84.55**	22.48	**67.45**	**86.98**	13.91
Journals etc.	39.45	32.16	**76.96**	18.21	52.50	**79.85**	9.16
Professional organisations	33.30	18.54	**61.52**	9.68	47.02	**75.54**	7.44
Additional variables							
Process	72.80	**73.31**	**75.58**	**71.71**	**73.94**	**70.89**	**68.11**
Goods	52.62	**63.44**	**68.89**	51.83	49.53	53.43	44.34
Services	35.30	42.07	45.83	35.23	30.96	37.91	30.46

Note: Percentage of firms within each cluster with a score of 2 (=important) or 3 (=very important) or, for the binary variables, a score of 1 (=yes). Percentages larger than 60% are marked in bold.

Figure 1 presents the distribution of the identified innovation modes across the investigated countries.

Figure 1: Distribution of innovation modes by country and cluster



Note: Observations are weighted. See Table A5 in the Appendix.

Based on the analysis of the institutional settings presented in section 4.2., the expectations regarding **Norway** (Cluster 1) are that innovation modes characterised by a combination of R&D, employee training and open innovation will dominate. Despite Norway being relatively specialised in knowledge-intensive services, the two dominant innovation modes identified in the country are both characterised by R&D-based innovation and employee training for innovation (**Modes 1 and 2**), thereby supporting the finding of recent studies that R&D is not associated with only manufacturing innovation (e.g. Leiponen, 2012). The two dominant innovation modes are of a relatively similar size. Both innovation modes are also oriented towards external sources, although the drawing on multiple sources is more prominent in the one, while firms in the other tend to focus mainly on clients/customers as external partners. Yet, both modes are equally focused on both product and process innovation. Overall, the dominant innovation modes identified in Norway are largely in accordance with the expectations derived from the analyses of the institutional settings.

Turning next to **Estonia** (Cluster 2), the institutional setting was assessed as being moderately favourable to employee training for innovation and drawing on external sources for innovation. However, the mode of innovation identified as being the most dominant in Estonia is the 'Low profile' mode (**Mode 6**), followed by the 'R&D-based and narrow market sources' mode (**Mode 1**). However, the third most prevalent mode of innovation (Mode 3, 'Internal and narrow market sources') differs only slightly from Mode 1 in terms of its frequency of occurrence. Finally, despite the relatively high degree of flexible security and the relatively high levels of trust seen in the case of Estonia, all the modes of innovation associated with drawing on various types of external sources are less frequently resented than in all the other country(ies) groups. Thus, Estonia seems to be the most complex example in terms of the extent to which the institutional setting is reflected in the dominant modes of innovation.

When compared to Estonia, the institutional settings of **Portugal, Hungary and Lithuania** (Cluster 3) appear to be less conducive to employee training for innovation and drawing on external sources for innovation. The two dominant innovation modes in Hungary are oriented towards external sources (**Modes 3 and 4**), whereas this is only the case for one of the two dominant innovation modes in Lithuania and Portugal (**Mode 3**), although in Lithuania in particular, Mode 3 plays a dominant role. In both Portugal and Lithuania, the second most prevalent mode of innovation is the 'Low profile' mode (**Mode 6**), whereas Hungary has a relatively lower frequency of firms assigned to this mode of innovation. However, the representation of the other modes of innovation is rather similar for all three countries. The exception here is the relatively low share of firms assigned to the mode of innovation associated with a focus on wide sources of knowledge (**Mode 5**) in the case of Lithuania. In conclusion, the findings concerning Portugal, Lithuania and Hungary are mixed in terms of their degree of accordance with expectations, with no clear indication of less external orientation than in Cluster 2.

Finally, in the case of Bulgaria, the institutional setting is interpreted as being discouraging for all the modes of innovation. The 27.4 percent frequency of innovation is in line with this assertion. The two most dominant modes of innovation in Bulgaria in terms of the frequency of firms assigned to them are the same as in Portugal and Lithuania (**Modes 3 and 6**): one is characterised by a focus on internal and narrow market sources, whereas the other is characterised by low scores for all the identified dimensions, being labelled as 'Low profile'. Yet, in terms of the balance between the two modes, the largest share of firms is assigned to the 'Low profile' mode of innovation, and Bulgaria is second to only Estonia in terms of frequency of the 'Low profile' mode (and only very marginally so). In addition, the two modes of innovation characterised by R&D-based innovation, employee training for innovation and drawing on a more or less wide set of external sources (**Modes 1 and 2**) are the least well represented in Bulgaria, accounting for only just above 6 percent of all innovative firms in total. Hence, the findings for Bulgaria are largely in accordance with expectations.

5. Concluding discussion

The present paper has explored how, and to what extent, national institutional settings are reflected in firms' modes of innovation. The empirical approach has been of an explorative nature, as there exist no well-tested methods for analysing such relations across several countries.

We do find certain indications of national institutional settings being reflected in firm-specific innovation modes. The most convincing results are found for the most 'extreme' countries included in the analysis. At one end of the spectrum, we find Norway, for which the identified innovation modes are a relatively good reflection of the institutional settings, particularly in terms of the dominance of R&D-based innovation and employee training for innovation, as well as the orientation towards clients and customers and broader collaboration as sources of innovation. At the other end of the spectrum, we find Bulgaria, for which the low overall frequency of innovation and the tendency for 'simple' or ad hoc modes of innovation to dominate are in accordance with an institutional setting that is generally unfavourable to all types of innovation.

For the four remaining countries, the findings are more mixed. The most complex case is Estonia, which shares several institutional features with Norway and, at the same time, has a labour market policy oriented towards passive support that is similar to that of Bulgaria. This is also reflected in the identified modes of innovation in Estonia, where both the R&D-based and weak modes of innovation dominate. One possible explanation for these mixed findings is the more specific and transient nature of the institutional features of those transition countries that have undergone systemic transformations as a result EU accession and that continue to carry the legacy of previous institutional endowments (Ahlborn et al., 2014; Rapacki & Czerniak, 2019). For example, Park (2008) points out that laws protecting intellectual property were either non-existent or based on different systems in some of the Eastern European countries (e.g. Lithuania) at the time when the index of patent rights was compiled for the period 1960–1990. This stands in contrast to the well-established and stable institutional environments of the 'traditional' OECD group of countries. One implication of the previous discussion is that it becomes more difficult, at least in the case of the transition countries, to establish a reliable association between the institutional setting and the dominant modes of innovation. This is because it is not obvious which aspects of the transformed institutional environment are more established and, therefore, more likely to have had a lasting influence on the behaviour of firms. Then again, the observed prevalent patterns of firms' innovation behaviour and organisation may reflect the institutional features of the previous system, which was rooted far back in history.

The present findings also reflect the existence of a hierarchy – at least to some extent – in terms of the dominance of the most 'advanced' (R&D-based) modes of innovation among countries at different stages of economic development. This view is supported by Ahlborn et al.'s (2014) study within the VoC tradition. This is also true of the level of IPR protection and enforcement, which varies positively with the level of economic development of the included countries. The evidence is hence in line with the notion that the capacity and the incentive of countries with regards to building IPR institutions or enforcing their protection are positively associated with both the market size and the R&D capacity (Park, 2008). Therefore, it is possible that some of the findings of this study concerning the relation between institutional settings and R&D-based modes of innovation are driven by the countries' differences in terms of their stages of development in addition to their institutional characteristics.

The aim of the present analysis has not been to identify the institutional settings associated with the 'best' modes of innovation or to suggest that there is as optimal distribution of innovation modes. Nor do we propose that one mode of innovation is necessarily superior to another. However, the analysis is based on the premise that it is relevant for policy reasons to understand whether particular aspects of the institutional setting are associated with incentivising firms to pursue specific orientations in relation to innovation behaviour. Thus, knowledge concerning the extent to which institutional settings may be associated with particular modes of innovation allows for innovation policies to take into account the institutional barriers as well as the facilitating features when assessing whether – and which – initiatives should be implemented to support particular modes of innovation.

5.1. Limitations and further research

As the present analysis is explorative in nature, the methods and data applied deserve considerable attention. While the two parts of the analysis – the grouping of the countries based on institutional settings and the identification of the modes of innovation of firms – are carried out by applying quantitative methods, the available data do not allow for the quantitative determination of the possible associations between institutional settings and modes of innovation. First, the number of included countries is too low to determine any statistical association between institutional settings and modes of innovation across the country groups, which could also control for other possible explanatory factors. Examples of such factors include the differences between countries in terms of economic wealth, the structure of economic activity, the allocation of public resources for R&D and the populations' education level. Other control factors include technology and sector-specific conditions as well as the different abilities (and characteristics) of firms across countries. Furthermore, it is not possible to account for the complex interaction that occurs between different elements of the institutional setting (e.g. patent rights and the labour market system), where the relative importance might, to a large extent, be dependent on the individual sector and the individual firm.

Second, although the included countries differ considerably in some respects, there may actually be too little variance within the group to identify distinct relations between patterns (cf. the mixed results for the 'intermediate' group of countries within Cluster 3). This, however, seems to be the one of the least demanding challenges for further analyses, as the availability of comparable data for a large group of countries is a more severe obstacle.

The quality of the data is also very likely to have influenced the findings. Although the innovation data should, in principle, be comparable across countries, there are differences in the ways that the Community Innovation Survey is carried out in the individual countries. We have attempted to take some of these differences into account by excluding variables and countries from the analysis that would ideally have been included. Nonetheless, differences remain, not all of which are clearly described in the available documentation. This applies to the procedures for calculating weights and, in one case (Estonia), a complete absence of weights different from zero.

In terms of the institutional setting, relevant data are sparse, and the data that are available are not necessarily very well described with regards to the collection procedures etc. Additional limitations stem from the ranking-oriented nature of some of the indicators used to characterise different aspects of the institutional set-ups of the included countries. The cases in point are the IPR protection indicators, which measure the strength and the quality of the IPR protections rather than the different types of IPR regimes. The key limitation of the IPR protection indicators is the theoretical bias that exists within the assumption that stronger IPR protection is always better for innovation, which is not always supported by empirical evidence, especially when countries at different levels of economic as well as technological development are considered. However, our choice of indicators can be justified on the basis of the harmonised nature of the IP-related regulatory environment across the EU countries, where most of the variation stems from differences in the strength and quality of institutions rather than from the types of institutions.

Accordingly, there is a strong need to develop the quality of the data available for this type of analysis and to do so for a larger number of countries. The findings presented in this paper suggest that much could be gained in terms of policy-relevant knowledge from embarking on such a development process. The quantitative, cross-country studies included in this paper would benefit from being supplemented by in-depth case studies focusing on the possible causal mechanisms that exist between institutional settings and innovation modes.

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Appendix

Table A1: CIS 2012 variables used in the analysis of the innovation modes

Variables		Measurement scale and value range	
Innovative activities for product and process innovations			
	In-house R&D (yes/no)	Binary	1,0
	External R&D (yes/no)	Binary	1,0
	In-house or contracted-out training for personnel for innovation activities (yes/no)	Binary	1,0
Importance of sources of information for product and process innovation			
	Internal source - Within enterprises and other enterprises within the enterprise group	Ordinal	0–3
	Market sources - Suppliers	Ordinal	0–3
	Market sources - Clients and customers	Ordinal	0–3
	Market sources - Competitors and other sources from the same industry	Ordinal	0–3
	Consultants, private laboratories and research institutes	Ordinal	0–3
	Universities and other HEI	Ordinal	0–3
	Government, public or private research institutes	Ordinal	0–3
	Conferences, fairs and exhibitions	Ordinal	0–3
	Scientific journals, professional journals and other professional publications	Ordinal	0–3
	Professional and industry organisations	Ordinal	0–3

The ordinal scale of 0–3 ranges from 0 for “not used” to three “high degree of importance”.

Table A2: Data availability

		Country													
		BG	CY	CZ	DE	EE	ES	HR	HU	LT	NO	PT	RO	SI	SK
Innovation mode(s) indicators (micro-aggregated CIS 2012)															
Innovation activities	Internal R&D (RRDIN)	X	X*	X	m	X	X	X	X	X	X	X	X*	X	X*
	External R&D (contracted out) (RRDEX)	X	X*	X	m	X	X	X	X	X	X	X	X*	X	X*
	Training for innovation activities (RTR)	X	X*	X	m	X	X	X	X	X	X	X	X*	X	X*
General	Employees tertiary degree (EMPUD)	X	X*	X	m	X	X	X	X		X	X	X*	X	X*
Methods of protection		X	x		m	x		x	x	x	x	x	x	x	x
Sources of innovation (importance)	Sources within enterprise (SENTG)	X	X*		m	X	X	X	X	X	X	X	X*	X	X*
	Supplier of equipment etc. (SSUP)	X	X*		m	X	X	X	X	X	X	X	X*	X	X*
	Clients or customers (SCLI)	X	X*		m	X	X	X	X	X	X	X	X*	X	X*
	Competitors (SCOM)	X	X*		m	X	X	X	X	X	X	X	X*	X	X*
	Consultants etc. (SINS)	X	X*		m	X	X	X	X	X	X	X	X*	X	X*
	Universities (SUNI)	X	X*		m	X	X	X	X	X	X	X	X*	X	X*
	Government, public or private research institutes (SGMT)	X	X*		m	X	X	X	X	X	X	X	X*	X	X*
	Conferences etc. (SCON)	X	X*		m	X	X	X	X	X	X	X	X*	X	X*
	Journals etc. (SJOU)	X	X*		m	X	X	X	X	X	X	X	X*	X	X*
	Professional organisations (SPRO)	X	X*		m	X	X	X	X	X	X	X	X*	X	X*
Importance of enterprise objectives	Increase market share (GOMKT)	X	X*		m	X		X	X	X		X	X*	X	X*
	Reduce costs (GOCOS)	X	X*		m	X		X	X	X		X	X*	X	X*
	Increase turnover (GOTURN)	X	X*		m	X		X	X	X		X		X	X*

	Increase profit margins (GOPRF)	X	X*		m	X		X	X	X		X		X	X*
Institutional setting indicators (various sources)															
Intellectual property rights	IP protection rating	X	X	X	X	X	X		X	X	X	X	X	X	X
	Legal and political environment	X	X	X	X	X	X		X	X	X	X	X	X	X
	Integrity of the legal system	X	X	X	X	X	X		X	X	X	X	X	X	X
Labour market system (LMS)	Expenditure per unemployed person	X	X	X	X	X	X		X	X	X	X	X	X	X
	Passive LMP supports	X	X	X	X	X	X		X	X	X	X	X	X	X
	Active LMP measures	X	X	X	X	X	X		X	X	X	X	X	X	X
	Training	X	X	X	X	X	X		X	X	X	X	X	X	X
	Labour market mobility	X	X	X	X	X	X		X	X	X	X	X	X	X
Trust	Corruption perception index	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Trust in others	X	X	X	X	X	X	X	X	X	X	X		X	X

Note: **X:** data available, **X***: data available, but only a very low number of innovative firms in the national data set, **m:** data missing for a large share of innovative firms; **Empty cell:** data not available; **Grey shades:** Countries included in the analysis.

Data from Cyprus (CY), the Czech Republic (CZ), Germany (DE), Spain (ES), Croatia (HR), Romania (RO), Slovenia (SI) and Slovakia (SK) were excluded from the analysis. Observations from the Czech Republic were omitted due to a lack of information on the importance of the sources of information for the innovative firms (national CIS data set). Germany's observations were not included due to a large amount of missing information concerning most of the variables used in the analysis of the modes of innovation (national CIS data set). Croatia lacks data on most of the variables used in the analysis of the institutional setting and, therefore, was omitted. Observations from Cyprus, Romania and Slovakia were excluded due to the very low number of innovative firms in the national CIS data sets. Furthermore, the small data set in the case of Cyprus gave peculiar results when tested in a single country analysis of the modes of innovation, whereas Romania also lacks data concerning trust in others. Finally, the observations from Spain were not included as doing so would mean that we would have only one large country in our data set. With respect to the indicators concerning the modes of innovation (CIS), the variables on the share of employees with a tertiary degree, the methods of protection and the importance of the objectives of innovation were omitted since including them would have implied that two more countries (Norway and Lithuania) needed to be excluded from the analysis. The selected indicators regarding the institutional setting were already narrowed down based on an inspection of a larger pool of indicators and, therefore, were all included in the analysis.

Table A3: Factor analysis on innovation activities across all the countries (Bulgaria, Estonia, Hungary, Lithuania, Norway and Portugal)

	(1) Non-market sources	(2) Internal/market sources	(3) R&D based
Internal R&D	0.21205	0.05213	0.76823
Training for innovation activities	0.04996	0.19638	0.51142
External R&D	0.26790	-0.09337	0.76975
Sources within enterprises	0.01631	0.58003	0.55970
Suppliers as sources	0.18308	0.70828	0.02327
Clients and customers as sources	0.28313	0.72269	0.19360
Competitors as sources	0.46348	0.64009	-0.01730
Consultants etc. as sources	0.73269	0.19551	0.22139
Universities as sources	0.78528	0.04615	0.39791
Government, public or private research institutes as sources	0.81072	0.06566	0.30197
Conferences as sources	0.70169	0.37350	0.09360
Journals etc. as sources	0.71759	0.30728	0.11343
Professional organisations as sources	0.74917	0.28679	-0.02937

Note: Estimations are weighted (sum of the weights is 15,477); the number of observations is 8,945; three factors with eigenvalues > 1 were detected, which explains 62.50% of the total variance; extraction method: principal component; rotation: varimax.

Table A4: Identification of clusters (K-means clusters) across all the countries (Bulgaria, Estonia, Hungary, Lithuania, Norway and Portugal)

Clusters\Factors	(1) Non-market sources	(2) Internal/market sources	(3) R&D based
Cluster 1 (Mode 3)	-1.005398601	**0.527498190**	-0.088441799
Cluster 2 (Mode 5)	**1.226623212**	0.122664041	-0.507677329
Cluster 3 (Mode 1)	-0.330867463	0.161128440	**1.162482879**
Cluster 4 (Mode 2)	**1.095728412**	-0.037343580	**1.220475553**
Cluster 5 (Mode 4)	0.031705272	**0.805090674**	-0.809960658
Cluster 6 (Mode 6)	-0.512927005	-1.075856585	-0.627858823

Note: Averages are weighted (sum of the weights is 15,477); frequency > 5; strict criteria value = 1.23; max cluster = 6; CCC = 2.844. Clusters are reordered and renamed as modes. They are referred to in the text by the names given in parentheses.

Table A5: Distribution of the innovation modes by country

Country \Mode	Mode 1 R&D based and narrow market sources	Mode 2 R&D based and wide sources	Mode 3 Internal and narrow market sources	Mode 4 Internal, market and professional sources	Mode 5 Wide sources of information	Mode 6 Low profile	**Total**
Norway	**24.35%**	**20.71%**	17.24%	17.29%	15.59%	4.84%	1758
Estonia	**25.71%**	8.93%	21.43%	9.29%	4.29%	**30.36%**	560
Hungary	13.32%	9.76%	**20.62%**	**25.99%**	15.00%	15.32%	1547
Lithuania	16.26%	8.44%	**30.14%**	13.89%	6.07%	**25.21%**	972
Portugal	13.39%	9.52%	**24.24%**	18.73%	14.02%	**20.11%**	5685
Bulgaria	4.21%	1.99%	**25.79%**	23.57%	15.03%	**29.42%**	1710

Note: Observations are weighted (sum of the weights is 15,477).

Table A6: Countries' "VoC cluster" membership, 1995–2009, according to Ahlborn et al. (2014)

	2007–2009	**2004–2006**	**2000–2003**	**1995**
Bulgaria	CEEC LME	CEEC LME	CEEC LME	MME
Estonia	CEEC LME	CEEC LME	Baltics/ESP/PT	CEEC LME
Lithuania	CEEC LME	CEEC LME	Baltics/ESP/PT	CEEC LME
Hungary	CEEC CME	Conti/CEEC	Nordic	Conti/Nordic
Portugal	MME	MME	Baltics/ESP/PT	MME
Norway	Nordic	Conti/CEEC	Nordic	Conti/Nordic

CEEC LME: Central and Eastern European countries' type of liberal market economy capitalism; **CEEC CME**: Central and Eastern European countries' type of coordinated market economy capitalism; **MME**: Mixed market economies; **Baltics/ESP/PT**: Baltic countries, Spain and Portugal group; **Nordic**: Nordic countries' type of capitalism; **Conti:** Continental European countries' type of coordinated market economy (CEM) capitalism.
Source: Adapted from Ahlborn et al. (2014)

CHAPTER 5

V Continuity and Changes in Modes of Innovation

Marija Rakas (rakas@business.aau.dk)

Department of Business and Management

Aalborg University, Denmark

Abstract

This paper aims at providing new evidence on the dynamics of firms' innovation modes. While previous taxonomic studies at firm level have contributed to a better understanding of the variety and the interdependencies of the various dimensions of the learning or innovation modes or strategies of firms at a specific point in time, the dynamic aspect of the modes of innovation based on the Community Innovation Survey (CIS) firm-level data remains largely unexplored. The empirical analysis is based on the pooled firm-level data from both the Business Register and the Danish section of the European CIS, covering five rounds of survey from 2002-2015. To this end, I first identify distinct dimensions of firms' innovation modes (e.g., R&D, source of information, and objectives), and then group firms based on their scores on these dimensions following a common empirical approach based on a principal component and cluster analysis. In the case of Denmark, the four distinct modes of innovation in firms were identified. By considering changes in successive cross-sectional waves of the surveys, and in terms of the mode switches of specific firms through time, I show that there has not been a systematic movement towards the use of a mixed or any specific mode of innovation over time. I then formally test for the differences in the probability of change and upgrade across innovation modes. The results of the analysis show that different innovation modes are associated with different propensities to change and upgrade.

1. Introduction

The issue addressed in this paper is the dynamics of innovation modes or strategies applied by firms. I examine two aspects of this issue. First, I look for whether there is any evidence of the systemic changes in modes of innovation over time. Second, I enquire whether different modes of innovation are associated with a difference in propensity to persist or to change. The phenomena of persistence in this paper refer to the firms sticking to the same mode of innovation in the subsequent time period. The aim is to explore the differences across innovation modes followed by firms in terms of the likelihood of changing to a different mode. The phenomenon of upgrading is a sub-category of change, and it refers to movement in the direction of more systemic engagement in innovation. This analysis builds on and extends the empirical literature based on the firm-level data that focuses on heterogeneity in firms' approaches to innovation, generally referred to as modes of innovation (Arundel & Hollanders, 2005; T. H. Clausen, Korneliussen, & Madsen, 2013; De Jong & Marsili, 2006; Evangelista & Vezzani, 2010; Hollenstein, 2003; Leiponen & Drejer, 2007; Peneder, 2003; Srholec, Verspagen, Srholec, & Verspagen, 2008; Tether & Tajar, 2008); or modes of learning (Apanasovich, Alcalde Heras, & Parrilli, 2016; Corrocher, Cusmano, & Morrison, 2009; Fitjar & Rodríguez-Pose, 2013; González-Pernía, Parrilli, & Peña-Legazkue, 2015; Nunes, Lopes, & Dias, 2013; Thomä, 2017).

While previous empirical studies have examined the variation in innovation patterns within and across firms, sectors, regions, and countries, as well as in relation with the innovation and economic performances in a static sense, only more recently has the literature begun to focus on the dynamics of innovation modes (Hollenstein, 2018a; Love, Roper, & Vahter, 2014; Verspagen & Clausen, 2012). The temporal features of the innovation patterns have been at the centre of prior quantitative research on the differences in stability and persistence in innovation activities across firms, sectors and countries (Cefis & Orsenigo, 2001; Malerba & Orsenigo, 1996). However, the major part of the latter has been focused on the persistence of firms' innovation activities as reflected in R&D expenditures or patenting, which is regarded to provide insights only for the subset of R&D intensive firms. In addition, prior research has mainly been conducted in the context of a manufacturing sector and relyed on the structural characteristics of firms, such as size, ownership, and sector membership in order to explain the variation in the degree of persistence. Moreover, while the previous literature recognizes various potential sources of variation in the degree of persistence in innovation, such as the firm's environment, specific organizational features, strategic orientation, technological and organizational capabilities, and resources, it has mainly been concerned with the empirical relevance of the innovation persistence phenomena. In turn, a smaller subset of work has started to exploit the Community Innovation Survey (CIS) firm-level survey data repeated over time to study the phenomena of innovation persistence (Antonelli, Crespi, & Scellato, 2012; Le Bas, Mothe, & Uyen Nguyen-Thi, 2015; Peters, 2009; Raymond, Mohnen, Palm, & Schim Van Der Loeff, 2010). Latter studies have extended earlier research by focusing on the persistence of various types of innovation measured as the introduction of new products and processes or their combination, and their determinants in the context of both manufacturing and service sector (Antonelli et al., 2012; Antonelli, Crespi, & Scellato, 2013; Le Bas & Poussing, 2014).

Another addition to the more recent literature is the analysis of the persistence of innovation output behaviour in relation to the variety of innovation modes of firms. More specifically, Clausen et al. (2011) provide empirical support for the idea that the initial differences in innovation strategies across firms are important drivers behind the persistence of product innovation. The results of the previous study suggest that persistence of innovation may be an important aspect of the innovation strategies of firms and are related to different and long-lasting choices with respect to the ways of pursuing their innovation goals. The study above also proposes a firm heterogeneity in the form of stable strategic differences.

A first attempt to define the innovation strategy of firms in a dynamic way based on two waves of the innovation survey was by Bart Verspagen and Tommy Clausen (2012). The central premise of this perspective is that firms might choose to pursue their innovation goals by engaging in activities that might be subject to different temporal patterns. In addition, González-Pernía, Parrilli, and Peña-Legazkue (2015) use firm-level data over an average period of seven years, but their focus is on a narrower aspect of firms' collaboration for innovation, and how changes in these are related to the innovation output. However, the definition of innovation modes adopted as well as the resulting empirical strategy here is somewhat different. The approach adopted in Bart Verspagen and Tommy Clausen (2012) is more adequate if the aim is to explore the persistence of the specific elements of the innovation strategy. The empirical strategy adopted here is closest to that of Hollenstein (2018b) and Love et al. (2014) who use information on overall changes and/or specifically firms' switches of the innovation strategy over time to provide a descriptive account of the dynamics of a firm's innovation strategies. Yet, Hollenstein (2018a) focuses on the input-, output-, and market-oriented measures in identifying specific strategies of innovation. However, only input side factors such as R&D activities, sources of information and objectives are used in this paper that is similar to the literature on innovation patterns and learning modes. Furthermore, Hollenstein (2018a) does not deal with the statistical association between the modes of innovation and the temporal persistence by applying econometric methods. On the other hand, Love et al. (2014) specifies four innovation strategies *a priori*, based on the internal R&D and external collaborative linkages and focuses on static and dynamic complementarities, though only in the context of manufacturing firms. I extend this line of research by focusing on the dynamic aspects of innovation modes in the Danish case and by testing formally differences in their temporal stability.

I start the discussion by reviewing past assessments of the strength and weaknesses of the Danish innovation system (IS) in terms of modes of innovation. Against this background, as a preliminary step of the analysis, I empirically identify the modes of innovation or firms' strategies. In doing so, I follow the tradition in a part of the literature (e.g., the literature on technological regimes and trajectories as well as the STI and DUI modes of learning) that defines innovation strategies based on the innovation-related, input-side measures that the CIS offers (Jensen, Johnson, Lorenz, & Lundvall, 2007; Leiponen & Drejer, 2007; Srholec et al., 2008; Verspagen & Clausen, 2012). More specifically, I draw on a set of CIS-based indicators on the firms' R&D activities, sources, and objectives. Furthermore, I follow an inductive approach to defining and measuring innovation modes (T. Clausen et al., 2011; Leiponen & Drejer, 2007; Srholec et al., 2008) by applying the principal component and cluster analysis on the pooled microdata from the six waves of the Danish equivalent of the CIS covering a period of 13 years (2002 to 2015). Numerous studies using CIS data in examining the firms' innovation modes provide certain confidence that it is a reliable basis for the empirical approach adopted in this paper.

In the next step, I utilize the availability of five waves of the innovation survey to construct the unbalanced panel data, and I explore the usefulness of the taxonomy and the methodology that makes it possible to address the systemic stability (or changes) in the firms' innovation modes. With respect to this, I set out to explore i) if modes of innovation show a great systemic stability or if they change over time, and if so ii) what is the direction of such changes, and iii) whether the specific modes of innovation and other broad categories of factors (e.g., firm structural characteristics) can be associated with the greater stability (or changes). The first two issues are investigated with the help of uni- and bivariate descriptive statistics. A binary, random-effect logit model is used to estimate whether there are differences between the identified modes of innovation in terms of the likelihood of change and upgrading over time.

The descriptive analyses provide no support for the systemic movement in the direction of any specific or innovation intensive mode of innovation in the population of Danish innovative firms over the considered period. Yet, the switches between the modes of innovation are common and vary to a great extent among the identified modes of innovation. Moreover, the modes of innovation show a persistent hierarchy in terms of their innovation performances and differences in the likelihood of changes and upgrading over time. I consider the implications of these findings for the literature and innovation policy.

The paper is structured in the following manner. The following section provides the theoretical background as well as a summary of empirical evidence with respect to the modes of learning and innovation and their dynamic features. Section 3 provides the background and describes the data utilized. Section 4 elaborates on the methodology applied for identifying modes of learning and innovation and presents the results of the analysis as well as the basic characteristics of the identified modes of learning and innovation. In section 5, a descriptive analysis of the dynamics of modes of learning and innovation over time is presented. In section 6, I present the econometric estimates of the relationship between the firms' modes of innovation and their persistence. In the final section, a discussion of the main findings and the conclusion are presented. In addition, I present the main limitations of the study and propose avenues for further research.

2. Modes of innovation and learning

2.1. Theoretical and empirical background: static taxonomic studies

Taxonomies as classification tools in the empirical research on innovation patterns have a long history, starting from Pavitt's (1984) influential taxonomy on sectoral patterns of technological change. The underlying assumption of this approach is that sectoral differences in the sources of technology, users' needs, and the means of appropriating benefits from innovation explain sectoral differences in the technological opportunities and constraints that in turn explain to a large extent how firms innovate (choices and behaviour) or the different technological trajectories that they can follow. These technological trajectories of firms in turn largely determine the key strategic choices and possible paths or future activities of the firms in terms of diversification of technology and of products. Since then, Pavitt's Taxonomy has been modified and extended in the subsequent research (Archibugi, 2001; Malerba & Orsenigo, 1997; Marsili & de Jong, 2006; Marsili & Verspagen, 2001). In the later literature, the patterns of innovation activities have been related to the concept of technological regimes, which in turn refer to synthetic representation of the economic properties of technologies and the characteristics of the knowledge bases and the learning processes that are involved in innovative activities of firms within sectors (Malerba & Orsenigo, 1996). In the same literature, the dimensions along which innovation patterns across sectors are expected to differ are technological opportunities, appropriability and firms' cumulativeness conditions and the properties of the science and technological knowledge bases.

Subsequent waves of taxonomic studies based on CIS data have empirically tested the underlying assumption that sectors are at the appropriate level to explain the innovation patterns of firms. This led to the suggestion that it is more appropriate to use a taxonomy to describe and classify innovation patterns at the firm or strategic group level (Arvanitis & Hollenstein, 1998; Frenz & Lambert, 2012; Hollenstein, 2003; Leiponen & Drejer, 2007). More specifically, based on the growing empirical evidence that firms within the same sector are rather heterogeneous in the ways they innovate, it is suggested that the concept of the generic innovation strategies of firms are more appropriate than their sectoral patterns of innovation. As a consequence, the subsequent line of work started assessing to what extent the sectors versus firm-level factors are relevant with respect to heterogeneity in innovation activities or strategies of firms (Hollenstein, 2018a; Peneder, 2010; Srholec et al., 2008). From an empirical perspective, the results of these more recent taxonomic studies suggest usefulness of grouping firms based on the various dimensions of the innovation activities that were used in extracting Pavitt's Taxonomy at the firm-level (Arundel & Hollanders, 2005; Hollenstein, 2003; Leiponen & Drejer, 2007; Srholec et al., 2008; Verspagen & Clausen, 2012).

Another influential taxonomy at the firm-level includes two modes of learning, STI and DUI, based on the relative importance of the four types of knowledge and the corresponding ways and channels of learning associated with the innovation processes, as introduced in the influential study by Jensen et al. (2007). The four types of knowledge include know-what, know-why, know-who and know-how. The main argument for the usefulness of the conceptual distinction between these two modes of learning is that both are present and play a role in most sectors of the economy, and that the innovation processes of firms are not limited to scientific and technological knowledge and the formal process of learning through R&D. However, the two modes of learning are expected to play a more prominent role and to be practiced with different intensities in certain firms and sectors depending on the sector's characteristics and the firm's strategies. Moreover, firms that practice mixed strategies combining both modes of learning are regarded to be more likely to excel in innovation performances (Jensen et al., 2007).

It is worth noting that according to Jensen et al. (2007), this dichotomy of the STI and DUI modes of learning and innovation refers to two "ideal types," while in practice, this distinction tends to be much more blurred. The STI mode of learning gives priority to the production and use of know-why knowledge, which is characterized as highly explicit and global. The use and production of explicit and codified types of knowledge is manifested in the entire process of the STI mode of innovation, from the initial efforts of R&D personnel to translate the local problem in terms of a formal scientific code, through using codified and global know-why knowledge from internal and external sources in solving these problems, and through translating the obtained knowledge into codified form for the purpose of documenting and communicating the innovation results within and across the organisational borders. The main external innovation partners in this mode of learning and innovation are researchers attached to universities and scientific institutions.

The DUI mode of learning and innovation refers to know-how and know-who types of knowledge are by nature highly tacit and localized. The tacit and local element of the knowledge is defined as being difficult to codify, embedded in people and rooted in practical experiences that usually start from a local problem. Know-how type of knowledge is acquired through apprenticeship and is embodied in a skilled worker, whereas the know-who type of knowledge is learned through the informal processes of socialising as well as through specialized environments of education. Examples of the latter include reunions, conferences, and professional societies. This type of knowledge is also developed as a by-product of the regular contacts with partners in the value chain such as customers, contractors, and independent institutes. This type of learning occurs both as an unintentional by-product of the design, marketing, and production activities of the firms, and as a result of the intentional structures and relationships put in place to support learning by doing, using, and interacting. The examples of organisational practices that promote learning and knowledge exchange and thus stimulate the innovation performances include project teams, problem-solving groups, and job and task rotation. In terms of external interactions, learning is associated with close interactions with the users of products and services (Jensen et al., 2007).

The usefulness of the conceptual distinction between the modes as a basis for understanding difference in innovation performances of firms have been tested in the seminal study by Jensen et al. (2007), who shows that firms in Denmark that combine the elements of STI and DUI-modes of innovation and learning tend to perform better in terms of new to market innovation than those primarily relying on any of the learning modes alone. Subsequent studies have confirmed these results in other contexts (Asheim, Isaksen, Moodysson, & Sotarauta, 2008; Aslesen, Isaksen, & Karlsen, 2012; Fitjar & Rodríguez-Pose, 2013; Nunes et al., 2013), which have provided a more nuanced understanding of the relationship between the modes of learning and innovation performances of firms (Parrilli & Alcalde Heras, 2016) as well as suggested that the relationship might have changed (Parrilli & Elola, 2012). The other line of research associated with the STI and DUI modes has been oriented towards exploring the diversity of sources of knowledge and types of collaboration of enterprises relying on different modes. The examples include studies concerned with the relevance of different knowledge sources associated with different modes of learning of firms in regional industries (Isaksen & Karlsen, 2010).

Similar to a part of the above-reviewed literature, I identify the taxonomy based on the various dimensions that are considered as relevant elements of the innovation modes/strategies of firms (or modes of learning) in the earlier and most recent taxonomic studies (Apanasovich et al., 2016; González-Pernía et al., 2015; Leiponen & Drejer, 2007; Nunes et al., 2013; Srholec et al., 2008; Thomä, 2017; Verspagen & Clausen, 2012), applied in an inductive way. As were common in previous studies, the elements of the innovation strategy used in the analysis are limited to those aspects that the innovation survey offers. More specifically, the innovation strategy aspects considered include firms’ choices on the innovation activities (e.g., R&D), sources of knowledge (e.g., suppliers, customers, etc.), and objectives (e.g., gaining market share, improving quality of goods). The formal R&D activities and the various sources of knowledge or information for innovation have been commonly used as the elements of a firm's STI or DUI modes of learning. Hence, the aspects of the innovation modes or strategies that are considered in this paper are recognized in both streams of the taxonomic studies as well as in the innovation studies literature. Therefore, the obtained innovation modes in this study build on the contributions in both Pavitt-inspired and the STI and DUI modes of learning taxonomies.

While the taxonomic studies at firm-level have contributed to a better understanding of the variety and the interdependencies of the various dimensions of the learning/innovation modes or strategies of firms within sectors, the dynamic aspect of the modes of innovation based on the CIS firm-level data remains largely unexplored. The following section reviews some of the earlier and more recent attempts to account for the dynamic aspect of the innovation activity (s) or the modes of innovation of firms.

2.2. Dynamics of the patterns of innovation

2.2.1. Stability of the patterns of innovation activity

In the early literature on the sectoral innovation patterns, the degree of stability or dynamism was measured in terms of the degree of stability in the hierarchy of innovators (within technology classes) and in the ranking of technology classes (e.g., in terms of birth rates) over time (Malerba & Orsenigo, 1995). High stability was defined by low changes in the hierarchy of persistent innovators and in the ranking of technology classes (low ease of innovative entry). In turn, high stability in patterns was associated with the technological regimes characterized by high opportunity, appropriability and the "cumulativeness conditions" of firms (e.g., the chemical industry). On the other hand, low stability was a typical characteristic of traditional sectors. The former regime thus allows (or favours) a group of firms to accumulate technological knowledge and capabilities continuously (Malerba & Orsenigo, 1995). The notion of firms' cumulativeness conditions is interpreted as persistence of innovation (R&D) at the firm over time, which in turn is driven by the cumulativeness in technology development, market feedbacks, and the organizational capabilities (Malerba & Orsenigo, 1997).

The literature on technological trajectories suggested that the firms' rate and the direction of search and learning (and accumulation of competencies in the future) is dependent on the opportunities and the incentives (Pavitt, 1991). The perceived or real opportunities that firms face, on the one hand, and the prior accumulated competencies and the experiences, on the other hand, where both are to a large extent sector specific. In turn, the strategic choices that firms face differ between the firms' profiles of accumulated competences, which in turn largely correspond to main trajectories. Here, the strategic choices of firms refer to technological and/or product diversification strategies. Moreover, the accumulated technological competences of firms are characterized as stable over time within sectors and differentiated across sectors. At least in the context of large multi-technology corporations, Granstrand et al. (1997) showed that firms' technological activities within sectors are fairly stable and differentiated.[1] They also showed that firms have been increasingly widening and deepening their experience in a variety of knowledge fields and inputs due to the systemic interdependencies with the supply chain changes and growing technological opportunities. This process of new competence building in firms is described as a dynamic process of learning requiring the combination of internal and external sources of technology accompanied with increases in in-house R&D expenditures.

Similarly as in the static taxonomic studies previously discussed, the firm- rather than technology or sectoral-level study of the dynamics of (persistence) technological activities proved to be an appropriate level of analysis (Crespi & Scellato, 2014). In more recent years, the phenomena of technological innovation persistence have been studied from various theoretical perspectives, moving beyond the early explanations. Yet, it is important to note that technological innovation persistence at the firm-level has mainly been measured with indicators such as patents, R&D, and major innovations (Le Bas, Mothe, & Nguyen Thi, 2011). In broad, the empirical literature on persistence provides two alternative but complementary interpretations for the observed empirical regularities of the persistence (or lack thereof) in innovation behaviour of firms. The first perspective is that the firm's past experience in innovation activity or outcome has a causal effect on its innovation activity or outcome in the

[1] Granstrand et al. (1997) defined the stability and differentiated nature of the patterns of technological activity in terms of the stability and differentiated nature of the patent mixes of very large firms by technological fields within sectors.

present and future, leading to higher persistence. Theoretical interpretations for the latter include the success-breeds-success processes, the learning processes and dynamic increasing returns, and the sunk cost in R&D investment (Peters, 2009). The success-breads-success idea is that firms' successful commercialization of innovation creates profits, which in turn can be reinvested in present and future innovation activities (Flaig & Stadler, 1994; Le Bas & Latham, 2006). In turn, the learning effect and the dynamic increasing return of innovation production refers to the idea that firms become persistent innovators due to the positive feedback between the accumulation of knowledge and the production of innovation, which in turn is a subject to dynamic economies of scale, meaning that increasing the extent of innovation activity at any point in time, a firm is more likely to innovate in the subsequent period (Geroski, Reenen, & Walters, 1997). Leiponen and Helfat (2010) also found increasing return to a greater number of objectives and sources of knowledge when coupled with persistent R&D activities. The third line of reasoning is that an essential motive for entering and staying in a specific mode of R&D activity at the level of the firm is the sunk cost nature of the R&D expenditures (Manez, Rochina-Barrachina, Sanchis, & Sanchis, 2009; Sutton, 1991). In sum, the discussion above suggests the importance of internal mechanisms and/or market feedbacks in explaining the persistence in R&D or output behaviour of firms. The main finding from these studies is that the persistence in innovation (using either R&D or output-based measures of innovation) at the level a firm exists, but there is no consensus regarding the degree of persistence.

Another interpretation that builds on the theoretical arguments on the cumulativeness and firm-specificities in the generation of knowledge and the processes of competency building is that the initial differences in innovation strategies of firms are the main source of differences in innovation persistence. More specifically, the accumulation of knowledge and the continuous process of competence building (under specific conditions) may lead in some firms to the development of dynamic capabilities, which in turn may favour the systemic reliance on the innovation strategy by firms in order to maintain the competitive advantage in the long run (D. J. Teece, 2007). In other words, dynamic capabilities can be viewed as the organizational and management sources of firms' innovation persistence.

2.2.2. Changes in modes of innovation over time

In the tradition of the evolutionary theory of firms, Pavitt (1991) argued that the decisions on the content of strategy (innovation activities) are based on "routines" (rules of thumb), which embody the firm-specific competences and the management and organizational factors associated with innovation, at least in the large manufacturing firms. However, Pavitt (2006) considered these decisions to reflect the competencies and behaviour of senior managers rather than institutionalized procedures in small firms. These routines are built over time either by firms' choice or trial and error in order to cope with uncertain and complex activities such as innovation in the context of the ever-changing environment. In the context of uncertainty and complexity, the adaptation and change of these routines is argued to be incremental and coupled with the localized processes of learning about the context (from internal and external sources). Of these, the relative importance varies across modes. The feedback from these processes of learning is considered as essential for modifying the content of strategy. Implementation of a strategy in turn helps to define the direction of future learning as well as changes in the context. While Pavitt (1984) did not analyse if and how the pattern of innovation changes over time, he suggested that the supplier-dominated firms (firms characterized as having low internal technological capabilities and predominantly rely on suppliers as well as other sources of information for process innovations directed at cutting costs) may try to adopt the scale-intensive strategies (e.g., textile firms), or information-intensive strategies (e.g., commercial and financial services) (Keith Pavitt, 1990). In addition, the scale-intensive firms may move to the supplier-dominated modes (e.g., synthetic chemicals) (K. Pavitt, 1991). However, successful entry into these new areas is not automatic or costless and require the willingness of firms to pay the extensive and lengthy entry costs associated with learning about new technologies or markets.

Similarly, Bart Verspagen and Tommy Clausen (2012) treat the firm heterogeneity in the form of innovation strategies (mix of inputs and sources) as stable (i.e., long-run decisions that firms make on the ways in which they choose to innovate in order to account for difference across firms in terms of their persistence in innovation over time). The stable nature of strategic differences is based on the theoretical arguments on the nature and pace of changes of routines/capabilities on which these choices are made, from the evolutionary theory of firms and the strategic management literature, respectively. According to the former, the nature of routines, which embody factors that affect innovation, and the strategic factors of firm's behaviour are semi-stable, and they are expected to change very slowly and only incrementally.

In addition, the strategic management literature uses the concept of organisational inertia to imply that a firm's strategy is stable and difficult to change in the short run (Hannan & Freeman, 1984). The dynamic capabilities literature also suggest that strategic changes are difficult, costly, incremental, and close to the firm's previous activities due to the self-reinforcing and path-dependent nature of the routines and procedures (D. Teece, 2008; D. J. Teece, Pisano, & Shuen, 1997). The strategy here is understood as choosing among and committing to long-term paths of competence building (D. Teece, 2008). The later perspective argues that some firms develop over time dynamic capabilities, the subset of the firms' competences, which allow these firms to continuously innovate and respond to the changing environments. These capabilities are considered primarily to be the province of large firms operating in a highly dynamic environment (Augier & Teece, 2008). Hence, the previous discussion suggests that changes in modes of innovation (or strategies) are cumulative and incremental, proceedings on the basis of the previous experiences and the technological competencies (path-dependent), and thus can be predicted to show a rather stable pattern.

On the other hand, the literature on the STI and DUI modes of learning anticipated the blurring boundaries between the categories of the taxonomies based primarily on the knowledge bases of firms (e.g., Pavitt's Taxonomy) over time, and consequently the need for firms to adopt a mixed strategy (meaning including more systematic connection to various sources of knowledge), especially in the high-income countries (Jensen et al., 2007; B.-Å. Lundvall & Lorenz, 2007). More specifically, firms that are found in the non-science based modes are expected to draw more on scientific sources of knowledge, while firms in the science-based modes are expected to move in the direction of integrating elements of the strategies found in modes relying on other sources of knowledge. The use or adoption of a mixed strategy is seen as favourable for both adaptations to change and for stimulating innovation in order to stay competitive in the context of the learning economy. This new context has been characterized by heightened competitive pressures and new knowledge and technological opportunities, which in turn provides a strong inducement for firms to integrate new aspects in their strategies. Jensen et al. (2007) showed the co-presence of a set of practices associated with the two modes of learning and suggested that practices associated with these two modes of learning can be made complement and that the major task of knowledge management is to balance the strong version of two modes.

The previous arguments can be linked to the strategic innovation management literature claim that emphasize the importance of openness in terms of combining various internal and external knowledge sources and the role of complementarities for enhancing innovation performances. Yet, Love et al. (2014) find little evidence of a systemic shift or pattern in terms of the joint use of internal R&D and external linkages in case of the Irish manufacturing firms in the period 1991-2008. Moreover, Love et al. (2014) provide evidence that switches between four strategies are common (around 50% overall) but more so for the intermediate strategies (60-70%) than either for NEITHER (29%) or BOTH (43%) strategies. The NEITHER strategy stands for no R&D and has no linkages, while the BOTH strategy includes R&D and has linkages. Two intermediate strategies are external (no R&D and has linkages) and internal (has R&D and no linkages) (ibid.). Relatedly, Hollenstein (2018a) argues that in the context of the required structural changes in the advanced economies such as the Swiss one, there is a need for firms to constantly increase the content of their innovation activities. Hollenstein (2018a) finds empirical support for the claim that overall more innovative strategies (the science-based strategy and two IT-based strategies) have attracted more firms over time. Moreover, based on the frequency of changes in a three-year period, Hollenstein (2018a) finds that overall frequency of changes is high (63%) and does not differ among four out of five identified innovation strategies (61-69%).

In principle, the modes of innovation reflect the generic strategies or modes of innovation followed by firms. If the latter argument that the mixed strategies are more attractive for firms in general has empirical validity, there should be a systemic trend over time towards firms adopting a particular mode. On the other hand, if the argument for a relatively stable heterogeneity of innovation modes over time is valid, there should be a fairly stable pattern in terms of identified modes over time. The analysis of the frequency of changes overall and specific firms' switches between the various modes of innovation over time makes it possible to examine these arguments. The first and second research questions explored in this paper consider whether there is any evidence of systemic changes in modes of innovation (and not technological competencies or specific innovation activities in isolation), and if so, what is the direction of these changes. This is done by considering successive cross-sectional waves of the survey and in terms of the mode switches of specific firms over time.

2.2.3. Hypothesis

Consistent with the ideas from a previously discussed literature about overall stable patterns in innovation efforts of firms, I expect that temporal persistence differs across the identified modes as suggested in prior research by Verspagen and Clausen (2012). In particular, the modes of innovation might differ with respect to the persistence effect of sunk costs, learning processes, and success-breads-success dynamics. In what follows, I differentiate between the three modes of innovation in terms of the scope of innovation (i.e. R&D, breadth in knowledge sourcing and objectives) in generic terms, such as low-profile (low), intermediary (specialized), and high-profile (broad). More specifically, firms in low-profile or supplier-based modes of innovation (associated with very low in-house commitment to innovation, external sources and objectives for innovation) may be expected to be the least stable. The reason is that this mode is associated with the absence of sunk costs, and less strong learning and success-breads-success dynamics (the factors used to explain the findings in the literature on the persistence of innovation or lack thereof). For example, pursuing a particular objective or engaging with the particular source of information may be related to a single-innovation project rather than to continuous efforts. On the other hand, intermediary or specialized modes (associated with the focus on the specific goals and pursuing information from industry or other professional sources) are expected to be more persistent than the low-profile strategy. This is due to the fact that seeking information from industrial or professional sources requires firms to invest in these relations and thus commit to them in the longer term, and thus pursuing these strategies may be associated with higher sunk costs (Verspagen & Clausen, 2012). Finally, the high-profile innovation strategy (associated with the focus on R&D and a broad range of sources for innovation and goals) may be expected to be the stickiest due to the sunk costs associated with R&D and external sourcing but also due to the success-breeds-success process and learning dynamics from prior innovation.

The results from the previous empirical studies do not provide unambiguous evidence in terms of differences in the likelihood of changes between different innovation modes. On the one hand, Love et al. (2014)

find the persistence to be relatively higher for strategies that are associated with both NEITHER (no R&D or external linkages) and BOTH (R&D or external linkages) innovation strategies. On the other hand, Hollenstein (2018a) finds small differences in terms of likelihood of change for four out of the five identified innovation modes, except for the high-profile strategy, which shows much higher persistence. In a similar vein, Bart Verspagen and Tommy Clausen (2012) show that only R&D and external cooperation show persistence in the frequency of the activities between the two waves (2001 and 2004). Even though the main focus of Bart Verspagen and Tommy Clausen (2012) is not on changes but dynamic aspects of innovation strategies, they identified three stable clusters of strategies including i) persistent innovators (R&D) (21%); ii) persistent intensive innovators (R&D and external cooperation) (11%); and iii) non-innovators (meaning persistent low innovation activity) (45%).

Based on the theory and the results from the previous analysis (Hollenstein, 2018a; Love et al., 2014; Verspagen & Clausen, 2012) I hypothesize the decreasing probabilities of change as one moves from low- to high-profile innovation modes in terms of the scope of innovation (R&D, breadth in knowledge sourcing, and objectives).

Hyphotesis 1: More systemic modes of innovations are characterized by a higher persistence, making firms associated with this mode less likely to change as compared to firms associated with less systemic modes.

Similarly, I hypothesize the decreasing probabilities of upgrading as a firm moves in the direction from a narrower to a broader innovation mode in terms of the scope. For instance, firms that are initially found in the low-profile innovation mode (limited activities and sources of knowledge and objectives) may be capable over time to establish some links with the market or professional-oriented sources of information when pursuing a specific aim (product- versus process-oriented aims) and thus upgrade their initial position (intermediary mode). In addition, firms initially found in the low-profile mode may accomplish the changes towards intermediary position by pursuing some specific goal and engaging in ad-hoc problem-solving activities in the short run at a much lower costs (Winter, 2003). However, they may fail to enhance the absorptive capacity that is necessary to engage with more science-based knowledge sources (high-profile mode) due to no previous engagement in in-house R&D. On the other hand, firms that are already embedded in some form of market and/or professional oriented knowledge network (intermediary or specialized modes) may be more capable to engage in other forms of industry or professional related external interactions when pursuing specific goals (process versus product-oriented aims) than firms initially found in low-profile mode (the same goes in the opposite direction). At the same time, changes towards more complex innovation strategies in case of intermediate modes would require substantial commitment of resources to internal R&D activities or various sources of information in the long run, as well as organizational and management capabilities for combining different objectives and sources of innovation that are necessary for exploiting new opportunities, and thus may be expected to be less likely to upgrade. In addition, the processes of localized learning and dynamic increasing returns may result in firms pursuing intermediary or more specialized modes being locked into trajectories and thus less likely to upgrade.

Hyphotesis 2: Firms associated with more systemic modes of innovation are less likely to upgrade to even more systemic modes.

3. Background and Data

Background

In order to provide background, this section presents a summary of the main insights from the prior studies that focus on firms' modes of learning and innovation based on firm-level innovation data in the Danish context. While basing their analysis on the dimensions of innovation activity that were used in deriving the influential Pavitt's (1984) taxonomy and the firm-level CIS-data (1994-1996), Leiponen & Drejer (2007) found that "market-driven" (specialized suppliers) and "incremental innovators" are the most prevalent mode of innovation in the case of Denmark.[2] Based on the study carried out in the second part of the 1990s (DISKO project, 1996-1999) Danish system has been evaluated as being particularly strong in interactive learning based on experience-based knowledge and relatively weak in science-based learning.[3] The prevalent "mode of innovation" has been characterized by small and medium size enterprises (SMEs) continuously

[2] The results of the study, however, need to be taken with a caution due to the relatively poor quality of the data.

[3] The modes of learning are defined in relation to different types of knowledge.

making incremental innovations based on learning by doing, learning by using and learning by interacting, especially with customers and suppliers (DUI mode) (Edquist & Hommen, 2008; Lundvall, 2002, 2009). The exception to this was a scale-intensive agro-industrial sector with a focus on process innovation and pharmaceuticals, a science-based industry responsible for a majority of patent activities. Other important features encompassed the specificities of the flexible labour market and the wider socioeconomic setting, including institutional set-up being well suited for the prevailing mode of innovation. In turn, these structural and institutional characteristics that are rooted in the historical processes are said to be reflected in the strengths and weaknesses of an innovation system in terms of form, content and rate of innovation and to persist even in a long term perspective (Lundvall, 2002). For example, historically weak links between SMEs and universities due to a lack of demand and absorptive capacity of firms in terms of historically weak investment in R&D from the industry side are said to persist as a characteristic weakness of the Danish IS (ibid.). Yet, subsequent work based on the CIS-data (1998-2000) has shown that firms, including SMEs, have invested more in R&D, collaborated more with universities, and relied more on an educated labour force in comparison to previous results (Edquist & Hommen, 2008). These findings led the authors to suggest that the Danish innovation system has started to transition towards a more mixed mode, where learning by doing, using and interacting mode were combined with a science and technology-driven mode of innovation. Further, the study by Jensen et al. (2007), now drawing on the results of the Danish DISKO survey for the same time period (1998-2000) showed that the combined share of Danish firms in the STI (10%) or STI-DUI mode (18%) was only slightly smaller than the share of firms in DUI (30%) mode of learning alone (Edquist & Hommen, 2008). These results suggest that a large segment of the Danish business sector undergone a transformation in a rather short period of time. Given that most of the prior research rely on data prior to 2000, this study seeks to provide novel evidence by exploiting the availability of several waves of the CIS referring to more recent time periods.

Data

The data used in this study stem from the Danish part of the European CIS from 1998 to 2006 carried out by the Danish Institute for Studies in Research and Research Policy. It is important to note, though, that from

2008 onwards, the research was conducted by Statistics Denmark.[4] The Danish CIS is based on a standardized questionnaire and a standardized method developed by Eurostat on the basis of the Oslo Manual and the Commission Regulation No 1450/2004, both of which provide details of the compilation of innovation statistics. For the purposes of this study, the data from five waves of the Danish Community Innovation Survey are used, covering the period 2002-2015. The CIS survey provides information on the innovation process, sources of information, innovation cooperation, and objective of enterprises as well as some economic indicators such as the number of employees and staff turnover. The business register data on additional structural characteristics of firms such as firm size, age, ownership, and the sectoral affiliation is also used. Below, the specificities of the Danish CIS, the quality of data, and comparability of statistics across the years are documented (for an overview see Table A.1 in the Appendix).

CIS2004 covers the period 2002-2004 with the reference year 2002 for status information. The sample is drawn from the NewBiz, a business register containing updated information from the Central Business Register and other sources. The survey methodology is based on a combination of census and a stratified random sample survey. Regarding the sampling technique, the combination of a panel (834 enterprises satisfying at least one of the criteria in relation to R&D or innovation, the NACE or the size class) and a PPS-modified allocation method is used. For the sampled enterprises, the stratification is based on the principal economic activity and size. The survey is based on a sample of 3,364 enterprises (excluding the ineligible units), with the response rate of 62% corresponding to 2,097 enterprises (including estimated responses). The answers are weighted based on the criteria such as the withdrawal probabilities and the response rates of the main industry and size category combinations. The weights are further calibrated with respect to the total number of employees, the forms of ownership and the main sources of differences in innovation intensity that corresponds to the entire survey population. The quality of the data from the CIS2004 has been assessed as high (Research Institute for Research and Research Policy, 2004).

[4] From the reference period 2007, the statistics are collected and published annually (Danmarks Statistik, 2012)

CIS2008[5], CIS2010, CIS2013 and CIS2015 cover the three-year period with the reference years 2008, 2010, 2013 and 2015 for status information, respectively. In contrast to CIS2004, from 2007 onwards the target population is extracted from the Business Statistic Register, which is the basis for all business statistics prepared by Statistics Denmark. In addition, the sample selection changed from 2009 and onwards. The probability of being selected in a sample is 100% for companies based on their size (250+ employees or turnover of more than DKK 1 billion); documented costs for R&D or innovation; or because they belong to industry 73 (R&D). The units that are preselected are stratified separately and only by industry, while the rest of the units are stratified by industry and size. From 2007 and onwards, the statistics are collected in a single questionnaire together with statistics on business R&D on a yearly basis. The surveys are based on the realized sample of 4,438 (22,215), 4,322 (19,483), 4,787 (18,674), 5,044 (17,856) firms, respectively.[6]

As the analysis aims at identifying modes of learning and innovation, the combined dataset includes only innovative firms. An innovative firm is defined as a firm that has introduced a product or process innovation independently of the innovation processes being delayed or abandoned.[7] The pooled data consisting of the five waves of the CIS survey that covers the period from 2002 to 2015 (13 years) is constructed[8]. The pooling of data is done in order to permit a quantitative comparison of the firms' modes of

[5] In contrast to surveys from CIS2000 to CIS2006, CIS2008 and CIS2010 and latter surveys used NACE Rev. 2 classification of economic activities. From 2007 onwards, Danish versions of the survey follows the Danish Branch Code 2007 (DB07), a subdivision of the EU NACE Rev. 2 classification of economic activities. Businesses are grouped into the following groups based on the number of full time employees: under 10; 10-49 employees, 50-249, and 250 or more.

[6] The figures in the parenthesis refer to the size of the target population.

[7] Since prior to CIS2006 information on "broader" types of innovations, such as organizational and marketing, is not included the analysis is limited to "traditional" types of innovation (i.e. product and process innovation) only. In addition, in the latter surveys firms that responded to the question on "broader" types of innovation were not asked the question on the importance of sources of information and knowledge.

[8] The analysis assumes that the results of the cluster analysis on the subsamples of the separate waves of the innovation survey will not differ substantially from the results of the cluster analysis which uses the total sample (five waves of the CIS survey).

innovation over time, which would be limited to a qualitative assessment of the observed patterns if the analysis was carried out on the separate waves of the survey. It is worth noting that some of the included waves of the survey have a one-year overlap in the reference period. The main rationale for including the overlapping waves of the survey is due to the fact that this enables me to use as much information as possible (five instead of four waves of the survey) and to include the latest available wave of the survey. However, this overlap has a drawback since it makes it difficult to fully associate results with the proceeding reference period due to the fact that it is not clear whether the results are mainly due to the overlapping year or due to the activities associated with the years not covered in the preceding wave of the survey. This can also affect the comparison of results (but especially changes) over time.

Table 1 presents the number of all firms and innovation active firms (columns 1 and 2) by separate waves of the survey and in total (last row), including the share of innovation active firms by separate waves of the survey (column 3). Columns 4 shows the number of innovation active firms by waves of the survey and in total (last row) after deletion of observations with all the missing values, whereas column 5 presents the share of observations by separate waves of the survey in the pooled dataset.

Table 1: Composition of the dataset for each survey round and the

	Respondents (*n*)	Innovative firms (*n*)	Innovative firms (%)	Obs. after deletion of obs. with all the missing values (*n*)*	Obs. in the total sample (%)
CIS2004	2,097	1,195	56,99%	1,195	13,38%
CIS2008	4,438	2,033	45,81%	1,967	22,03%
CIS2010	4,322	1,920	44,42%	1,900	21,28%
CIS2013	4,788	1,950	40,73%	1,941	21,74%
CIS2015	5,044	1,931	38,28%	1,926	21,57%
Total	20,689	9,029		8,929	100%

Note: Column 3 presents shares of the innovation active firms in the separate waves of the survey, whereas column 5 stands for the shares of the innovation active firms by the waves of the survey in the pooled sample. *A total of 100 observations with missing values on the variables of interest were deleted from the final dataset.

The final dataset is an unbalanced panel of five cross sections since not all firms included in the sample took part in each wave of the survey. The

8,929 observations are almost evenly distributed over CIS2008, CIS2010, CIS2013, CIS2015 (22%, 21%, 22%, and 22% of the sample) whereas CIS2004 accounts for a proportionally lower part of the total number of observations (13% of the sample) (Table 1, column 5). This reflects the fact that the response rate of the CIS2004 survey, which was not mandatory (Eurostat, 2014), was much lower than in the subsequent surveys, which were mandatory (Danmarks Statistik, 2011). Additionally, the share of innovation-active firms differs between the CIS2004 (56% of the sample) and the rest of the included waves (46%, 44%, 41%, and 38% of the sample) (Table 1, column 3). This divergence in the share of innovative firms between the CIS2004 and the surveys conducted from 2006 on has been attributed mainly to the quality improvements from 2006 and to a lesser extent to changes in the shares of innovative firms in reality. I also corrected for item non-response by imputing missing values in order not to lose additional observations. The applied method involves a variable-by-variable approach to imputation by using chained equations that have been proposed for the imputation of categorical and continuous variables (Horton & Kleinman, 2007). In a nutshell, the model is specified (depending on the scale of variable)[9] for each incomplete variable using other complete variables as predictors. At each step, the imputed value of the incomplete variable is derived and further used in the imputation of the next incomplete variable. The process of imputation based on Gibbs sampling procedure continues until it reaches convergence (Van Buuren & Groothuis-Oudshoorn, 2011). Table A.2 in the Appendix presents the composition of the final dataset by sector and size and over time. Altogether, the pooled data is representative of the underlying samples in terms of sector and size.

[9] Predictive mean matching is used for the imputation of continuous variables. It consists of several steps. First, the estimates of the parameters of the multivariate regression of y (variables subject to missing) on x (fully observed variables) are derived from complete cases (that are different for incomplete cases with different sets of missing variables). Second, for each incomplete case the multivariate regression of the missing y's for that case (y_{mis}) on x and the observed y's for that case (y_{obs}) is estimated by sweeping on the variable (y_{obs}). Third, the prediction of y_{mis} for an incomplete case and the complete cases are obtained and matched (nearest observed value). Finally, the value of y_{mis} from the matched case is used to fill the value.

4. Identification and interpretation of innovation modes

4.1. Variables

In identifying modes of innovation, the CIS is first searched for indicators to measure different modes of learning and innovation. Most of the existing taxonomic studies rely on one or several of the standard measures used for indicating formal processes of innovation (or learning by researching) or strong capacity to generate, use, and absorb scientific and technological knowledge. The indicators used are the expenditures on R&D, the number of R&D departments, the number of R&D personnel, the share of personnel with university degree, the patents, the use of patent protection, and the level of interaction with sources of codified and scientific knowledge such as universities (Apanasovich, 2016; Jensen et al., 2007; Nunes et al., 2013; Parrilli & Elola, 2012; Srholec et al., 2008; Thomä, 2017). In this paper, the formal R&D activity is measured as the log of the full-time equivalent (FTE) of R&D personnel. The FTE of R&D personnel corresponds to the working hours of an employee who is engaged in full-time R&D for an entire year. One full-time equivalent thus corresponds to one person-year. A better alternative would be to use the ratio between the FTE personnel in R&D over the total FTE of all employees. However, I only have information on the total number of employees and not a full-time equivalent.

A set of indicators used to capture the informal processes of learning by doing, using, and interacting is rather diverse across the existing studies. The indicators used for learning by doing and learning by using aspects encompass the expenditures on marketing and technological preparation for production (Apanasovich, 2016) or promotion activities linked to the introduction of new or improved products on the market (Amara, Landry, Becheikh, & Ouimet, 2008). Unfortunately, due to a lack of available data, I am only able to include the indicators on the informal processes of learning by interacting. The common indicators used on external interaction and cooperation include the interactions with the partners within the supply chain such as suppliers, customers and outside competitors (Fitjar & Rodríguez-Pose, 2013; Jensen et al., 2007). These are also standard measures used for different sources of knowledge and information in the literature on patterns of innovation (Leiponen & Drejer, 2007; Srholec et al., 2008). While relevant, the indicators on the firm's organisational and management practices and policies that support organizational learning are not considered since no standardized data that could be used for this purpose exist up to now.[10]

I draw from the same block of questions in the survey for sources of information variables.[11] As common in the above-mentioned studies, the research- or science-mode related sources of knowledge and information are accounted by means of the importance of the sources of information for innovation with the following partners: i) universities or other higher education institutions; ii) consultants, private laboratories and research institutes[12]; iii) scientific journals, professional journals, and other professional publications;[13] and iv) other public research institutions.[14] In turn, the process of learning by interacting include related sources of knowledge and information that are measured by means of the importance of sources of information for innovation with the following partners: i) internal sources within the enterprise or the enterprise group; ii) suppliers;

[10] The existing studies that include these aspects mainly rely on the additional questions that go beyond the standardized version of the CIS survey (e.g., Thomä, 2017) or are based on survey data specifically collected for the purpose of the study (e.g., Jensen et al., 2007).

[11] Unfortunately, no information on the firm's cooperation on innovation with the different partners is available. However, have shown that the type of insight provided in the question on cooperative arrangements on innovation tends to overlap with the information contained in the question on the importance of source of knowledge and information for innovation.

[12] The CIS2000 (1998-2000) questionnaire does not include question on this source of information.

[13] In the CIS2000 (1998-2000) questionnaire, the two questions on other sources of information cover several sources of information together. The first question relates to importance of professional conferences, meetings and journals, while the second question refers to importance of fairs and exhibitions. In the following waves of the survey these sources of information are combined in a different way in the questions. For the first time period, we combine the answers on the questions concerning these sources of information into a single variable.

[14] The CIS2000 (1998-2000) and CIS2004 (2002-2004) questionnaires do not include this source of information and other public research institutes are thus not considered in the analysis for the first time period. The CIS2000 questionnaire includes other sources of information for innovation such as government or private, non-profit research institutions, while CIS2004 also includes GTS, a network of independent Danish research and technology organisations. However, these sources of information are excluded from the subsequent waves of the survey and are thus not included in the analysis.

iii) clients or costumers; and iv) competitors. I also take into account the importance of professional sources of information such as v) professional and industry organisations; and vi) conferences, fairs and exhibitions. Firms are asked to indicate on a fourth-point Likert scale (1=not relevant; 2=low; 3=medium; and 4=high) which sources of information for innovation were of a major importance. The answers were recoded as zero for "not relevant" to three for "high importance."

Finally, I used the question on the importance of aims of innovation activities. The importance of aims is used for capturing relevant dimensions of the strategic innovative behaviour of firms in several previous studies (Evangelista, 2000; Galende & de la Fuente, 2003; Leiponen & Drejer, 2007; Keith Pavitt, 1984; Srholec et al., 2008). It is worth noting that the question is framed differently, that is, as the effects of innovation activities for the CIS2004, whereas for other periods the question is framed as the aims of innovation activities. The comparison of the frequency distribution of the variable importance of effects of innovation for CIS2004 and the variable importance of aims of innovation for the remaining waves of the survey shows that the differences are not very large. Yet, using these two variables as measuring the same feature of the innovation mode remains problematic. In the survey, the variables on aims/effects of innovation activities are grouped into three broader categories: i) product oriented aims; ii) process oriented aims; and iii) other oriented aims (health and safety aspects and regulation and standards). The same fourth-point Likert scale is used as for the question on the importance of sources of information.

4.2. PC and cluster analysis

By way of the principal component analysis the number of variables is reduced into distinct components, which summarize combinations of the selected sets of variables. The principal component analysis is performed separately on the two sets of variables that correspond to the two types of CIS questions on the importance of sources of information and aims of innovation. Table A.3 in the Appendix provides the definition and measurement of variables used in the principal component analysis. The extracted principal components are interpreted as the dimensions of innovation modes. An alternative approach would be to perform the principal component analysis on all of the variables at once. Following

Srholec & Verspagen (2008), the former approach is adopted since it ensures that all dimensions of the innovation modes are well represented.[15] Since all variables feeding into the principal component analysis are measured on an ordinal scale I computed a polychoric correlation matrix as an input to the analysis.[16]

Two principal components for each set of variables with eigenvalues greater than one were retained that account for more than 50% of total variance. To ease the interpretation of the results, the most widely-used varimax normalization rotation method is utilized. Tables 2 to 3 provide overview of the results of the principal component analysis on the importance of sources and aims of innovation.

[15] The principal component analysis was also carried out on all the variables. The results of using the PCA on all the variables at once is a four principal component solution (with eigenvalues >1). The resulting principal components are quite similar to the ones obtained in the PCA on the separate sets of variables, with the exception of R&D that splits between (1) Science and professional sources and (4) Product and Market oriented aims. I proceed with the PCA on the separate sets of variables due to the fact that the obtained components are easier to interpret.

[16] The results are based on unweighted data, since no weights are available for the CIS2004 wave of the survey. Alternatively, I could run the analysis without including the CIS2004 wave of the survey to check the sensitivity of the obtained results due to the fact that the use of unweighted data makes the obtained results not representative for the population.

Table 2: Principal component analysis on the importance of sources of information

Source of innovation	(1) Science and professional sources	(2) Market and internal sources
Universities and other HEI	**0.73**	0.12
Consultants, private laboratories, and research institutes	**0.58**	0.18
Internal sources—within enterprises and other enterprises	0.11	**0.70**
Market sources—clients and customers	0.19	**0.78**
Market sources—suppliers	0.19	**0.57**
Market sources—competitors and other sources from the same industry	0.27	**0.67**
Professional and industry organisations	**0.75**	0.22
Conferences, fairs, and exhibitions	**0.70**	0.31
Scientific journals, professional journals, and other professional publications	**0.82**	0.20

Note: Estimations are not weighted; number of observations is 8,929 (sum of weights is 26,393); two components with eigenvalue > 1 were detected, which explain 54.1% of total variance; extraction method: principal components; rotation: varimax. Bold: The high loadings of the original variables on the principal components.

Table 3: Principal component analysis on the relevance of aims of innovation

Aims of innovation	(3) Process- and corporate responsibility-oriented aims	(4) Product- and market- oriented aims
Increased range of goods and services	0.17	**0.88**
Increased market or market share	0.24	**0.86**
Improved quality of in goods and services	0.45	**0.68**
Improved production flexibility	**0.85**	0.22
Improved production capacity	**0.88**	0.19
Reduced cost of produced units	**0.80**	0.27
Improved environmental impact or health and safety aspects	**0.57**	0.31

Note: Estimations are not weighted; number of observations is 8,929 (sum of weights is 26,393); two components were detected with eigenvalue > 1, which explains 71.1% of total variance; extraction method: principal components; rotation: varimax. Bold: The high loadings of the original variables on the principal components.

Specifically, the first component accounts for high loadings on the importance of sources of information such as universities and other HEIs, private consultants, journals, conferences and professional organizations and is therefore labelled as Science and professional sources. Component 2 returns significant loads on sources of information such as internal, customers, suppliers, and competitors, and thus label Market and internal sources (see table 2). The high loadings on the process- oriented aims of innovation, and the environment impact, health, and safety standards are marked as Component 3 that refers to Process- and corporate-responsibility oriented aims (see table 3). There are other three variables that are suitable for labelling product- and market-oriented aims as component 4, including aims such as increased range of and quality in goods and services, as well as increased market or market share.

In the next step, the scores on the four components derived from the principal component analysis are computed for each observation and are used as input for the hierarchical clustering analysis. The log of FTE of the R&D employees, which is meant to enrich the analysis, is also used as an input. Enterprises are thus grouped according to similar patterns in their scores on the four identified components and R&D. In deciding on the optimal number of clusters the following criteria are used: i) a sensible number of firms assigned to the clusters, and ii) interpretability of the obtained clusters as distinct modes of innovation (Mooi & Sarstedt, 2011).

Table 4 shows the results for the four cluster solution with the average component scores on the main dimensions of the innovation modes and the R&D intensity. For the purpose of further analysis, the clusters are ordered from a low to high profile of innovation mode. At the opposite ends, I find a **Low-profile** cluster (18.6%) that scores low on all the ingredients, especially Market and internal sources and Product- and market-oriented aims, and a **High-profile** cluster (19%) that has high scores on all ingredients, but especially Science and professional sources of innovation. The two clusters in between are more distinct in terms of their scores on the dimensions of innovation modes. The cluster labelled as **Product-market sources** (22.7%) scores high on the Product- and market-oriented aims, but also on Market and internal sources. Finally, the **Process-external sources** (39.7%) cluster scores high on the Process- and corportate responsibility- oriented aims.

Table 4: Hierarchical cluster analysis

	(1) Low-profile	**(2) Product-market sources**	**(3) Process-external source**	**(4) High-profile**
R&D (log of FTE)	1	1,85	1,26	**67,53**
PC1: Science and professional sources	-0.37	-0.29	0.1	**0.5**
PC2: Market and internal sources	-0.94	0.28	0.11	**0.35**
PC3: Process- and corporate responsibility- oriented aims	-0.92	-0.88	**0.78**	0.32
PC4: Product- and market-oriented aims	-1.12	**0.72**	-0.04	0.33

Note: Columns represent the four modes of innovation that have been derived by cluster analysis, while rows show average scores (mean value in the case of R&D) on the main components of the innovation modes. Bold: The highest mean for each variable.

In summary, the number of variables related to the importance of various sources and aims of innovation can be synthesised into four components that are interpreted as specific ingredients or dimensions of innovation modes. Moreover, the cluster analysis results in four specific groups of firms, which are interpreted as specific modes of innovation.

4.3. Characteristics of innovation modes

In the following section, the results of the validation and profiling stage of the cluster analysis based on both the original set of variables used in the clustering step and with respect to an additional set of variables are provided. Table A.4 in the Appendix provides the definition and measurement of variables used for validation and evaluation of the obtained clusters. In order to assess the validity of a cluster solution, the structural characteristics of firms such as size classes and industry are used since modes of learning and innovation are considered to vary across industry and firm size. The choice of the so-called "external criteria"[17] for evaluating the effectiveness of the obtained cluster solution is driven by theoretical consideration and the available set of variables. More specifically, I investigate whether some industry or size groups have greater representation in each cluster compared to their representation in the sample. Even though I acknowledge that each sector and size class can be characterized in terms of the distribution of diverse modes of innovation, as discussed in the literature review, firms belonging to the specific modes can be expected to show higher tendency of being situated in particular industry and/or size classes (Peneder, 2010). Table 5 provides in detail the mean values of these variables for the four clusters and the total sample. In what follows, a short description of each cluster in terms of the previously introduced variables is provided. In the analysis, firms are classified into five broad sectors.[18]

Cluster 1: Low-profile cluster

The firms of this cluster generate process innovation. With respect to the importance of sources of information and aims of innovation, this category of firms relies, to a low extent, on external knowledge sources and attaches very little importance to any of the objectives for innovation. The cluster is

[17] These "external criteria" are additional variables that are not used in the clustering analysis, but can serve for evaluating the usefulness of the obtained cluster solution.

[18] "Low-tech manufacturing" (NACE 5-9, 10-18, 31-32); "Mid-high-tech manufacturing" (NACE 19-30, 33); "Knowledge- intensive business services (KIBS)" (NACE 58-66, 69-75); "Other services & utilities" (NACE 35-39, 45-47, 49-51 and 52-53) and "Others" (agriculture and fishing) (NACE 1-3), construction (NACE 41-43) and selected service and semi-public sectors (NACE 74, 82). We use three size categories: fewer than 50 employees; 50-249 employees; and more than 250 employees.

overrepresented with small firms (fewer than 50 employees) and firms belonging to other services and other sectors. This cluster includes 1,660 firm-wave observations.

Cluster 2: Product-market sources cluster

This cluster consists of firms mainly producing product innovation. Besides their internal knowledge base, firms mainly rely on market sources of information such as clients and customers, but also the competitors. Moreover, the most important aims of innovation of firms are the range and quality of the products, expanding the market and/or increasing the market share. Firms belonging to knowledge Intensive services (KIBS) and small firms are over-represented in this cluster compared to the total sample. The cluster includes 2,025 firm-wave observations.

Cluster 3: Process-external sources cluster

The firms of this cluster mainly create process innovation. While relying on the internal knowledge base, firms put importance on a wide array of external innovation sources, with firms along the value chain (but especially suppliers), external non-market (professional organizations, conferences, journals, universities) and market sources (consultants) being the most prominent. Moreover, the firms in this cluster aim strongly at process efficiency but also at improving the quality of the existing goods and services. Compared to the overall mean, the low-tech and mid-high-tech manufacturing industries and firms with fewer than 50 and 50-249 employees are overrepresented in this cluster. This is the largest cluster that includes 3,459 firm-wave observations.

Cluster 4: High-profile cluster

Activities of firms in this cluster are generating both product and process innovation. The firms of this cluster show the highest importance of achieving both process but especially product and market development aims. While having the highest internal R&D, the extent to which this can be a size effect is difficult to assess, since it is not measured in relative terms. Furthermore, firms complement their research-intensive internal knowledge base with external non-market and market sources. This cluster is similar in size with the low-profile cluster with 1,695 firm-wave observations. The firms of this cluster are overrepresented in the mid-high tech manufacturing and the knowledge-intensive business services. In addition, this cluster consists of a large share of medium and large firms (firms with more than 50 employees).

Table 5: Characteristics of the four identified clusters

	Total	**Low-profile cluster**	**Product-market sources cluster**	**Process-external sources cluster**	**High-profile cluster**
# obs., unweighted	8,929	1,660	2,025	3,549	1,695
Overrepresented industry		Other services and Other	KIBS	Low-tech and mid-high tech man.	Mid-high-tech man. and KIBS
Overrepresented firm size		< 50 empl.	< 50 empl.	< 250 empl.	≥50 empl.
Internal R&D (FTE)	13.92	1	1.85	1.62	**67.53**
Sources					
Competitors	47%	24%	50%	49%	**59%**
Conferences	37%	20%	34%	42%	**50%**
Consultants., etc.	25%	14%	18%	30%	36%
Customers, etc.	**71%**	40%	**79%**	**73%**	**88%**
Internal	**88%**	**61%**	**95%**	**92%**	**99%**
Journals, etc.	26%	13%	18%	31%	39%
Prof. organizations	21%	11%	15%	27%	26%
Suppliers	**57%**	36%	**53%**	**65%**	**64%**
Universities	20%	10%	11%	21%	37%
Aims					
Cost	**55%**	8%	29%	**81%**	**76%**
Flex	46%	4%	18%	**76%**	**58%**
Health	35%	7%	20%	**51%**	45%
Capacity	45%	3%	13%	**76%**	**59%**
Market	**57%**	10%	**72%**	**62%**	**74%**
Quality	**71%**	15%	**79%**	**86%**	**83%**
Range	**61%**	13%	**81%**	**65%**	**78%**

Note: Bold: The percentage for each variable higher than 50%.

In summary, the four obtained clusters can be interpreted as specific modes of innovation in relation to both the original set of variables used in the clustering step and with respect to an additional set of variables and structural characteristics of firms.

In the following, a brief comparison with the results of some previous firm-level studies on modes of innovation is provided. However, it is important to emphasize that the comparison of the results with the previous studies that are concerned with the different taxonomies of modes of innovation is not straight forward due to the differences in the indicators used, the methods, and the scope of the studies. Therefore, no one to one comparison is possible. Yet, some of the previous studies find similar modes of innovation as in this paper. These are: High-profile cluster (cluster 4) (Fitjar & Rodríguez-Pose, 2013; Hollenstein, 2018b; Srholec et al., 2008), Low-profile cluster (cluster 1) (Fitjar & Rodríguez-Pose, 2013; Hollenstein, 2018b; Srholec et al., 2008), Process-external sources, and Product-market sources. Despite the similarities, the modes of innovation identified in this paper also show specificities in comparison with the ones obtained in the previous studies in several respects as explained below.

For example, in the Danish case, the Low-profile cluster seems to be the province of small firms from other services sector. In addition, at least in the case of Denmark, the Product-market development cluster seem to be more specialized in terms of drawing more exclusively from market partners (and to a lesser extent from other external sources) and to be less production-intensive than is the case in the previous studies such as User-driven (Srholec et al., 2008), and Market-driven (Leiponen & Drejer, 2007). In contrast, the Process-external sources cluster relies on both knowledge stemming from suppliers and some freely accessible sources and tends to be production intensive. This cluster corresponds with Externally-sourced (Srholec et al., 2008), and Production intensive/Supplier dominated (Leiponen & Drejer, 2007). Besides, the High-profile cluster is not confined to science-based knowledge sources but utilizes all sources of external knowledge. In addition, internal conditions for absorbing the external knowledge in terms of high internal R&D appear to be associated only with the single cluster labelled High-profile. This cluster shares the characteristics of Science-based firms (De Jong & Marsili, 2006), High profile (Srholec et al., 2008), Scale-/Science-based (Leiponen & Drejer, 2007), and Combined DUI and STI cluster (Jensen et al., 2007).

The identification of the innovation modes of firms is only the first step that is necessary for answering the first two research questions raised in this paper on the dynamics of modes of innovation. Therefore, the following sections examine these questions.

5. Changes in innovation modes over time

I now examine the evidence for changes in modes of innovation over time in two ways. First, since each wave of the survey is designed to be representative of the innovative firms in the population, I compare the distribution of innovative firms across each wave of the survey, and determine if there are more firms in the category associated with the high-profile strategy. Second, due to the panel nature of the dataset, I address more specifically the tendency of firms to switch to another strategy by considering only firms for which information is available for two successive waves of the survey.

5.1. Has the use of mixed or any specific mode of innovation become more prominent over time?

Table 6 shows the distribution of innovative firms in each mode or strategy for the whole period and how the distribution of innovative firms in each mode has changed over time. Since the panel is unbalanced, this could happen for the following reasons. First, firms adopting the High-profile strategy may be more likely to survive due to some performance premium and thus form a larger proportion of the population of the innovative firms over time. Yet, better-performing innovative firms may also choose to become more systemic in their innovation efforts. Second, new firms entering may be more likely to adopt the High-profile strategy, leading to a higher proportion of the firms in this category over time. Third, the firms present in two or more waves may switch to High-profile strategy through time due to the actual or perceived benefits of doing so. Comparing the proportion of innovative firms in each wave thus includes the net results of these effects and should be interpreted in this way.

Table 6: Innovation mode, by time period

Strategy	2002-2015 % (N)	CIS2004 (2002-2004)	CIS2008 (2006-2008)	CIS2010 (2008-2010)	CIS2013 (2011-2013)	CIS2015 (2013-2015)
Low-profile	18.6 (1660)	15%	31%	15%	15%	16%
Product-market sources	22.7 (2025)	21%	16%	22%	27%	27%
Process-external sources	39.7 (3549)	42%	32%	44%	41%	41%
High-profile	19.0 (1695)	22%	21%	19%	17%	17%
Total	100.0 (8929)					

Overall and considering the whole time period, Process-external sources is the most dominant mode of innovation and accounts for almost 40% of observations, while the other three modes of innovation account for relatively similar shares of observations. The Low-profile and Process-external sources orientation modes show a remarkable degree of stability over time (from 15% to 16% and 42% to 41 %, respectively) when comparing the first and the latest period, with a slightly lower share for the latter in the latest considered period. Further, the Product-market mode shows a slight increase in the last period in comparison with the initial period. In contrast, the representation of the High-profile cluster shows a drop in the share (from 22% to 17%). Interestingly, all modes except for the High-profile mode show a high degree of turbulence in the second period (2006-2008), with a doubling of a share for the Low-Profile mode (from 15% to 31%) and, a 10% lower share of the Process-external sources mode (from 42% to 32%). This rather different representation of the modes for the same time period (2006-2008) is also true in the case of the Product-market mode, where the representation changes from 21% in the first period (2002-2004) to 16%. One possible reason for rather different shares of the modes in the period 2006-2008 might be due to the result of overheating of the economy in years prior to the financial crisis in 2008. Subsequently, the last two periods show an almost-identical representation of the modes, thus suggesting great stability in relation to all modes in comparison to the previous waves of the survey. This high stability may or may not be due to the one-year overlap between the last two waves of the survey. For example, this is not the case for the reference periods 2006-2008 and 2008-2010 despite the same one-year overlap between the two waves of the survey. Overall, the results suggest that modes of innovation in the Danish case are rather stable and have not shown any systematic tendency to greater use of High-profile strategy during the period considered and when measured aggregated.

While it is not possible to infer from these data whether the High-profile or Product-market orientation mode results in improved innovation performances, it may be informative to look at the average aggregate innovation performances of firms using each strategy. I use the following indicators: i) the share of firms that introduced a new product; ii) the share of firms that introduced a new process; iii) the share of turnover from new and significantly improved products; and iv) the share of turnover from marginally improved and changed products. Table 7 shows the average innovation performances of firms using each strategy. The research-based modes of learning and innovation are expected to be associated with the higher objective of novelty of new goods and/or services and thus higher tendency in introducing more radical innovation. The firms that are associated with other modes of learning and innovation are expected to be associated with more incremental innovations (Thomä, 2017). Table 7 shows a clear hierarchy in terms of all indicators for each innovation mode, except for the share of process innovators. In other words, the firms using High-profile strategy are more likely to introduce product innovation and are associated with the higher share of sales from both incrementally improved and new products and services.

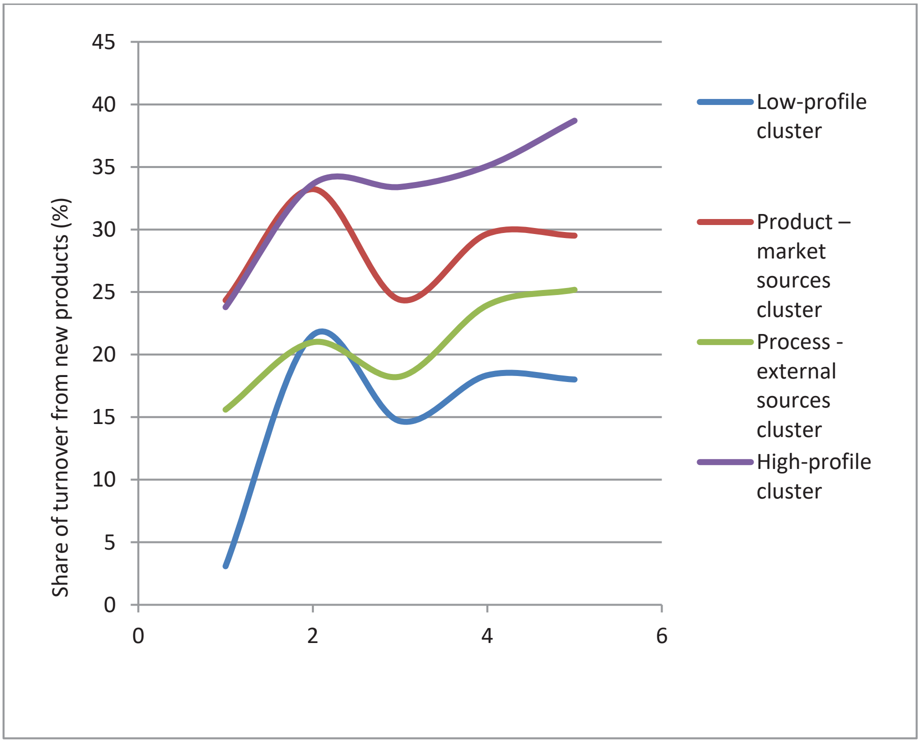
Table 7: Innovation performances by innovation mode

Strategy	Product innovators (%)	Process innovator (%)	Incremental inn. (%)	Radical inn. (%)
Low-profile	50%	54%	41%	17%
Product-market sources	75%	54%	47%	28%
Process-external sources	59%	**76%**	44%	21%
High-profile	**86%**	69%	**54%**	**33%**

Also, it may be informative to look whether the average innovation performance associated with each innovation mode has changed over time, or whether the hierarchy associated with the innovation performances of firms using each strategy persisted over time. Figure 1 shows the relative innovation performances of the four modes of innovation over time.

Interestingly, the first and second surveys show no difference between the Product-market and High-profile clusters, while the second surveys show no differences between the Process-external sources and Low-profile clusters. Afterwards, the clear hierarchy in relation to the relative innovation performances of the four strategies exists and persists over time; but with relatively little changes over time for Low-profile cluster and Product-market orientation. This is not the case for Process-external sources and High-profile cluster that show increased average aggregate performances regardless of the fact that the proportion of the former has changed very little, while the proportion of the latter has declined.

Figure 1: Innovation performances by strategy by wave of the CIS



5.2. Has there been systematic switching towards mixed or any specific mode of innovation?

I now examine whether there is any systemic strategic movement among innovative firms associated with each of the innovation modes in Denmark.

I take into account only firms with observation in at least two successive waves of the CIS survey. The successive means the subsequent available wave, which may or may not follow immediately after the initial wave. As a result, the reduced sample consists of 3,263 observations. However, the time elapsed between the two successive waves of the survey amounts to two- (from 2008 to 2010, and from 2013 to 2015), three- (from 2010 to 2013) or a four-year period (from 2004 to 2008). The study by Hollenstein (2018) shows that the differences in the frequency of switches in innovation modes between a three-year period and a six-year period exist but are rather small. Therefore, it shouldn't be problematic to pool together observations where the time elapsed between the two successive (but non-adjacent) waves differs. Table 8 shows the transition matrix for the reduced sample.

I find that 1,628 out of 3,263 observations (~50%) switch their innovation mode in the short run at least once. Firms present in more than two successive waves can switch their mode more than once. This finding is in contrast with the results obtained by Hollenstein (2018) who finds that, at least in the case of the Swiss innovative firms, around 63% or 69% of firms switch to another mode of innovation in the three-year and the six- and nine-year periods, respectively. On the other hand, the results are in line with Love et al. (2014), who finds that in the context of Irish manufacturing over the period 1991-2008, 49.5% of plants switch their strategy at least once. In line with both previous studies, I find that all the fields are populated, suggesting that all strategic switches are possible in practice, even though some are clearly more likely than others.

The interpretation of the transition matrix can be illustrated with the case of Low-profile mode, where the evidence of switching is most notable. Of the 461 firms which were initially classified in this category, 106 (23%) stayed, 126 (27.3%) switched to Product-market, 180 (39%) switched to Process-external sources, and 49 (10.6%) moved to High-profile cluster. Interestingly, the frequency of switches varies between the identified clusters to a greater extent. On the one hand, firms in the Low-profile cluster (cluster 1) and Product-market sources mode (cluster 2) show more evidence of switching (77% and 63%, respectively). On the other hand, firms in the Process-external sources (cluster 3) and High-profile (cluster 4) mostly stayed within their mode (55% and 65%, respectively). These findings suggest that some modes of innovation (Product-external sources, but especially the High-profile mode) tend to be more stable or persistent over time. In terms of the evidence on the overall movement towards more mixed or any other specific strategy, the Process-external sources mode seems to receive most of the firms moving from their initial category. Despite this, there is little overall evidence of the systemic changes in the direction of any specific mode. More specifically, the overall changes in the proportions of the firms in each category as an outcome of the observed switches are very small and range from a slight decrease in the share of Low-profile mode (from 14.1% to 11.9%) and High-profile mode (from 31.1% to 29.7%) to a slight increase in the proportion of Product-market sources mode (from 18.8% to 20.5%) and Process-external sources (from 36% to 37.8%).

Table 8: Transition matrix of the four innovation modes (number of observations in the parentheses)

	Ending mode				Total
Starting mode	Low-profile	Product-market sources	Process-external sources	High-profile	
Low-profile	**23% (106)**	27.33% (126)	39.05% (180)	10.63% (49)	100% (461)
Product-market sources	13.2% (81)	**37.13% (228)**	33.88% (208)	15.8% (97)	100% (614)
Process-external sources	13.03% (153)	18% (211)	**54.77% (643)**	14.22% (167)	100% (1,174)
High-profile	0.05% (50)	10.26% (104)	19.92% (202)	**64.9% (658)**	100% (1,014)

One caveat to bear in mind is that in the reduced sample firms classified into the High-profile cluster (cluster 4) are overrepresented; while those in the Low-profile cluster (cluster 1) are underrepresented in comparison to that of the total sample, at least in terms of mode membership.[19] Due to the slight underrepresentation of the firms belonging to the Low-profile cluster (cluster 1), the frequency of switches associated with this cluster may be underestimated, while the stability of the High-profile cluster (cluster 2) may be overestimated due to its overrepresentation.

[19] In comparison to the clusters composition of the total sample, firms belonging to the Low-profile cluster (cluster 1) are underrepresented by around 6 p.p., and firms from the High-profile cluster (cluster 4) are overrepresented by 10 p.p. in the restricted sample.

Alternatively, one can follow the approach by Hollenstein (2018) in determining whether there are any evidence of the systemic patterns of switches in innovation modes. The main reason for doing so is to be able to compare the results with those of the previous study. First, the absolute number of outflows from each of the initial mode to each other mode and the overall outflows and inflows for each of the modes are calculated, while not taking into account the number of firms staying in the initial innovation mode. Second, the ratios of inflows from and outflows to the same mode for each specific modes and overall is computed. Third, the previously calculated ratios are transformed into qualitative values in order to account for the relevance of switches from one mode to another and overall.

Table 9 shows the ratios between the net inflows and outflows to and from the specific cluster and overall in a qualitative manner. I find that both Product-market and Process-external mode have the overall positive ratios among the four modes, but the sources of inflows making these positive ratios differ. To the extent that it is possible to make a comparison with the modes of innovation identified by Hollenstein (2018), both clusters 2 (Product-market) and 3 (Process-external sources) and not cluster 4 (High-profile cluster), as in the Swiss case, seem to attract more firms. In addition, firms belonging to less innovative mode (Low-profile cluster) tend to be the main source of the observed overall positive ratio for Product-market sources, whereas both High- and Low-profile mode switches tend to contribute to the overall positive ratio of Process-external mode. Hence, there is no evidence of any systematic pattern of movement toward any specific mode of innovation when keeping in mind that the overall proportion of firms belonging to any of the identified clusters did not change very much over time despite the instances of switches.

Table 9: Inflows and outflows in modes of innovation

Starting mode	Ending mode Low-profile	Product-market sources	Process-external sources	High-profile
Low-profile		+++	+	
Product-market sources	- - -			
Process-external sources	-			-
High-profile			++	
Overall	- -	+	+	-

Note: Three positive or negative signs (+++/---) indicate that the deviation from one (inflows from and outflows to the same mode are equal) amounts to more than 30%. Two signs (++/--) represent divergences of 20% to 30%, whereas one sign (+/-) presents differences of 10% to 20%. Empty cells stand for less than 10%. Tables used to calculate the ratios can be found in the Appendix.

Overall, the descriptive analysis does not support the suggestion of a shift over time towards the more common use of the mixed-mode or any other specific mode of innovation, at least in the Danish case. On the contrary, the composition of the innovation modes seems rather unchanged over time despite the observed switches in the direction of the modes associated with the higher innovation intensity (as shown in Table 7 and Figure 1). Yet, the descriptive data does give some support for the argument that certain modes of innovation tend to be more likely to persist. In order to explore the last research question and test formally whether the innovation modes or strategies differ in their likelihood of changes, I in the next section consider other possible factors that influence persistence.

6. The probability of a change in modes of innovation

Up to now, I investigated the stability of distinct modes of innovation using uni- and bivariate descriptive statistics. To investigate the proposition that modes of innovation differ in their probability of a change and upgrade, I now test this relationship in a multivariate setting on firm level.

6.1. Model

I use the panel dataset that consists of all observations for which the information is available for two or more successive waves (2-5 waves) of the considered surveys (2,830 observations of which 1,716 are unique firms).[20]

To provide evidence for hypothesis 1 (mode stability), I use a firm's change of the mode of innovation (*Change*) between the wave t and t_{+1} as a dependent variable. Thus, I consider the binary variable indicating whether a firm belongs to a same cluster or not in relation to two subsequent waves. Afterwards, to test hypothesis 2 (mode upgrading), I do not consider a firm's change of mode per se, but their upgrading (*Upgrade*) towards higher profile and more systemic modes of innovation as my second dependent variable. This variable is coded as 1 if the change is a movement to broader in scope mode in the subsequent period and 0 otherwise. For example, if the firm changed its cluster membership from cluster 1 in the first period to cluster 2, 3 or 4 in the second period, it will be regarded as an upgrading. However, I don't consider changes from the cluster 2 to cluster 3 (the same goes in the opposite direction) as an upgrading since these modes are rather similar in their scope. This model is run only on a subsample, where I only consider firms with the potential to upgrade, meaning I exclude firms currently associated with mode 4 (highest-level mode, so no upgrading possible) as well as the ones remaining in the same mode. Due to the dichotomous nature of the dependent variables, I deploy a logistic regression for panel data.

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[20] The number of observation differs from the dataset used in the section 5.2 (2,830 observations as against 3,263) due to the fact that I don't consider here firms for which information is not available for two immediately following time periods. More specifically, I only include those observations where the time elapsed between the two successive waves do not exceed three years. The main reason for doing so is that I am interested in the paths of change in the modes of innovation and expect these paths to be gradual in a three-year period, which might not be the case for the observations for which information is available for two subsequent waves where the time elapsed between the two waves amounts to, for example, six years. The reduction of the number of observations, which amounts to 13% compared to the number of observations used in the section 5.2, changes the distribution of firms by clusters in relation to the total sample to some extent. The clusters 1, 2, and 3 are underrepresented by 1,5%, 3,7%, and 4,7%, respectively, and the cluster 4 is overrepresented by 14%.

For the independent variable, I use the results of the previous cluster analysis that served for identifying the modes of innovation. I include three dummies for the firm's cluster membership (*Cluster*)—one dummy is used for each innovation mode (3/4)—where the baseline category corresponds to cluster 1 (Low-profile cluster) so that the significance of variables for other clusters should be interpreted in relation with this benchmark.

I specify a model that includes the following categories of control variables. The model controls for a set of factors that are likely to be associated with both modes of innovation and changes in modes of innovation. Previous studies on the persistence in innovation provide evidence that the characteristics of firms such as firm size, ownership, and persistent behavioural traits tend to exert an influence on the subsequent dynamics in terms of innovation (T. Clausen et al., 2011; Verspagen & Clausen, 2012). The first group of variables includes structural characteristics of firms such as size (*Firm size*), measured as logarithm of the number of employees and age (*Firm age*) measured as logarithm of number of years since the foundation. I also control for the nature of firms' ownership (*Firm ownership*), which is a categorical variable, including collaborative ownership, publicly listed companies, sole entrepreneurs and others. The variable is coded 0 if an enterprise belongs to others, coded 1 if an enterprise is classified as collaborative ownership, coded 2 if it is a publicly listed company and 3 if an enterprise is a sole entrepreneur. The second group of variables includes indicators of innovation output such as share of turnover from incremental (*Incremental innovation*) and radical innovation (*Radical innovation*). Third, I control for the sector with a set of dummy variables indicating the sector class to which the firm belongs (*Sector*). The reason for doing so is based on the recent findings in Verspagen and Clausen (2012), who show that sectoral context matters for innovation strategies of firms, at least in a limited number of cases. In addition, the sectoral features may gain more importance in the context of a single country analysis due to the fact that these may be more homogenous within than between the countries. In addition, I use three time dummies for 2008, 2010, and 2013 in order to control for specific characteristics of the individual waves of the survey. The rows in Table 10 show descriptive statistics for the reduced sample over the whole period of the analysis, the four clusters, and over the separate waves.

Table 10: Descriptives

	Total	Low-profile	Product-market sources	Process-external sources	High-profile
	Mean		Cluster means		
Dependent variable					
Change (%)	48%	79%	62%	44%	33%
2004	53%	69%	86%	61%	30%
2008	50%	79%	62%	43%	34%
2010	49%	80%	67%	45%	37%
2013	44%	80%	53%	39%	29%
Upgrade (%)	18%	79%	15%	15%	/
2004	34%	69%	40%	23%	/
2008	37%	79%	16%	16%	/
2010	23%	80%	13%	15%	/
2013	20%	80%	9%	10%	/
Independent variables					
Cluster (%)	100%	13%	19%	35%	33%
2004	359	8%	16%	35%	41%
2008	774	22%	13%	30%	34%
2010	778	8%	19%	40%	33%
2013	919	11%	25%	35%	29%
Firm size (number of employees)	398	162	191	302	688
Firm age (number of years)	26	24	24	27	27
Firm ownership (%)					
Collaborative	16%	24%	23%	15%	13%
Others	2%	2%	2%	2%	2%
Public Listed	81%	74%	75%	82%	85%
Sole Entrepreneur	0%	0%	1%	1%	0%
Innovation					
Incremental inn.(% of turnover)	49%	41%	49%	45%	56%
Radical inn. (% of turnover)	27%	18%	32%	24%	32%
Sector (share of firms by sector, %)					
KIBS	33%	30%	46%	28%	33%
Low-tech	12%	13%	6%	15%	12%

manufacturing					
Mid-high-tech manufacturing	31%	17%	20%	29%	44%
Other services	18%	30%	21%	20%	10%
Others	6%	10%	6%	8%	1%
Total number of observations	2,830	365	532	994	939

Note: The row Upgrade is empty over the whole period and for the separate years for the High-profile mode (column 5) since no upgrading is possible to observe for this mode.

Over the whole period for the restricted sample, 48% of the observations changed, and 18% upgraded their mode of innovation. The average change of mode, as indicated in Table 10, differs among the four clusters and over time. It varies between 33% for cluster 1 (High-profile) and 79% for cluster 4 (Low-profile) and between 44% in 2013 and 53% in 2004. Similarly, firms' membership varies across identified clusters and over time. On average, firms in the restricted sample are large, with a size of around 398 employees and an age of around 26 years. A fairly large size of the firms in the restricted sample by Danish standards is due to the fact that larger firms have a higher chance of being included in the sample due to the sampling method used by the Denmark Statistics (see section 3). However, the average size and age differs across the clusters. Likewise, 2% of firms are owned by others, less than 1% by solo entrepreneurs, 16% by collaborative ownership, and 81% are publicly listed companies. Over the whole period of the analysis, 49% of the turnover was from incremental and 27% from introducing radical innovations. Finally, the distribution of firms over four industry classes varies within clusters. Table 11 provides a correlation matrix. Few of the considered variables are highly correlated. The highest correlation is between the change and upgrade, which is expected since there can be no upgrade without a change in modes of innovation.

Table 11: Correlation matrix

Variable	Mean	SD	Min	Max	1	2	3	4	5
1. Change	0.48	0.5	0	1					
2. Upgrade	0.18	0.38	0	1	0.49				
3. Firm size (log employees)	4.44	1.66	1	10.03	-0.13	-0.03			
4. Firm age (log years)	2.99	0.8	1	5.45	-0.06	-0.01	0.39		
5. Increment. inn. (% turnover)	49.2	49.2	42.43	100	0.02	-0.01	0.18	0.13	
6. Radical inn. (% of turnover)	27.44	27.44	35.94	100	-0.04	-0.06	-0.12	-0.09	-0.43

Note: The dataset that consists of observations for which the information is available for two or more successive waves (2-5 waves) of the considered surveys (2,830 observations of which 1,716 are unique firms).

6.2. Econometric results

I use a binary logit model since two dependent variables are dichotomous, categorical variables. I account for unobserved heterogeneity of the panel data through the incorporation of random effects.[21] Table 12 shows the results of the first set of models used to explain the association between the changes in modes of innovation and the firms' cluster membership. Models 1 includes some aspects related to the importance of the previously specified categories of control variables, while model 2 contains only the independent variable, the firms' cluster membership. Finally, model 3 encompasses the variables representative of the firms' cluster membership and other control variables.

In Model 1 (Table 12, column 1), I include the variables representing structural firms' characteristics (size, age and ownership), orientation to incremental or radical innovation, and categorical controls for the wave,

[21] Aside from the random effect estimation, I run alternative specification based on fixed effects, but the Hausman's (1978) test provided no conclusive evidence against the use of the random effects estimation for the models. Since I am interested in the effect size of time-constant variables I am controlling for, such as industry and firm characteristics that can be estimated with random estimation I proceed with the random-effect estimation.

ownership type, and sector.[22] The model shows a statistically negative and significant coefficient only for firm size, suggesting that larger firms are less likely to change their mode. However, the effect of firm size is rather small.

Table 12: Random effect logit estimation : Change in modes of innovation

	(1)	(2)	(3)
Mode 2		-0.911^{***}	-0.914^{***}
		(0.180)	(0.181)
Mode 3		-1.771^{***}	-1.707^{***}
		(0.170)	(0.168)
Mode 4		-2.260^{***}	-2.116^{***}
		(0.173)	(0.179)
Size (log)	-0.229^{***}		-0.128^{***}
	(0.035)		(0.035)
Age (log)	-0.013		-0.025
	(0.065)		(0.065)
Turn.inc	0.001		0.003^{**}
	(0.001)		(0.001)
Turn.rad	-0.001		0.001
	(0.001)		(0.001)
Period dummies	Yes	Yes	Yes
Sector dummies	Yes	No	Yes
Ownership dummies	Yes	No	Yes
N	2,830	2,830	2,830
Log Likelihood	-1,877.799	-1,788.697	-1,776.430
Akaike Inf. Crit.	3,787.598	3,593.393	3,590.860
Bayesian Inf. Crit.	3,882.766	3,640.977	3,703.873

Note: $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$, standard errors in parentheses

[22] The unreported coefficients on sectoral affiliation are negative and significant in the case of the Mid-high tech manufacturing, and this is to a lesser extent also true for the Low-tech manufacturing and KIBS. In the case of other services, the coefficient is negative and insignificant.

Model 2 only includes the variables representing the firm's mode of innovation (with mode 1 as reference) plus the controls for time. It shows negative coefficients which are statistically significant at the 1% level for the three modes of innovation variables. The coefficient of the Product-market sources mode (2) is the smallest, while in the case of the Process-external sources (mode 3) is of an intermediate size. The negative and significant coefficient in the case of the High-profile (mode 4) is the highest. As expected, the hierarchy in the likelihood of change between the modes is visible, providing first evidence for hypothesis 1. In other words, there is a monotonic increase in the size of the coefficient on the four modes of innovation. Model 3 contains all independent and control variables jointly. Here, all innovation mode related effects remain, while the magnitude of firm size is roughly halved, indicating the increased persistence of higher-level modes of innovation to not be driven by underlying firm characteristics.

In order to provide a more nuanced interpretation of the changes, in the second set of models, I use *upgrading* (changing towards a higher-level mode of innovation) as dependent variable.[23] Here, I follow the same modeling strategy as in the set of regressions presented in Table 12. In Model 1 (Table 13, column 1), only including the control variables, the positive and significant coefficient shows for the firms' size. These results indicate that larger firms are more likely to upgrade their mode of innovation despite being less likely to change their mode. This may be due to the resource advantages as well as strategic factors associated with large firms.

[23] As previously indicated, the number of observations differs due to the fact that I exclude firms that did not change their cluster membership in the subsequent time period.

Table 13: Random effect logit estimation: Upgrading in modes of innovation

	(1)	(2)	(3)
Mode 2		-0.640***	-4.480***
		(0.025)	(0.646)
Mode 3		-0.649***	-4.586***
		(0.023)	(0.628)
Size (log)	0.137***		0.311***
	(0.040)		(0.070)
Age (log)	-0.032		-0.098
	(0.071)		(0.111)
Turn.inc	0.0001		0.004**
	(0.001)		(0.002)
Turn.rad	-0.001		0.004
	(0.002)		(0.002)
Period dummies	Yes	Yes	Yes
Sector dummies	Yes	No	Yes
Ownership dummies	Yes	No	Yes
Observations	1,891	1,891	1,891
Log Likelihood	-1,063.932	-783.377	-764.951
Akaike Inf. Crit.	2,159.863	1,582.754	1,565.902
Bayesian Inf. Crit.	2,248.581	1,627.113	1,665.710

Note: *p<0.1; **p<0.05; ***p<0.01, standard errors in parentheses

In Model 2, I only include the independent variable (the innovation mode, where mode 1 is again the reference) plus the time dummies. The negative and significant coefficients on modes 2 and 3 are quite similar, indicating that both modes are equally less likely to upgrade to the High-level mode 4, as compared to an upgrade from mode 1 to any other mode. This provides initial evidence for hypothesis 2, suggesting the change between modes indeed to become more difficult when moving towards High-level modes. Model 3 again contains all the variables. The positive and significant effect of firm size remains but becomes stronger. Likewise, the negative and significant coefficient on modes 2 and 3 remain negative and increases by orders of magnitude when controlling for firm-level variables. Finally, there is a weak positive effect associated with incremental innovation.

In summary, the regression analysis provides a number of insights. First, the evidence shows that firms in the modes of innovation which are broader in scope are less likely to change vis-à-vis the firms found in the Low-profile mode. More specifically, innovative firms in the High profile mode (mode 4) are less likely than firms in modes 3 and 2 to change their mode of innovation vis-à-vis the firms found in the Low-profile mode (mode 1). In addition, firms in modes 3 and 2 are almost equally less likely to upgrade their modes of innovation vis-à-vis the firms found in the Low-profile mode (mode 1), indicating that there is no hierarchy between the two in this respect. After allowing for other firm- and industry level conditioning there is an increase in the size of the negative effect for the two modes of innovation. With respect to the effect of firm size, a statistically significant and positive relationship is found for upgrading.

7. Discussion and Conclusion

The main purpose of the paper was to explore the dynamic aspect of firms' modes of innovation. To this end, I identified four modes of innovation based on a set of CIS-based indicators and drawing on the pooled firm-level data from both the Business Register, and the Danish part of the European Community Innovation Survey (five waves), covering the period 2002-2015. I interpreted these modes as generic strategies of firms and, based on their emphasis on the elements of the innovation processes, labelled them as Low-profile, Product-market sources, Process-external sources, and High-profile. The identified modes are plausible in terms of the number of firms assigned to them and their interpretability. While the comparison on the one-to-one basis with the results obtained from the previous taxonomic studies dealing with the firms' modes of innovation or learning is problematic due to the reasons explained in section 4.3, the obtained modes are broadly in line with the previous taxonomic studies.

By examining either systemic changes in the number of firms in identified modes of innovation over the extended period of time as well as specifically in terms of specific firms' switches to other modes of innovation, this study finds no empirical support for the expectation of the systemic move towards any specific mode of innovation over time, at least in the Danish case. More specifically, there is evidence of a slight decrease in High-profile cases and an increase in Product-market orientation mode for the whole period. Yet, the evidence shows that, through time, firms do make mode switches and that all mode-switch options are possible, but that these are masked when considering the aggregate number of firms in each of the categories. In other words, the switches in innovation modes of firms do take place rather often, while the resulting outcome at the system level can be characterized as rather stable and slowly adjusting.

However, the descriptive analysis provides suggestive evidence that some modes of innovation (Process-external sources, but especially the High-profile mode) tend to be more stable than others. In order to explore this issue further, I formally test whether there are differences between the identified modes of innovation in terms of the likelihood of change and upgrading over time. To this end, I econometrically estimate the model, which includes additional factors that can influence the temporal stability of modes of innovation.

With respect to the first hypothesis, which states the decreasing probability of change towards High-profile mode of innovation, I found that the coefficient is negative and significant (in the case of change) for the three identified modes of innovation (Product-market, Process-external, and High-profile) relative to the base Low-profile mode (mode 1). The negative coefficients indicate that these firms are less likely to change their innovation mode than those found in the Low-profile mode in the initial period. In addition, the coefficients for these three modes of innovation differ from each other, as expected. The negative coefficient in the case of the firms initially found in the High-profile mode (mode 4) mode is the highest one. This is followed with the firms initially found in the Process-external sources (mode 3) mode, where the negative coefficient is of intermediate size, and with the Product-market sources mode (mode 2) yielding the smallest negative coefficient. Overall, the results confirm the first hypothesis that different modes of innovation lead to different probabilities of change and that this tendency shows a hierarchy with respect to a scope of the innovation mode pursued by firms. More specifically, a stronger emphasis on the different elements of the modes of innovation leads to a more persistent pursuit of the initial innovation mode. These results support the idea made in section 2.2.3 with respect to the different degrees of persistence of the activities underlying different modes of innovation. More specifically, the mode of innovation associated with the R&D activities seems to be the most persistent one (Verspagen & Clausen, 2012). Yet, this is also true, although to a lesser extent, for the Process-external sources mode that relies on various internal and external sources of information in pursuing both process efficiency and the product quality aims. The hierarchy in terms of the baseline probability of change in the case of the two intermediary or specialized modes (Product-market sources and Process-external sources) is less clear in the sense of their emphasis on different sources and objectives, which on the whole are rather similar in their scope. This higher persistence of Process-external sources mode is in line with the point made in Clausen et al. (2011) that the lack of influence of the innovation strategies in explaining the persistence of the process innovation in comparison to the product innovation (measured as innovation output) may be explained by the fact that the process innovation is less based on a strategy but more on learning by doing.

With respect to the second hypothesis in relation to the decreasing probability of upgrading defined as moving to a broader in scope (the stronger emphasis on the different elements of innovation modes), the evidence support the hypothesis that upgrading is less likely if the firm is initially found in either Product-market (mode 2) or Process-external mode (mode 3) relative to the baseline Low-profile mode (mode 1). Interestingly, in terms of upgrading, no hierarchy is evident between the firms found in the two intermediary modes of innovation (Product-market and Process-external). Therefore, the firms in these two modes of innovation appear to be almost equally less likely to upgrade then the firms found in Low-Profile mode in the initial period. This seems to suggest that it is equally difficult to achieve upgrading (movement to mode 4) from these two starting points. This result is strengthened when I control for other firm- and industry-level factors. Moreover, the effect of firm size on the probability of upgrading is statistically significant and positive. The positive coefficients indicate that larger firms are more likely to upgrade their innovation mode. This is also the case for the Mid- and high-tech manufacturing and KIBS vis-à-vis the Other sectors and for the Collaborative ownership and Publicly-listed firms vis-à-vis firms in other ownerships. This clearly identifies some sectors and corporate ownership forms of firms that do seem to matter in explaining the probability of upgrading. In terms of Mid- and high-tech manufacturing sector, this is in line with the results in Love et al. (2014), who find in a dynamic context that a tendency of switches towards both strategies (has R&D and external linkages) is associated with more innovation-intensive manufacturing plants. Yet, these are very broad aggregates and more refined level of disaggregation is needed to explore this matter further.

From a policy perspective, the following implications may be drawn. The results about a lack of systemic changes towards a so-called mixed mode (combining elements of R&D and interacting) which increases firms' innovation potential raises the questions why this is the case and more importantly how to encourage firms to move in the direction of adoption of modes that will improve their innovation performances and make them more competitive as well more capable to cope with changes. In relation to the first question, Gokhberg and Roud (2016) makes several suggestions, including the relative stability in the overall system of innovation and especially in terms of the incentives system, but also the cumulative and path-dependent processes of learning of firms and thus gradual improvement of the innovation strategies.

In connection with the concepts of open or mixed innovation modes, this study confirms that these innovation strategies are not an only or a simple choice for the firm. In other words, only one cluster of firms, labelled as High-profile, shows characteristics of combined R&D practices and relatively well-developed external linkages to diverse sources. One could, therefore, argue that R&D-based firms are increasingly using a wide range of non-science based sources of information and knowledge, but that this has not been followed with an overall increase in R&D activities that indicate a strong capacity to absorb and link to scientific knowledge sources in other non-science-based modes. Moreover, the finding that firms in the Process-external mode—associated with low focus on R&D—and High-profile mode—associated with high R&D orientation—undertake the broadest external search strategies, although with different intensities and priorities, is consistent with previous studies (Herstad, Bloch, Ebersberger, & van de Velde, 2010; Laursen & Salter, 2004), emphasizing the need for policymakers to direct their efforts to supporting broadening of the search strategies of firms rather than focusing exclusively on science-based sources. Nevertheless, encouraging firms to adopt more "open" (greater openness in terms of external search for information, cooperation, and sourcing of technologies) or mixed innovation strategies (integrating different modes of learning and interacting) may not be optimal in every case in terms of maximizing private or social benefits for the economy as a whole (Love et al., 2014; Parrilli & Alcalde Heras, 2016). For example, moving away from a mixed strategy or maintaining the specialized strategy may still be optimal for some individual firms.

The finding that firms in the Process-external mode-associated with low focus on R&D, and High-profile mode—associated with high R&D orientation—undertake the broadest external search strategies, although with different intensities and partners suggest that the determinants of absorptive capacity need to be understood relative to the types of knowledge absorbed. In other words, R&D activities are not the only factor of the capacity of firm to absorb external knowledge, and different factors (e.g., related prior knowledge/experience and the employees' skills) might matter with respect to different kinds of knowledge (e.g., scientific and knowledge from the business sector) and sources (e.g., universities versus customers), which in turn vary across the modes of innovation (Schmidt, 2005).

The presence of different modes of innovation also supports the idea about the path-dependent nature of absorptive capacity for different types of sources in terms of searching in the area of previous experience and related knowledge sources. One implication is that innovation policy needs to take as its point of departure different innovation modes of firms and carefully balance between supporting and incentivizing knowledge development, accumulation and integration within firms (e.g., R&D, design, training for innovation, organizational practices that support learning) on the one hand, as well as the ability of firms to link to narrow and/or heterogeneous sources of information or collaboration partners on the other hand as pointed out in Kirner and Som (2011). When it comes to differences between the modes of innovation in terms of temporal stability, the policy implications become more complex.

The study has several limitations and some of them are avenues for future research. The identified modes of innovation are influenced by the available data and the selection of variables feeding into the principal component and cluster analysis. However, the previous studies suffer from the same deficiency to more or less extent. More specifically, better indicators of different practices of the DUI-mode of learning are needed to provide an adequate understanding of this mode and how it is combined with other aspects of the innovation activities of firms. In addition, firms can use a mix of strategies in relation to different innovation projects, something which cannot be accounted for in this type of survey. Another limitation is that the findings of the association between the specific modes of innovation and changes are only valid relative to other innovation active firms because the dataset contains only innovation active firms. In addition, due to the cross-sectional nature of data the results of the regression analysis need to be interpreted as conditional correlation and not casual relationships. Another limitation is that I am not able to tell much about the stability and changes in innovation modes within different industries over time. Indeed, a promising line for future research is to relate the modes of innovation to firms' innovation and economic performances. Another topic that may be interesting for the future research is to investigate the dynamic aspects of innovation systems as reflected in the changes of modes of innovation in the context of less developed countries that differ from the highly developed country like Denmark in order to determine how the findings discussed here might change.

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Appendix

Table A.1: Comparability over time

	CIS2004	CIS2008	CIS2010	CIS2013	CIS2015
Survey methodology					
Sampling frame	Official business register				
Data collection	Survey method				
Survey type	Combination of sample and census	Mandatory, combination of sample and census			
Sampling design	Stratified simple random sampling with a panel sample and PPS-modified allocation method				
Stratification NACE sectors	DB03		DB07		
Size classes	6				
Gross initial sample	3,364	4,438	4,322	4,788	5,044
Net sample	1,697	4,438	4,322	4,788	5,044
Estimated	400	/	/	/	/
Realized sample	2,097	4,438	4,322	4,788	5,044
Sample rate (realized) %	62%	100%	100%	100%	100%
Unweighted unit response rate	50%	/	/	/	/
Non-response analysis	Yes	/	/	/	/
Population size	NA	22,215	19,483	18,674	17,856
Innovation active	1,195	2,033	1,920	1,950	1,931
% Innovation active	57%	46%	44%	41%	38%

Table A.2: Composition of the total sample by industry and size classes

	2002-2004		2006-2008		2008-2010		2011-2013		2013-2015		Total	
	N	%	N	%	N	%	N	%	N	%	N	%
Sector												
KIS	357	30%	781	40%	667	35%	740	38%	650	34%	3,195	36
Low-tech manuf.	174	15%	177	9%	226	12%	213	11%	270	14%	1,060	12
Mid-high manuf.	330	28%	452	23%	456	24%	407	21%	435	23%	2,080	23
Other services	253	21%	451	23%	390	21%	388	20%	382	20%	1,864	21
Other	81	7%	106	5%	161	8%	193	10%	189	10%	730	8
Size class												
< 50	486	41%	1,030	52%	975	51%	994	51%	1,016	53%	4,501	50
50-249	429	36%	577	29%	615	32%	670	35%	660	34%	2,951	33
250 and more	280	23%	360	18%	310	16%	277	14%	250	13%	1,477	17
Total	1,195	13%	1967	22%	1900	21%	1941	22%	1926	22%	8,929	100

Table A.3: Innovation indicators used in the principal component analysis (PCA)

Indicator	Measurement scale and value range	
Importance of sources of information		
Universities and other HEI	Ordinal	0, ..., 3
Consultants, private laboratories, and research institutes	Ordinal	0, ..., 3
Internal source—within enterprises and other enterprises within the enterprise group	Ordinal	0, ..., 3
Market sources—clients and customers	Ordinal	0, ..., 3
Market sources—suppliers	Ordinal	0, ..., 3
Market source—competitors and other sources from the same industry	Ordinal	0, ..., 3
Professional and industry organizations	Ordinal	0, ..., 3
Conferences, fairs, and exhibitions	Ordinal	0, ..., 3
Scientific journals, professional journals and other professional publications	Ordinal	0, ..., 3
Aims of innovation		
Relevance of product oriented aims		
Increased range of goods and services	Ordinal	0, ..., 3
Increased market or market share	Ordinal	0, ..., 3
Improved quality of goods and services	Ordinal	0, ..., 3
Relevance of process oriented aims		
Improved production flexibility	Ordinal	0, ..., 3
Improved production capacity	Ordinal	0, ..., 3
Reduced cost of produced units	Ordinal	0, ..., 3
Relevance of other oriented aims		
Improved environmental impact or health and safety aspects	Ordinal	0, ..., 3

Note: It is worth noting that the question differs for the CIS2004 (2002-2004) wave, where it was framed as the importance of the effects of company's innovation activities.

Table A.4: Indicators used to characterize and evaluate the clusters

Indicator	Measurement scale and value range	
Innovation indicators used in the cluster analysis		
R&D (log of full time equivalent of R&D employees)	Continuous	
Aims of innovation activities (% of firms with score 2 or 3 on a four-point ordinal scale (for definition see Table 1)	Continuous	0, …, 100
Source of information for innovation (% of firms with score 2 or 3 on a four-point ordinal scale (for definition see Table 1)	Continuous	0, …, 100
Incremental vs. Radical innovation		
Share of turnover from new or significantly improved products (%)	Continuous	0, …, 100
Share of turnover from marginally improved or changed products (%)	Continuous	0, …, 100
Structural characteristics		
Firm size		
Number of employees (the log of)	Continuous	1 or more
Share of firms (%) by three size classes (no. of employees): fewer than 50; 50-249; more than 250	Continuous	0, …, 100
Industry affiliation		
Share of firms (%) by five industry classes (%):	Continuous	0, …, 100

Table A.5: Inflows and outflows

A.5a Inflows and outflows	Inflows from				Overall outflows
Outflows to	Low-profile	Product-market	Process-external	High-profile	
Low-profile		126	180	49	355
Product-market	81		208	97	386
Process-external	153	211		167	531
High-profile	50	104	202		356
Overall inflows	284	441	590	313	1,628

A.5b Ratio of inflows from and outflows to modes (column)				
	Low-profile	Product-market	Process-external	High-profile
Low-profile		1.55	1.18	0.98
Product-market	0.64		0.98	0.93
Process-external	0.85	1.01		0.83
High-profile	1.02	1.07	1.21	
Overall ratio	0.80	1.14	1.11	0.88

A.5c Ratio of inflows from and outflows to modes (columns)				
	Low profile	Product-market	Process-external	High profile
Low-profile		+++	+	
Product-market	- - -			
Process-external	-			-
High-profile			++	
Overall	- -	+	+	-

Note: Table A.5a shows in the columns the number of firms a specific mode receives from other modes and the overall inflows (the last row), while rows present the number of firms outgoing from a specific mode to the targeting mode and the overall outflows. For example, Low-profile mode receives 81 firms from Product-market mode, 153 from Process-external, 50 from High-profile mode, and 284 firms overall. Similarly, of the firms initially found in Low-profile mode, 126 switch to Product-market, 180 to Process-external, 49 to High-profile and 355 overall. However, this table is only used to calculate the ratios (second step) reported in the Table 6b. Table A.5b shows that cluster 1 (Low-profile cluster) loses 36%

more firms to cluster 2 (Product-market sources) and 15% more firms to cluster 3 (Process-external sources) than it gains from these clusters. Yet, it gains 2% more firms from cluster 4 (High-profile cluster) then it loses to that cluster. Overall, the overall inflows to cluster 1 (Low-profile cluster) are 20% lower than the overall outflows to other clusters. The opposite is true for cluster 2 (Product-market sources), which, overall, receives 14% more firms than it loses to other clusters (overall ratio is 1.14). In this case, large inflows from cluster 1 (Low-profile cluster) are more than prominent (it attracts 55% more firms from cluster 1 than it loses to this cluster). According to the overall ratio, cluster 3 (Process-external sources) is the second most attractive cluster that receives 11% more firms than it loses to other clusters. The net inflows to this cluster are especially prominent from cluster 4 (High-profile cluster) and cluster 1 (Low-profile cluster). The net inflow ratios are 1.2 and 1.17 respectively. In contrast, the net inflows ratio from cluster 2 is largely balanced (ratio of 0.99). When considering cluster 4 (High-profile cluster), overall, this cluster attracts less firms than it sends to other clusters (overall ratio is 0.88). The net loses, primarily reflect the net outflows to cluster 3 (Process-external sources) (it loses 17% more firm from cluster 3 than it gains from the same cluster). In sum, cluster 2 (Product-market sources) and to less extent cluster 3 (Process-external sources) tend to be on the receiving side. In turn, cluster 4 (High-profile cluster) and cluster 1 (Low-profile cluster) seem to be on the losing side, the overall ratio between the net inflows and net outflows being rather high 0.88 and 0.80, respectively.

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