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The Activities and Functions of Innovation Systems:

A Step Towards a General Theory of Innovation?

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Abstract

'The system of innovation approach' has been prominent in innovation research for more than three decades. In this paper, we ask whether this work has taken us closer to what could be called a 'general theory' of innovation. We argue that there is now a considerable literature addressing what happens in the innovation systems (and not only which elements and components they include). This literature places the focus on the causes of innovations in terms of functions and activities in the systems. Analysing this literature, including the several studies on activities and functions, is the focus in this paper. We aim to find out whether the work on activities and functions can be seen as a step towards developing a general theory of innovation. We argue that as a 'collective research community', we have already tried to do this, and that we have made some progress. We indicate how such work can continue to develop the systems of innovation '*approach*' into a '*theory*'. However, such a formal and general theory of innovation remains yet to be developed. In this paper, we aim to outline one direction in which such work can potentially be pursued.

Keywords: activities of innovation systems; functions of innovation systems; general theory of innovation; systems of innovation

1. Introduction

It is sometimes argued that innovation is too complicated a matter to make it possible to talk about causality related to innovation processes. It means that innovation processes cannot be explained and that we should forgo issues of causality in both innovation research and innovation policy.

However, we argue that we need to know about causal relationships in order to understand innovation processes, especially why and how they emerge. Most importantly, because it is impossible to design and pursue public innovation policies without having an idea about the main causes (or *determinants*) of the innovation processes that we want to influence. The same goes for firm innovation strategies. For example, the selection of public policy and firm strategy instruments must be based upon knowledge about determinants that can influence innovations processes. Without such knowledge it is better to completely abstain from trying to pursue innovation policies or firm innovation strategies. Put briefly, we need a theory of innovation. And this theory must be causal, i.e., it must connect causes (determinants) and effects to each other.

In general systems theory, a 'system' must have elements or components, and there must be relations among them (Fleck 1992, 5; Edquist 1997, 13–15). A system must also have a function, i.e., it must perform or achieve something. In the case of systems of innovation, the system produces innovations. In addition, it must be possible to make a distinction between the system and the rest of the world. Systems may be closed or open (Edquist, 2005, p. 187), but systems capturing innovation processes should be regarded as open systems. This means that components that are outside the system at one point of time, can later become part of it. Also, completely new components may be created.
In physics and chemistry, one and the same theory is often used for making both explanations and predictions. However, we do not intend to make such a strong claim for the innovation theory for which we are searching. We rest content with trying to contribute to creating a theory that *ex post facto* can explain the emergence of innovations. We do not expect it to be immediately useful in making straightforward predictions of where and when innovations next will occur. Nonetheless, a theory is needed when trying to actively create good public innovation policies.

Developing a theory is a matter of identifying the causes of certain phenomena (for example innovations). To develop a theory, it is necessary to make a clear distinction between causes and effects. Jon Elster formulated this as follows: "I argue that all explanation is causal. To explain a phenomenon (an *explanandum*) is to cite an earlier phenomenon (the *explanans*) that caused it" (Elster 2015, 1). In other words, no-one who wants to develop a theory (of innovation) can avoid the issue of causality.

A theory should provide convincing propositions as regards established and stable relations between different kinds of phenomena (variables or concepts).[1] It should be specific about what are the causes/determinants and what are the effects and the relations between the two. In a causal theory of innovation, the effects are the innovations as such. The causes/determinants are the factors that influence the development and the diffusion of innovations. Conceptual clarity is required for the formulation of theories (of innovations). In section 2, we will therefore return to definitions of the main concepts used. [2]

Our point of departure is the systems of innovation approach, developed in the late 1980's. Christopher Freeman was first to use the term (1987) and the first two books on systems of innovation, edited by Lundvall and Nelson, were published in 1992 and 1993. The development of this approach meant a significant leap forward in our understanding of innovation processes and in our ability to pursue innovation policies. The system of innovation approach has diffused enormously and has dominated innovation research for the past decades. It is the result of a collective effort by the broad innovation studies community.

However, the systems of innovation approach has often been criticised for being too static because of its strong focus on elements or components of the systems, such as institutions and organisations (Bergek et al. 2008; Hekkert et al. 2007). This focus has allegedly not

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[1] "Stable" does not necessarily mean that the relations are eternal truths that are beyond discussion. Theories may be revised, and new paradigms may replace previous ones. This is true for the natural sciences and, to a larger extent, for the social sciences, including innovation research. "Stability" regarding relations between phenomena can also be expected to be less in new fields of research than in established ones. The topic of this paper is actually an example of a research field that have developed from very new and immature to more mature during the decades covered in the text. "Maturity" in various fields of research is a matter of degrees.

[2] We choose not to go into specific details concerning different kinds of causal explanations and what theories actually are. Such discussions are pursued in Fragkandreas (2023), Lewis (2023) and Borrás and Edquist (2019).

contributed to an understanding of what is actually 'happening' inside the systems. More specifically, there has been a need for a clearer understanding of the processes inside the innovation systems that influence innovation processes, i.e., of the determinants of innovation. We will return to this issue in section 2.2.

Early on, we judged the status of a 'system of innovation' in the following way: "The system of innovation approach does not provide convincing propositions as regards established and stable relations between variables. Hence, it does not fulfil the requirements to be labelled a formal theory, and we ourselves have preferred the terms approach and conceptual framework" (Edquist 1997, p 28).

However, perhaps the time has come to try to develop the systems of innovation approach into an innovation theory? The purpose of this paper is to discuss whether this is possible to do, and, if so, how far has the existing work on activities and functions taken us. The central question is: What is needed for a transformation of the systems of innovation approach into a general theory of innovation? At the same time, it is important to note that this article does not set out to create a theory of innovation by itself, but analyses one possible direction towards it.

One reason why the development of a general theory might now be possible is the fact that the volume of research results in the field of innovation studies has increased enormously during the latest decades. Although there are still different and competing definitions of "system of innovation", the research field has also matured. There is now a considerable literature addressing what happens in the systems (and not only which elements and components they include). This literature places the focus on the causes of innovations in terms of functions and activities in the systems (see the Appendix in this paper). Analysing this literature, including the work on activities and functions, will be the main focus in this paper. We will try to find out whether the studies on activities and functions are useful for developing a general theory of innovation.

In particular, we look at how different authors have identified the activities or functions in innovation systems. This will allow us to determine whether there has been a general consolidation of "systems of innovation" as a developing theory to understand and explain innovation processes. We will argue that we, as an "invisible college" or

"collective research community", have already tried to do this, and that we have made progress, by addressing activities and functions in innovation systems. We will try to indicate how this work can continue to develop the systems of innovation "*approach*" into a "*theory*".

After presenting some definitions in section 2, we will address activities and functions in innovation systems in detail in section 3. On this basis we will, in section 4, return to the issue of the development of a general theory of innovation.

2. Definitions

In this section we define and briefly discuss the two central concepts of this paper – *innovation* and *system of innovation*.

2.1 Innovation

The widespread use of the concept of 'innovation', in many different areas with many different meanings, requires some clarification. "Innovation" has been defined in many ways by many authors. There are narrow specifications and there are comprehensive ones. It would absorb a lot of time and many pages to specify all these definitions – and it would take even longer to compare them to each other. It is, however, crucial that we are clear about what we mean by "innovation" and that we inform our readers about it.

As a point of departure, we have chosen to use the general definition of innovation that is provided by the Oslo Manual, as it is presented in the latest version (OECD, Eurostat, 2018). The Oslo Manual is the standard basis for such discussions. The *general definition* of innovation by the Oslo Manual (2018) is as follows:

"An innovation is a new or improved product or process (or combination thereof) that differs significantly from the unit's previous products or processes and that has been made

available to potential users (product) or brought into use by the unit (process)." [3] (OECD and Eurostat 2018, 60) This general definition is relevant to *all* sectors. [4]

Definitions like these are not right or wrong. They are good or bad for certain purposes. Our purpose here is to explain innovation. We are interested in innovation output, i.e., the actual development and diffusion of new products and new processes (innovations), that can, in principle, be measured. We are also interested in the causal explanations of this innovation output.[5]

Just like the general definition of the Oslo Manual, we define innovations as an output or result that can be divided into product innovations and process innovations. Product innovations are new – or better – material goods as well as intangible services. Process

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[3] By units, the Oslo Manual means "all institutional units or entities" (OECD and Eurostat, 2018, p.60), including government units and business enterprises. It is important to mention, however, that in a system of innovation innovations are normally carried out by firms, i.e., by organizations. The Oslo Manual probably includes firms in the notion of institution, which can be questioned.

[4] "All sectors" are, according to the Oslo Manual, the following: "Business, Government, Non-profits serving households, and Households)" (OECD and Eurostat, 2018 p 22)

[5] We noted in section 1 that it is necessary to make a distinction between causes and effects to be able to achieve causal explanations and develop theories. In parts of the Oslo Manual, a clear distinction is not made between cause and effect; explanans and explanandum. The Oslo Manual also uses the term "activities" which we will also use in the main part of this paper. However, the two of us mean different things with "activities". We mean "determinants" or "causes". The Oslo Manual means "innovation processes". This means that the Oslo Manual's work on creating a conceptual framework with regard to innovation is not useful when it comes to developing a general theory of innovation. The Oslo Manual also suffers from several other important deficiencies (repetitions, unclarity, contradictions) - possibly because of being a result of a consensus-seeking process, which lead to compromises. Lack of space does not allow us to sort these issues out in this paper. Our intention is, however, to do so in another context.

innovations are new ways of producing goods and services. They may be technological or organizational (Edquist 2005: box 7.1, page 182).

For us, the effects are the innovations as such, i.e., the innovation outputs. They are the new products and the new processes that have been developed. The causes are the factors that influence (or lead to) the effects. They are the determinants or inputs of (the development and diffusion of) innovations. We are here interested in innovations as such and in the determinants of innovations. However, we are, in this paper, *not* interested in the consequences (or outcomes) of innovations, although they are astonishingly important – for productivity growth as well as for effects on the environment, climate, and health and other societal issues. [6]

2.2 System of innovation

We define an innovation system as one that include 'all important economic, social, political, organizational, institutional and other factors that influence the development, diffusion and use of innovations' (Borrás and Edquist, 2013; Edquist, 2005, 1997: 14). This definition reflects a dynamic approach that goes beyond identifying the components of a system of innovation and includes the various processes that drive change in those systems.

The concept of 'system of innovation' was born as a reaction to the *linear model* of innovation (Bush 1945). Often called a "supply and technology-push" view, the linear model took as an assumption that innovations are "generated by a process consisting of well-defined, consecutive stages, e.g., basic research, applied research, and development work" (Borrás and Edquist 2019). However, research and development (R&D) is only one of the determinants of innovation.

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[6] Innovations have been the source of more than 90 percent of all increased productivity since 1870. (Baumol 2010). Productivity growth can be transformed into higher wages, larger profits and increased taxes, and is thereby the most important basis of welfare in its turn. Some innovations have destroyed our environment and others are instruments that can help us mitigate the threats to the climate, or to our health.

The systems of innovation approach did not only constitute a supplement to the previously dominant "linear", partial and supply-push understanding of innovation processes (which were strongly oriented towards research as the dominant determinant of innovations).[7] The systems of innovation approach, in which demand side determinants of innovation processes are also important, actually *replaced* the linear view.

This occurred in innovation *research*. However, the innovation *policies* pursued in practically all countries are also still partial (captures only a few determinants) and linear (strongly emphasizes research as a determinant of innovation processes). In this sense, innovation policy is far behind innovation research, and innovation policy designers can learn a lot from innovation research.

Since there are many determinants of innovation processes, the understanding of innovation processes and innovation policies has to be generalized from a partial view into a holistic one. A *holistic innovation policy* is here defined as one that tries to integrate *all* public actions that influence or may influence innovation processes – not only, or mainly, research. Holistic policies are not driven by the supply side only but have a much wider scope. Therefore, holistic policies require a wide and comprehensive understanding of what a system of innovation is.[8]

One needs to acknowledge, that innovation can have a number of different determinants, some of which we may currently not even be aware of. Therefore, any definition based on determinants, must also be open to accommodating our expanding knowledge of innovation by including new determinants.

The system of innovation approach offers a view based on determinants of innovation. Both Lundvall (1992) and Nelson and Rosenberg (1993), in their pioneering work on

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[7] The "linear" view is further discussed below.

[8] 2005 was the first time that the word holistic was used in an innovation systems context. The holistic perspective has later been developed by Edquist (2011, 2014, 2019), and Borras and Edquist (2019).

national systems of innovation, defined national systems of innovations in terms of determinants or factors affecting innovation processes. However, they only used a limited number of determinants. Nelson and Rosenberg (1993) emphasize the organizations that support R&D. Lundvall (1992) identified the structure of production and the set of institutions to define a system of innovation. Thereby his version can be characterized as *partial*. Similarly, the Nelson and Rosenberg version is partial and linear.

The emergence and development of the systems of innovation approach was a great leap forward in our understanding of innovation processes and in our ability to pursue innovation policies. We owe a lot of thanks and respect to the pioneers of this work, in particular Freeman, Nelson and Lundvall. One reason for why we use the SI approach in this paper is that it is the best "framework" or "approach" that we currently have. [9]

Research has continued on this basis and the literature is now enormous. Some researchers have addressed what they call functions and activities in systems of innovation. We believe that this is an important trajectory to follow, since it gives more specificity and (potentially) consistency to the approach. It is important for the development of both innovation theory and innovations policies in the future. In the rest of this paper we will summarize, compare, and analyse such attempts. We will also evaluate to what degree and how these contributions have added to the further development of the systems of innovation approach – or to an emerging theory of innovation.

3. Activities and functions in systems of innovation

In section 3, we will take a closer look at activities and functions. In particular, we will present and analyse the different contributions that address the activities or functions in innovation systems. We will do the following.

- We will introduce the phenomenon by providing examples of sets of activities/functions (section 3.1).

[9] We will present arguments for this in later sections.

- We will discuss how the different authors define "activities" and "functions", and if there are any differences between the two terms (section 3.2).
- We will discuss the main reasons and rationales of the different authors for creating and specifying their sets of functions/activities (section 3.3).

As indicated, each of the points above will be addressed in one subsection in section 3. A summary and conclusions will be presented in section 4. We will also address whether it would be possible and useful to move along the trajectory towards developing a general theory of innovation – or if this is even already a currently ongoing process.

3.1 Examples of activities/functions

The analysis of activities/functions in innovation systems has become one of the central pillars in innovation system studies. Two of the most notable articles on the subject are by Bergek et al (2008), and Hekkert et al (2007). It has been claimed that the 'citation burst' following the publication of the papers by Bergek et al (2008) and Hekkert et al (2007) marked one of the main 'intellectual turning points' in studying innovation systems (Z. Liu et al. 2015). According to Dahesh et al (2020), these are among the 10 most cited papers on the analysis of innovation systems and constitute the cornerstones of the distinctive "functions" cluster (together with an early paper by Carlsson and Stankiewicz (1991)).

These landmark studies by Bergek et al (2008) and Hekkert et al (2007) were, however, preceded by several earlier analyses that discussed the issue of what is 'happening' in innovation systems. Some of these early studies had already resulted in listing main functions or activities.[10] One of the earliest comprehensive lists was suggested by Galli and Teubal (1997), followed by a thorough analysis of the functions in innovation systems literature by Johnson (2001) [11].

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[10] See Appendix 1 in Bergek et al (2008) for a detailed comparison of the early lists of functions/activities.

[11] Johnson is A. Bergek's maiden name.

Around the same time, Liu and White (2001) suggested an early list of five activities, seeking to provide a tool for comparing innovation systems. Building partly on these early attempts, a comprehensive list of ten activities was compiled by Edquist (2005). The primary motivation of the authors of these papers was to escape the perception that the national system of innovation approach is too static because of its focus on elements of the innovation systems, such as organizations/actors and institutions/rules. These authors tried to avoid this by emphasising the processes leading to innovations, namely the activities and functions in innovation systems.

The main purpose for embarking on the discussion around activities and functions has thus been to develop a better understanding of innovation processes (Bergek et al. 2008) and their determinants (Edquist, 2005; Hekkert et al., 2007). This, in turn, has been based on the expectation that it would allow for comparative studies of different innovation systems (X. Liu and White 2001) and pursuing an overall stronger policy analysis (Hekkert et al. 2007).

The number of activities and functions varies considerably between the different lists, ranging from five to ten. At the same time, similar to the findings of earlier analysis (Bergek et al. 2008), these lists are to a large extent in agreement with each other on the main blocks of activities and functions.

The intention of this section (3) is not to provide an exhaustive overview of the literature, but to focus on a limited number of studies that we consider the most significant for the development of the activities/functions approach. First, we have included three early studies that are often cited as the first accounts of activities and functions – Galli and Teubal (1997), Johnson (2001) and Liu and White (2001). Second, we have included the three most cited studies – Edquist (2005), Hekkert et al (2007) and Bergek et al (2008) (with respectively 4 031, 3 072, and 2 612 citations in Google Scholar on April 12, 2024).[12]

[12] All these lists of functions and activities can be found in the Appendix in this paper.

Bergek et al (2008) have earlier compared a number of sets of activities and functions and found that they match each other to a large extent. Bergek (2012, 2019) compared the sets of Hekkert et al (2007) and Bergek et al (2008), concluding that, while similar, their empirical application reveals several differences in ”underlying assumptions, definitions and operationalizations” (p. 204). The current study builds on that and takes a step further, as we also analyse comparatively how various authors define activities and functions, as well as their rationale for studying activities/functions.

3.2 How do different authors define activities/functions?

In this subsection we will discuss how the different authors define *activities* and *functions*, what they mean by these terms, and which differences there are between them. We start our overview of the literature by looking at how the different authors have themselves defined the two terms. Initially, it is important to clarify that while Liu and White (2001) and Edquist (2005) use the term ’activities’, Hekkert et al (2007) and Bergek et al (2008) refer to essentially the same concept by using the term ‘functions’.

Among the earlier accounts, Galli and Teubal (1997) approach functions through the classic national innovation systems prism, where the “components or building blocks of an NSI comprise groups of organizations” (p. 346). As such, they take an organisation-centric view and state that a function is the role that an organisation performs. Liu and White (2001) use the term ‘activities’, but do not offer an explicit definition of it. However, they do see their object of analysis as the “fundamental set of activities related to the creation, diffusion and exploitation of technological innovation within a system” (p. 1093). Johnson (2001) defines a function through the concept of system components - “all system components contribute to the goal of the system or they would not be considered part of that system” (p. 2-3). A function is thus the “contribution of a component or a set of components to the goal” (p. 3), while, referring to Carlsson and Stankiewicz (1991), the goal of an innovation system itself is to “develop, diffuse and utilise innovations” (p. 4).[13]

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[13] Johnson (2001) is quite clear about functions being the causes of innovations. This early line of arguments is developed further in Bergek et al (2008).

Among the subsequent studies on the subject, Edquist (2005) defines activities as "factors that influence the development, diffusion, and use of innovations" (p. 190). Bergek et al (2008, 409) define 'functions of technological innovation systems' as processes "which have a direct and immediate impact on the development, diffusion and use of new technologies". Hekkert et al (2007) understand functions as "processes that are highly important for well performing innovation systems" (p. 413).

All-in-all, we can see that the definitions of activities and functions are surprisingly similar. There is a broad agreement that both activities and functions should help us understand the 'factors' (Edquist, 2005) or 'processes' (Bergek et al. 2008; Hekkert et al. 2007) that contribute to the main function (Edquist, 2005), or goal (Johnson 2001), of an innovation system. Thus, we can clearly see a common focus among the authors on understanding what influences the achievement of the overall goal of an innovation system, sharing a point of departure in the early work by Carlsson and Stankiewicz (1991).

Furthermore, while some authors use the term 'activities' (Edquist, 2005; Liu and White, 2001) and others use 'functions' (Johnson 2001; Bergek et al. 2008; Hekkert et al. 2007; Galli and Teubal 1997), there is no substantial difference between these terms in the current context. In fact, Hekkert et al (2007) use the term *activities* to explain the meaning of *functions.* More specifically, they emphasise that "since these activities have the function to contribute to the goal of the innovation system /.../ the activities are often called functions of innovation systems" (p.415).

Edquist (2005) explains his choice of the term "activity" primarily through the need to avoid confusion with the 'functionalist' approach in sociology. The 'functionalism' in sociology places an emphasis on the *consequences* of phenomena, whereas the goal of looking at functions/activities in innovation systems in this paper – and elsewhere - has been to study the *determinants/causes* of innovation. This is his fundamental reason to use the term "activity" instead of "function". (Edquist 2005, page 204, footnote 16)

3.3 What is the rationale/purpose of different authors to specify activities/functions?

In this subsection we analyse the reasons and rationales of the different authors for focussing on activities/functions. We try to answer the question if the various authors develop their sets of functions/activities with the purpose of analysing the *causes* or *determinants* of innovation processes? This question is important for us since we are interested in whether the sets of functions/activities have contributed to the development of a theory of innovation, i.e., a theory about the causes or determinants of innovation processes.

On one hand, we can see that the early studies (Galli and Teubal 1997; X. Liu and White 2001; Johnson 2001) emphasise the role of activities/functions in providing a useful tool for analysing and comparing innovation systems. Starting with Galli and Teubal (1997), we see that they study functions in order to understand the changing role of organisations in a national system of innovation. While "every organization within a building block predominantly performed a specific role or function" (p. 346), the organisations nowadays "tend to play increasingly multiple roles" (p. 346). Therefore, for a better (comparative) understanding of the innovation systems, it is necessary to distinguish between the organisations and the functions that they perform.

Liu and White (2001) argue that activities are important to consider, because of a "lack of system-level explanatory factors" (p. 1092) in national systems of innovation research. They are critical towards earlier approaches, since a focus on "organizational categories such as "research institute", "firm" or "government" can generate more confusion than insights" [14].. Thus, they suggest that "system-level analysis should begin with an understanding of how fundamental activities of the innovation process are organized, distributed and coordinated" (p. 1094). In saying that, they stand in agreement with Galli and Teubal (1997) that a focus on organisations in innovation systems analysis is too limiting and does not allow for proper comparative analyses between different systems.

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[14] This is because the organisational categories may have very different meanings in terms of the range of activities they undertake in different national contexts. (p. 1093)

It should also be noted that they use the term "activities" to refer to the processes taking place in innovation systems.

Johnson (2001) sees the overall aim of studying the functions in understanding the "contribution of a component or a set of components" (p. 3) to the innovation processes. At the same time, the more immediate role of functions is providing a tool for mapping the similarities between the different system approaches. In her own words: "The differences between and within approaches make it difficult to compare, or indeed combine, the findings of different system approaches. It might, therefore, be useful to look beneath their surface to see if there is any agreement between the approaches with respect to what they claim "happens" in an innovation system". (p. 2) [15] We can see that, similarly to Liu and White (2001), Johnson (2001) also points out the need for a framework that allows for better comparative analysis. However, for Johnson, the focus of comparison is not as much on innovation systems, but on *approaches* for studying innovation systems.

On the other hand, the later accounts (Edquist 2005; Hekkert et al. 2007; Bergek et al. 2008) set a focus on understanding the *determinants* of innovations. As a first example, Edquist (2005) sees activities as determinants or causes of the main function of an innovation system. He sees studying the activities as a way to understand what "happens"

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[15] Beyond this starting point, Johnson (2001) identifies five reasons why a functions' approach is necessary:
(1) it helps delimit system borders to "components that influence one or more of the identified functions" (p. 16);
(2) it can be used to "describe the present state of a system" (p. 16) and thus be the basis for any policy suggestions.
(3) it is useful for describing system dynamics, contributing to the "understanding of how innovation systems emerge and change" (p. 16);
(4) it allows to "assess the performance of an innovation system" (p. 17);
(5) it permits an uncoupling of actors "from what happens in an innovation system" (p. 17), thereby reducing "the risk of comparing system structure instead of system functionality" (p. 17).

(2005, 190) in the innovation systems, since what happens in the systems is more important than the components of the systems. Therefore, to understand the innovation processes, it is necessary to identify their determinants (activities) (p. 190).

In addition, it is important to consider the extent to which different determinants influence innovation processes - "A satisfactory explanation of innovation processes almost certainly will be multicausal, and therefore should specify the relative importance of various determinants" (Edquist 2005, p 191). We must also understand the relationships between the determinants, since they "cannot be expected to be independent of each other, but instead must be seen to support and reinforce—or offset—one another" (p. 190). Hence, there are relations between the different activities in innovation systems in addition to the causal relations between the individual activities and the overall function of the innovation system. Furthermore, according to Edquist (2005), an important purpose of looking at activities as determinants/causes is to identify the boundaries of innovation systems in a specific way: "/…/if we know the determinants of their development, diffusion, and use, we will be able to define the boundaries of the SIs in terms of activities" (Edquist 2005, 201).

Bergek et al (2008) argue that earlier literature on innovation systems has placed too much emphasis on the structural composition of systems. Therefore, including a perspective on processes (via *functions*) is important because it places a focus on "the dynamics of what is actually "achieved" in the system rather than on the dynamics in terms of structural components only" (p. 409). This separation of structure from content thus allows for more informed policy-decisions - "in order to be able to identify the central policy issues in a specific innovation system, we need to supplement a structural focus with a process focus" (p. 409)). Quite importantly, from their definition of functions as processes "which have a direct and immediate impact on the development, diffusion and use of new technologies" (Bergek et al. 2008, 409), we can derive that they consider the functions to be *determinants* of innovation, thereby placing their line of argument on the same line with Edquist (2005) and Hekkert et al (2007).

Hekkert et al (2007) claim that "in order to understand technological change, one needs insight in innovation system dynamics" (p. 417). In particular, to study the change in technological systems, it is necessary to look at activities that take place in the systems

(the 'functions of the innovation system'). These functions would provide a good starting point to "map the system dynamics" (p. 418). More specifically, Hekkert et al (2007) point out three reasons for using the functions approach: providing a framework for comparative analyses, analysing the determinants of innovation processes, and delivering stronger policy analysis.

There is a clear consensus among the papers by Edquist (2005), Hekkert et al (2007) and Bergek et al (2008), that it is important to understand the causal factors that lead to innovations. Both Edquist (2005) and Hekkert et al (2007) explicitly highlight that it is necessary to identify and understand the *determinants* or *causes* of innovation processes – and studying the activities/functions constitutes an important step towards that goal. This argument is supported by Bergek et al (2008), who in their definition of functions acknowledge the 'impact' of functions on innovation. Bergek et al (2008) also see the functions as processes in innovation systems that "directly influence the development, diffusion and use of new technology" (p.408). Hence we conclude that Edquist (2005), Bergek et al (2008), and Hekkert et al (2007) agree that the functions/activities are in fact the *determinants* of innovation processes, thereby strengthening the explanatory power of the SI approach and bringing us closer to a *general theory* of innovation.

The authors covered in the current study are in agreement, that the main purpose for focussing upon activities/functions is to "supplement a structural focus with a process focus" (Bergek et al. 2008). In other words, it can help us move our understanding of the innovation systems beyond an emphasis on organizations, institutions and other structural elements. Simultaneously, it can lead us towards important insights of the processes occurring within and between the organisational structures, and consequently in the systems of innovation.

We have addressed many sets of functions and activities in innovation systems in this paper. All those lists are presented in the Appendix at the end of the paper. This does not indicate that they are uninteresting. On the contrary, it is very rewarding to go through them in detail as examples of determinants that may influence innovation processes. And, as we have repeatedly argued, those lists are of terrific value for anyone who is interested in participating in the transformation of the systems of innovation approach into a theory

of innovation. We therefore strongly recommend our readers to consult those lists in the Appendix.

4. Summary and Conclusions

4.1 Summary of arguments

In sections 4.1 and 4.2 we summarise the main arguments of the paper. In section 4.1, we revisit the key points from the earlier sections of the paper. It is followed, in section 4.2, by a wider and more general discussion of how the identification and analysis of functions and activities in innovation systems can play - and has played - a role in the efforts to develop a theory of innovation[16].

We started with an argument that all social-scientific explanations are causal (See section 1). In sections 2 and 3 we have stressed the importance of making a clear distinction between *explanandum* and *explanans* in order to make it possible to causally explain a phenomenon. In the case of developing a theory of innovation, the explanandum is innovation output, and the explanans are the factors that influence innovation output. Hence causal explanations are matters of identifying those factors that influence innovation output.

The system of innovation approach meant a great leap forward for our understanding of innovation processes and for our ability to pursue innovation policies. The definitions by both Lundvall (1992) and Nelson and Rosenberg (1993) were based on selected determinants of innovation processes. Lundvall selected two determinants (structure of production and set of institutions) and Nelson and Rosenberg selected one (organizations

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[16] There are no references to the literature in section 4. At the end of each paragraph in sections 4.1, we instead explicitly refer to the specific earlier section in the paper where the argument was developed. The reader can find the full references to the literature there. Sections 4.1 and 4.2 are meant to constitute a combined summary and conclusion, and therefore include some repetition.

that support R&D). Therefore, the Nelson and Rosenberg definition can be characterized as *partial* and *linear* and the Lundvall one as *partial*. (Section 1 and 2.2)

At the same time, the Edquist (1997) definition of system of innovation included *all* factors (determinants or causes) that influence the development and diffusion of innovations and can therefore be characterized as *holistic*. Introducing the term *activities* (and listing ten of them), he pioneered the operationalization of the causal relationship between the determinants (*explanans*, explanatory factors, causes) and the resulting innovations (*explanandum*, outcome, phenomena to be explained, effects). The analysis of activities/functions in innovation systems has since become a central element in innovation system studies with the studies on activities and functions in innovation systems by Edquist (2005), Hekkert *et al* (2007) and Bergek *et al* (2008) being among the most cited papers in the field of innovation studies.(See section 3.1)

Compared to earlier discussions on activities and functions, the current study takes a step further as we also analyse comparatively how various authors define activities and functions, what is their rationale for studying these, and whether there is a difference between the activities and functions. (See section 3.1) While Liu and White (2001), and Edquist (2005) use the term 'activities', Hekkert *et al* (2007) and Bergek *et al* (2008) refer to essentially the same concept by using the term 'functions'. The terms 'activities' and 'functions' are used by these authors to describe the same phenomenon. (See sections 3.1, 3.2, and 3.3)

The primary motivation of the authors of these papers on functions/activities was to escape the perception that the system of innovation approach is static, because of its focus on elements in systems of innovation such as organisations/actors and institutions/rules. These authors have tried to counter this challenge by focussing upon activities/functions, i.e., on what is *happening* in innovation systems. (See sections 3.1, 3.2 and 3.3) In particular, Edquist (2005), Hekkert *et al* (2007) and Bergek *et al* (2008) bring attention to the need for identifying and understanding the *determinants* or *causes* of innovation processes. Studying the activities/functions constitutes a crucial step towards that goal – and, towards the further development of a general innovation theory. (See section 3)

Edquist (2005), Hekkert *et al* (2007) and Bergek *et al* (2008) have been working with identifying functions and activities in different ways – trying to solve different parts of the puzzle. Nevertheless, as an "invisible college" they have contributed to achieving the same objective: getting closer to formulating a causal theory of innovation. While contributing to this common goal, they might also have been very critical to each other's attempts. In this paper we have been trying to show that research often means joint efforts and may lead to joint results, even if it was not clear at the time to the participating researchers. (See sections 3.3 and 2.2)

We could notice that the definitions of activities and functions are very similar in the writings of different authors. They all agree that activities and functions help us understand what is 'happening' in the innovation systems, by identifying the 'factors' (Edquist 2005) or 'processes' (Bergek *et al* 2008, Hekkert *et al* 2007) that contribute to the main function or goal of an innovation system. This goal is commonly agreed to be to develop and diffuse innovations. (See section 3.2). We could also notice that Edquist (2005), Bergek et al (2008), and Hekkert et al (2007) agree that the functions/activities are in fact the *determinants* of innovation processes, thereby contributing to the explanatory power of the SI approach and bringing us closer to what could constitute a *general theory* of innovation.

Finally, an explanation of an innovation process will almost certainly be multicausal. The determinants cannot be expected to be independent of each other. Instead, they are likely to support and reinforce – or offset – one another. A theory of innovation should therefore specify the relations between the determinants as well as the relative importance of various determinants for certain categories of innovations. (See section 3.3)

4.2 General conclusions: towards a general theory of innovation

In sections 3 and 4.1, we have argued that much of the writings on "activities" and "functions" in the literature of innovation systems contributed to the analysis of determinants of innovation as an explanans (explanatory factor, causes) of innovations.

This literature thereby contributed to the development of the state of the art in the direction of a general theory of innovation.

What remains to be done is to achieve this to a larger extent and in the long run. This can be done by conceptual clarifications and developments that have been tried in this paper. The functions/activities proposed by different authors should also be further evaluated and compared. Progress in such conceptual work can then be used as a basis for formulating hypotheses to be tested in empirical studies. This is the main mechanism for gradually developing our knowledge about determinants (functions, activities) of the development and diffusion of innovations. Such empirical research must include the measurement of the resulting product and process innovations.

The possible end result of future work would be a general theory of (the determinants of) innovation. It would attempt to identify all hitherto important determinants of the development and diffusion of innovations and their relative weight for different classes of innovations. Thereby some of the instruments of innovation policy would also be identified since they are a subset of the determinants. Although causality is a complex matter in the social sciences, knowledge of causes, determinants and policy instruments is necessary for understanding innovation systems and for being able to pursue effective public innovation policies and firm strategies.

Of course, such an effort would absorb several or many calendar years and perhaps a couple of hundred person-years. Given the enormous significance of innovation as a force of change in our socio-economic, environmental and political systems, this is highly motivated. We should remember that innovations have been the source of more than 90 percent of increased productivity since 1870, that they are the most important source of welfare and that innovations have an enormous impact on the environment, climate issues and health. (See footnote in Section 2.2.)

Naturally, such a combined theoretical and empirical effort that we talk about here would be gradual and start by identifying the most important and obvious determinants of innovation. As a matter of fact, such a process has already started through the development and consolidation of the systems of innovation approach, through different

sets of determinants (activities/functions) that have been developed by different contributors and which have been summarised and discussed in this paper.

Appendix: Which activities/functions do the different studies propose?

In this Appendix we present the sets of functions/activities as proposed by all the authors addressed in this paper. However, we do not present any comments on or comparisons of the various lists. There are, however, some comments and comparisons presented earlier in this paper.

Galli and Teubal (1997), in their early attempt of listing the functions of national innovation systems, distinguish between 'hard' and 'soft' functions, where the former require 'hard organisations' (i.e. the ones with laboratories and performing R&D) and the latter relying on 'soft organisation' (who do not perform R&D, but play a "catalytic and interface" (p. 346) role).

The hard functions are:

1. R&D, involving universities and public (governmental, local, mixed) and non-profit organizations.
2. supply of scientific and technical services to third parties

The soft functions include:

1. diffusion of information, knowledge, and technology;
2. policy-making;
3. design and implementation of institutions;
4. diffusion/divulgation of scientific culture;
5. professional coordination.

Liu and White (2001) offer a list of five activities, building on "prior research on innovation systems and, more generally, the technological innovation process" (p. 1094):

1. Research (basic, developmental, engineering)
2. Implementation (manufacturing)
3. End-use (customers of the product or process outputs)
4. Linkage (bringing together complementary knowledge)
5. Education

Johnson (2001) suggests a list based on a comparison of different innovation systems approaches, "built around some basic functions that most authors seem to agree on" (p.

12). In what Hekkert et al (2007) describe as a list "almost synonymous with a set of policy recommendations" (p. 419), Johnson first outlines two functions "directly related to the innovation process" (p. 12):

1. Identify problem (bottlenecks)
2. Create new knowledge (R&D, search, and experimentation, learning, imitation)

These primary functions are followed by others that "support the innovation process indirectly" (p. 13):

1. Supply incentives for companies to engage in innovative work
2. Supply resources (capital and competence)
3. Guide the direction of search (influence the direction in which actors deploy—resources)
4. Recognize the potential for growth (identifying technological possibility and/or complementary resources)
5. Facilitate the exchange of information and knowledge
6. Stimulate/create markets
7. Reduce social uncertainty
8. Counteract the resistance to change that may arise in society when an innovation is introduced (provide legitimacy)

In later empirical work, the Johnson 2001 original list has been reduced to five main functions (Bergek and Jacobsson 2003; Jacobsson, Sandén, and Bångens 2004):

1. Creation of new knowledge
2. Guiding the direction of the search process
3. Supply of resources
4. Creation of positive external economies (exchange of information, knowledge and visions)
5. Formation of markets

Edquist (2005), suggests a list of ten activities, arranged into the categories of knowledge inputs (1-2), demand side factors (3-4), the provision of constituents of SIs (5-7), and support services for firms (8-10:

1. Provision of Research and Development (R&D), creating new knowledge, primarily in engineering, medicine, and the natural sciences.

2. Competence building (provision of education and training, creation of human capital, production and reproduction of skills, individual learning) in the labour force to be used in innovation and R&D activities.
3. Formation of new product markets.
4. Articulation of quality requirements emanating from the demand side with regard to new products.
5. Creating and changing organizations needed for the development of new fields of innovation, e.g., enhancing entrepreneurship to create new firms and intrapreneurship to diversify existing firms, creating new research organizations, policy agencies, etc.
6. Networking through markets and other mechanisms, including interactive learning between different organizations (potentially) involved in the innovation processes. This implies integrating new knowledge elements developed in different spheres of the SI and coming from outside with elements already available in the innovating firms.
7. Creating and changing institutions—e.g., IPR laws, tax laws, environment and safety regulations, R&D investment routines, etc—that influence innovating organizations and innovation processes by providing incentives or obstacles to innovation.
8. Incubating activities, e.g., providing access to facilities, administrative support, etc. for new innovative efforts.
9. Financing of innovation processes and other activities that can facilitate commercialization of knowledge and its adoption.
10. Provision of consultancy services of relevance for innovation processes, e.g., technology transfer, commercial information, and legal advice.

Hekkert et al (2007) suggest a list of seven functions, based on the "different categories of functions and several empirical studies" (p. 421)

1. Entrepreneurial activities
2. Knowledge development
3. Knowledge diffusion through networks
4. Guidance of the search
5. Market formation

6. Resources mobilization
7. Creation of legitimacy/ counteract resistance to change

Bergek et al (2008) propose a list of seven functions, "synthesized from a number of different system approaches to innovation" that have been "applied and further developed" (p. 414) by the authors and other researchers. The functions are:

1. Knowledge development and diffusion
2. Influence on the direction of search
3. Entrepreneurial experimentation
4. Market formation
5. Legitimation
6. Resource mobilization
7. Development of positive externalities

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