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An evolutionary model of innovation policy: Conceptualizing the growth of knowledge in innovation policy as an evolution of policy alternatives

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1 Introduction

Research on public policies for science, technology, and innovation is primarily a problem-oriented field. This research primarily focuses upon the need for
government investment into developing new scientific and technological knowledge and in stimulating their diffusion through education and through the use of new knowledge in firms for business innovations (McKelvey 2014). Hence, research on science, technology and innovation policy—innovation policy for short—is primarily driven by demands for normative advice instead of specific theories or paradigms (Morlacchi and Martin 2009). As a consequence, much research focuses upon rational policy choices, such as optimal levels of R&D subsidies or the structure of public venture capital funds, in order to address various forms of market or system failures (Arnold et al. 2013), and it pays less attention to the fundamental nature of the policy process and how the process unfolds over time (Flanagan and Uyarra 2016; Uyarra 2010). This paper therefore focuses upon policy processes, analyzed through an evolutionary approach.

One fundamental issue, that has received insufficient attention, is the capacity of policy organizations to implement policies and how this capacity evolves through learning (Borrás 2011; Kattel and Karo 2015). Already in their 1982 book Nelson and Winter noted the importance of this topic when they stated that the “design of a good policy is, to a considerable extent, the design of an organizational structure capable of learning and of adjusting behavior in response to what is learned” (Nelson and Winter 1982: 384). Similarly, Lundvall (1992) argued that policy learning was important for the adaptability of innovation systems. Recent research has stressed the importance this topic in the context of the trans-national transfer of innovation policies in European Union (Malik and Cunningham 2006; Suurna and Kattel 2010) and of mission-oriented innovation policies addressing grand societal challenges and aiming for smart, inclusive and sustainable economic growth (Mazzucato 2016, 2017).

Possible reasons for the scarcity of existing research include the lack of a clear conceptual foundation for studying learning in the context of public innovation policy organizations as well as an overall lack of attention to the policy process itself (Borrás 2011).

The purpose of this paper is to propose an evolutionary model of the growth of knowledge in innovation policy making, and thereby propose new directions for
further research on learning in the context of public policy organizations. The paper builds on, and extends, the few initial attempts that have been made to develop evolutionary models of aspects of innovation policy making (McKelvey and Saemundsson 2017; Witt 2003) and innovation policy capacity (Karo and Kattel 2016).

The conceptual model we develop in this paper is explicitly based upon evolutionary economic theory in three ways. First, we focus upon the dynamics of learning, using the broad concepts of variation, retention and selection over time as a way to understand the evolution and diffusion of knowledge (McKelvey 1996). Second, recurrent patterns of interdependent action by multiple actors—labeled as organizational routines in the evolutionary theory of the firm (Winter 2006)—have a central role in our model. We understand these patterns as expressions and embodiments of organizational capacity (Murmann et al. 2003) that reflects the growth of knowledge. Hence, we are arguing that organizational evolution plays a key role in the evolution of knowledge. Third, we pay special attention to how it is possible for this type of self-organizing system to transform itself through the generation of novelty (Witt 2002), leading to increased specialization and complexity of coordination (Metcalfe 2014).

We contend that our model is especially relevant for research on mission-oriented innovation policies. First, as introduced above, policy learning and adaptation are key to our perspective, and also have a central role in mission-oriented innovation policies as means to build the necessary knowledge within policy organizations to direct and coordinate private and public actors when “formulating and implementing policies that address societal challenges through innovation.” (Mazzacuto 2017, p. 7)). Second, our model shares a dominant feature of the mission-oriented policy approach; namely, an appreciation of the combination of top-down direction and bottom-up experimentation (Foray et al. 2012; Mazzacuto 2016). Finally, our model provides a conceptualization of complex policy organizations, thereby aligning with the broader policy literature on innovation systems, transformative change, and mission-oriented policy to focus upon system-wide transformation (Edquist and McKelvey 2000; Foray et al. 2012; Geels 2001; Mazzucato 2017; Schot and Steinmüller 2016).
The paper is structured as follows. In section two we specify growth of knowledge as an evolutionary process, which we put in the context of innovation policy making in section three. In section four we derive our evolutionary model of the growth of knowledge in policy making, and, finally in section five, we conclude the paper by summarizing the characteristics of the model and discussing its usefulness for studying cross-country similarities and differences in innovation policies and mission-oriented innovation policies.

2 Growth of knowledge as an evolutionary process

Evolutionary theories help explain how the characteristics of entities evolve as the entities adapt to their environment. They are most widely known for explaining the biological evolution of species, but are also used to explain the cultural evolution of knowledge, language and artifacts (Campbell 1987, Ziman 2000). Furthermore, evolutionary theories—evolutionary economics for short—have been developed to explain the evolution of economic entities, such as firms, industries, and economies (Nelson and Winter 1982; Dopfer and Potts 2008).

In evolutionary economics, knowledge plays a key role in explaining the evolution of economic entities. In their pioneering and enduring pre-eminent work, Nelson and Winter (1982) viewed human know-how as the key characteristics that evolved as firms adapted to their environment through market-based selection. Conceptualizing this know-how as organizational routines Nelson and Winter were able to account for the role of knowledge as a source of novelty and as an important determinant of firm performance selected for by the market. Thus, surviving firms adapt to their environment by growing their knowledge.

The broad evolutionary economics view in the Nelson and Winter tradition describes the growth of knowledge as an evolutionary process, but is primarily focused in the evolution of firms and industries. These ideas have been very influential for the study of science, technology and innovation, which have focused on explaining how the commercialization of scientific and technological knowledge by industrial firms is linked to economic growth and development.
through the rise and fall of industries (Foster and Metcalfe 2001; Dollimore and Hodgson 2014; Dopfer and Potts 2008; McKelvey 1996; Nelson and Winter 1982). Hence, evolutionary approach is relevant for the study of innovation policy making, but its core evolutionary principles need to be adapted to the new context (Hodgson and Knudsen 2006; Pelikan 2011; Witt 2014). Our point is that the growth of knowledge in innovation policy making takes place in policy organizations—not firms—and market-based selection does not play a central role. Organizational routines are still relevant, but we require a more abstract generalization, such as those that have developed in recent research by Sidney Winter and others (Winter 2006; Becker et al 2006; Salter and McKelvey 2016) and adapted to a broader set of organization and selection mechanisms (Foster 2000; Metcalfe 2014). Thus, we seek a more abstract conceptualization of the growth of knowledge as an evolutionary process in the context of organization that is still relevant in the economic context of innovation policy.

Therefore, we take a step back and draw inspiration from Metcalfe’s (2014) conceptualization of how capitalist economies evolve. Metcalfe applies the concept of organization at a high level of abstraction where the market is only one form of organization. A key concept in his work is the growth of knowledge in society through increased specialization of tasks and knowledge and the corresponding increase in the complexity of coordination, a theme which has also been addressed by other researchers (Loasby 2001; Langlois 2001; Holmén and McKelvey 2013).

Metcalfe (2014) argues that the evolution of capitalist economies is characterized by restless transformation of the economic order of increasing complexity. By economic order, he refers to behaviour patterns mutually determined by the interconnection of countless activities, which have the aim to solve specific problems related to meeting needs in a profitable manner. The economic order is the outcome of the organizational structure of the economy, which is designed to coordinate the action of individuals with different knowledge endowments. New knowledge may lead to incremental adaptation of the existing order or its transformation into a new order. The ordering and
transformation processes are both in the epistemic and in the material, with the former labelled as the growth of knowledge and the latter as economic growth.

Metcalfe’s evolutionary process of the growth of knowledge has two interacting components. On one hand, the ability to adapt grows through changes in the epistemic order, e.g. the introduction of new fields of knowledge specializations or the rearrangement of existing fields of specialization. On the other hand, the ability to adapt grows through incremental learning within the existing epistemic order through individual and mutual adaptations of the interconnected fields of specialization.

Thus, we embrace a broad view of the growth of knowledge as an evolutionary process from existing research within evolutionary economics, but raise the level of abstraction in order to adapt it to the context of innovation policy. Sharing the focus on the organizational aspects of knowledge and learning with evolutionary economics we draw inspiration from Metcalfe’s (2001;2002;2014) work on the transformation of economic order to identify two complementary aspects of the process: First, knowledge grows through an increasing number of knowledge specializations and the corresponding complexity of organization. Second, knowledge grows through experience and adaptation within an existing knowledge specialization. In the next section, we put these abstract ideas more firmly in the context of innovation policy making.

3 What is growth of knowledge in innovation policy making?

A broad definition of public policy includes anything a government chooses to do, or not to do. In this article, we use a narrower definition of public policy as an "officially expressed intention backed by a sanction, which can be a reward or a punishment" (Lowi and Ginsburg 1996: 607). A government intention (initiative, intervention) can be expressed in a number of way, such as by guidelines, law, statute, regulation or order and supported by governance mechanisms to coordinate activities for meeting the goals of the intervention and regulate any unwanted consequences (Borrás and Edler 2014; Fischer et al 2007).
Based on our definition of public policy, innovation policy is an officially expressed intention about the topic of innovation. The original focus of attention of innovation policy makers was the commercialization of scientific and technological knowledge by industrial firms made possible by mutual learning and adaptation among multiple heterogeneous actors at different levels of the economy (Fagerberg et al 2005). Today, the focus is broader in scope in terms of what is considered economically valuable knowledge and the type of actors considered, but with continued emphasis on mutual learning and adaptation. Along these lines we subscribe to Kuhlman’s (2001: 954) definition of innovation policy as “the integral of all state initiatives regarding science, education, research, technology policy and industrial modernization, overlapping also with industrial, environmental, labor and social policies”. This definition emphasizes the broad reach of innovation policy and the interconnected web of policy specializations that need to be coordinated.

Early studies of innovation policy from an evolutionary (Nelson and Winter 1982) or systemic perspective (Lundvall 1992) stressed the importance of policy learning. Nevertheless, the topic has received relatively little attention of innovation policy researchers (Borrás 2011). Reviewing the scarce number of existing studies below, we identify two streams of inquiry—the innovation policy history stream and the innovation policy capacity stream, respectively—and argue that they are concerned with the two complementary aspects of the growth of knowledge identified above.

The innovation policy history stream is concerned with the interaction between innovation theory and innovation policy practice and how it has shaped the evolution and delineation of the field of innovation policy (Carlsson et al 2010; Martin 2012; Miettinen 2014; Mytelka and Smith 2002; Schot and Steinmüller 2016; Sharif 2006). This research is historical in nature and usually based on the reflections of key participants in the development of the field at the national or international level. The various contributions review the intellectual foundations of innovation policy, identify key individuals and organizations, and describe how the scope and focus of innovation policies and innovation studies have co-evolved. While the details vary, the consensus seems to be that with an increased
understanding of the complexity of the innovation process, this has lead to an increase in the scope of intervention as well as the need for coordination across policy areas, such as education policy, science policy and economic policy, that previously were considered as separate policy fields. Sharif (2006), for example, explains how direct interactions between researchers and policy makers, as well as researchers moving into policy jobs, enabled the wide diffusion of the conceptualization of innovation systems into forming innovation policy in Europe. Learning went in both directions, from research to policy and from policy to research on innovation systems. Hence, this stream uses historical accounts, in order to identify a growth of knowledge amongst both researchers and policy-makers in relation to innovation policy.

The innovation policy capacity stream is also primarily empirical, and is concerned with how the capacities of policy organizations shape trans-national transfer of innovation policies and explain different policy trajectories of different countries (Borrás 2011; Karo and Kattel 2016; Nauwelaers and Wintjes 2008). The studies relate variances in policy learning and policy outcomes to differences in policy capacity, but differ in how they conceptualize the organization of the policy system and the dimensions of policy capacity. On the one hand they identify three levels of organization within a national innovation system—government and public organizations, networks of policy stakeholders, and socio-economic actors in the political system—each developing specific capacity. Government and public organizations develop administrative capacity—the capacity to implement innovation policies—, network of policy stakeholders develop analytical capacity—the capacity to select and design policy instruments—, and socio-economic actors in the political systems develop political capacity—the capacity to develop policy paradigms. On the other hand, they go beyond the concept of national innovation systems to include sub-systems, such as regional innovation systems, and supra-systems, such as the European Union and the OECD.

The two streams of previous research on innovation policy learning—the innovation policy history stream and the innovation policy capacity stream—help us to put the abstract idea of the growth of knowledge in the context of
innovation policy making. Firstly, the innovation policy history stream is concerned with the growth of knowledge through increasing number of knowledge specializations and the corresponding complexity of organization. Secondly, the innovation policy capacity stream is concerned with how knowledge grows through experience within an existing pattern of specialization. In the next section, we develop our conceptual model of the growth of knowledge in innovation policy making.

4 Conceptual model of the growth of knowledge in innovation policy making

We propose an conceptual model for understanding the growth of knowledge innovation policy making, by drawing upon concepts and processes introduced above. The key elements of the model are first introduced conceptually and then illustrated in the context of innovation policy. Thereafter, we specify evolutionary processes—how variety is generated and selectively retained— for a single policy knowledge specialization. This enables us to model its evolutionary trajectory, i.e. the outcome of its evolution through time. Finally, we discuss co-evolution by specifying how the evolutionary trajectory of one specialization affects the evolutionary processes of another.

4.1 Three key elements of the model

There are three key elements in our evolutionary model—policy alternative, policy field, and policy organization—as proposed in (Reference omitted during review).

First, a policy alternative is defined as a set of ideas and beliefs about action, which includes the performance of a series of interdependent tasks by a number of actors, expected to useful for solving policy problems. This follows a line of research on the cognitive nature of problems (Kingdon 2014; Mokyr 1998). Based on Pounds (1969) and applied to our context, we define a policy problem to exist when a policy maker experiences a difference between a current situation and a desired situation. Hence, policy alternatives are provisional means for reaching a desired situation given the current situation. The means
that alternatives are provisional in the sense that their usefulness is not always well justified. Some policy alternatives exist and have been repeatedly applied; some have been partially implemented and evaluated; and others are yet to be tried out.

Let us take the example of funding of university-industry collaboration through centers of excellence as an illustration. The policy problem to be solved is the development of new scientific and technological knowledge, and specifically, radically new areas thought to impact society in the future, e.g. to solve 'grand societal challenges' or specific missions. To achieve this goal, the underlying assumption is that the creation and diffusion of economically valuable knowledge can be stimulated through interaction between universities and companies. In many countries, the policy alternatives conceived and implemented include a set of rules for applying for, and receiving, funds for building and running centers of excellence where universities and industrial firms collaborate, as well as for developing the policy infrastructure necessary for reporting, monitoring and evaluating progress.

Note that our definition of a policy alternative bears strong resemblance to what in innovation policy studies is labeled as a policy instrument. While definitions differ, policy instruments usually refer to a set to techniques used by policy makers to achieve policy goals (Borrás and Edquist 2013; Cunningham et al 2013; Flanagan et al 2011; Martin 2016). However, our definition of a policy alternative is broader. First, we include not only action, or techniques (which are already tried out) but also ideas and beliefs about actions yet to be tried out. We contend this matters for learning because alternatives may exist and evolve without being tried out, e.g. through a dialogue between policy makers and researchers. Second, our definition of a policy alternative also subsumes the concept of a policy mix—a set of policy instruments that mutually interact to shape final outcomes (Cunningham et al 2013; Flanagan et al 2011). The reason we propose our broader concept is that it helps us account for a more complex organization of the policy system, especially linking together a number of sub-problems. These sub-problems can be analyzed as representing specific missions, e.g. to reduce carbon emissions by a certain amount within a specified
time period, or the sub-problems could be underlying steps that need to be address in order to achieve a mission. Thus, our model can deal with the possibility that policy alternatives include complex organization of heterogeneous actors (private, public, third sector, civil society) operating in multiple sectors.

Moreover, we propose that policy alternatives are the unit of selection. Therefore, we propose that policy alternatives have the characteristics of organizational routines, by applying literature that conceptualizes organizational routines as the expression and embodiment of competencies in firms (Winter 2006; Murmann et al 2003) to the context of public policy. Organizational routines are "repetitive, recognizable patterns of interdependent actions, carried out by multiple actors" (Feldman and Pentland 2003: 95). On the one hand, a routine is an abstract idea—how it is possible, given a specific situation, to reach a desired situation by performing the action prescribed by the routine—and, on the other hand, a routine is the implementation of the abstract idea in a given context producing performance results each time it is invoked (Feldman and Pentland 2003). Thus, we propose that a policy alternative contains the conceptualization of a certain class of procedures, interactions and resources intended to solve a particular policy problem, whose performance is based on the specific procedures, interactions and resources being instantiated at a certain point in space and time to solve a particular policy problem.

Second, we define a policy field as a set of policy alternatives that have the aim to solve a particular class of policy problems. Policy fields are at a higher level of abstraction than policy alternatives, for example, innovation policy, competition policy, or education policy.

Innovation policy emerged, both from science policy and industrial and competition policy (Carlsson et al 2010; Martin 2012; Lundvall and Borrás 2005). Both innovation policy and industrial and competition policy share the same overall ambition of solving the policy problem of sustaining economic growth through industrial activities. Innovation policy, however, focuses on the role of industrial renewal in growth, especially through new technologies and
new user demand. Thus, while innovation policy can be seen, especially in the beginning of its development, as a sub-field of industrial policy sharing a specific class of policy problems, innovation policy has developed into a policy field in its own right. Hence, innovation policy is characterized by a distinct set of policy alternatives addressing each of its identified sub-problems, many of which are not identified and addressed by traditional industrial policy.

Note that within the same policy field, there often exist different sets of policy alternatives, which propose different actions and different set of actors as means to solve the same identified problems. By this, we mean, for example, that some innovation policy alternatives are based upon traditional economics, while others are based upon theories related to evolutionary economics. They both share an underlying understanding of the economics of information argument, developed by Arrow (1962) and Nelson (1959), which states that information differed from traditional goods, due to the indivisibility and non-excludability of information. Information is understood to be more complex than traditional goods and services, especially since revealing information to a buyer meant it was disclosed and no longer had to be purchased. Therefore, the primarily policy recommendation is that government should invest in basic science, in order to solve the appropriability problem and to stimulate spill-overs. The primary focus here is on science policy, or R&D and regulation (Schot and Steinmüller 2016). Moreover, even if they recognize that information is a particular class of good, economists following traditional economics would argue that policy should only intervene in cases of market failure. An alternative theoretical stream of public policy alternatives was much later developed from the innovation system approach (Schot and Steinmüller 2016), and this literature has different epistemological grounds, arguing that knowledge is developed in institutions and collaboratively, as well as in firms (cf. Edquist and McKelvey 2000). Hence the goal of public policy is to stimulate scientific and technological knowledge useful in products and services, often through institutions and connections. As a comparison, while the first literature focuses upon the market, the second focuses upon a more problem-oriented and systemic approach, and thereby addressing a larger list of possible innovation system failures which may be
specific to a particular context (Arnold et al. 2003). The policy field in focus here is innovation policy, specifically policy alternatives based on national, sectoral and regional innovation systems. More recently, a policy alternative based upon transformative change has been emerging in the literature, focusing upon an active government, social as well as economic change, and system wide transformation. This third alternative draws upon a wide range of contributions (Schot and Steinmüller 2016), in how policy can solve grand societal challenges.

Therefore, we propose that within the transformative change discussions, mission-oriented innovation policies should be seen as a distinct set of policy alternatives. They thus propose new and different means to solve problems that have been identified within the innovation policy field. Due to the early stage of emergence, it is currently too early to know whether mission-oriented innovation policies will evolve into a policy field of its own. However, we predict that there are sub-problems identified within mission-oriented innovation policies that are not identified and addressed by traditional innovation policy, and therefore, it is likely to evolve into a distinct policy field.

Third, a **policy organization** is defined as an organizational context for suggesting, discussing, selecting and implementing policy alternatives. Our view is that policy organizations are more network-based, driven to solve problems, rather than defining the organization as government agents per se. This is similar to innovation policy capacity stream, such as Borrás (2011), which focuses on different levels within an innovation system. Moreover, we argue that policy organizations have fuzzy territorial boundaries, which can be regional, national or supra national, and include participants across different levels of government, multiple interest groups, the media, and research organizations.

The innovation policy history stream indicates that relevant policy organizations can differ greatly and may change over time. The core notion of innovation systems emerged from interaction between the policy-makers and researchers interested in exploring the impact of institutions and technological knowledge on economic growth (Sharif 2006). In small groups, abstract ideas about how the problem may be addressed were discussed, both in national policy organizations
in Europe and supranational policy organizations like the OECD, and to validate these ideas the researchers published in academic journals as well. Today the situation is different. In many countries, e.g. Sweden, policy organizations implementing innovation policy alternatives exist at the regional and national level in addition to organizations at the supra-national level, such as the European Union and the OECD. All these policy organizations are supported by a supra-national research community, which has specialized in innovation policy studies and is publishing in academic journals focusing on innovation policy (Martin 2012; Mytelka and Smith 2002; Schot and Steinmüller 2016).

To summarize the key elements in our proposed evolutionary model, we have defined the concepts of a policy alternative, a policy field, and a policy organization, and illustrated them through innovation policy. A policy alternative is the unit of selection and the level of selection is a policy problem in a policy organization. Hence, we put forth that the policy field is evolving—the set of policy alternatives that are selected for solving a particular class of policy problems and its sub-problems. Policy alternatives are both selected as abstract ideas and implementations. The evolutionary trajectory of a policy field, i.e. the outcome of its evolution through time, is manifested by emergence of new policy alternatives for solving an existing policy problem or a new sub-problem and by the relative frequencies of policy alternatives across policy organizations.

Due to the complexity of policy problems, we assume the existence of multiple policy fields each specializing in distinct class of policy problems. The evolutionary trajectory of these policy fields represents the growth of knowledge in policy making. We assume that each policy field has its own evolutionary processes—variation, selection, and retention— but that these processes are influenced by the evolutionary trajectories of other policy fields. In the next section, we specify the evolution of a policy field followed by an initial attempt at specification of how they co-evolve.

4.2 Evolution of a policy field

As a next step in conceptualizing the growth of knowledge in innovation policy making as an evolutionary process, Figure 1 specifies the three mechanisms of
variation, selection and retention of a single policy field. We will continue to use innovation policy as our illustration.\textsuperscript{1} To begin with, we assume the policy fields evolve without any external influence, i.e. the evolution is only affected by attempts to solve the class of problems that are specific to the policy field.

\begin{figure}[h]
\centering
\begin{tikzpicture}
  \node (v) [draw] {Variation \small \hspace{0.5cm} Search};
  \node (s) [draw, right of=v] {Selection \small \hspace{0.5cm} Anticipation \hspace{0.5cm} Trial};
  \node (r) [draw, right of=s] {Retention \small \hspace{0.5cm} Subjective \hspace{0.5cm} Objective};
  \draw[->] (v) -- (s);
  \draw[->] (s) -- (r);
\end{tikzpicture}
\caption{Evolutionary process of a policy field.}
\end{figure}

First, the concept of variation is represented as a search process to solve a problem. By this, we are assuming that the public policy actor is aware of different policy alternatives that they explore in their search for a solution to a policy problem\textsuperscript{2}. As mentioned above, policy alternatives are composed, on the one hand, of an abstract idea about the means needed to reach a desired situation given a current situation, and, on the other hand, of the instantiation of that abstract idea in a given situation. Thus, when different policy alternatives are explored the search can be for a new abstract idea or new ways of implementing an already existing one.

As an illustration, a policy maker addressing the problem of how to expand the commercial potential of nanoscience could choose either to fund university scientists only, or else fund university-industry centers including participants from universities and industries. In the former case, the rationale for the abstract idea of the policy alternative is the economics of information argument (Nelson

\textsuperscript{1}We do not claim that our examples confirm our theoretical arguments. Instead, they are used as illustration to help explain the meaning of the abstract concepts.

\textsuperscript{2}At this point we leave aside the origins of the initial set of policy alternatives for addressing the class of problems belonging to the policy field, but assume that this set exists. Later, when we extend our model to multiple policy fields we will revisit the issue.
1959; Arrow 1962), while in the second case, it is the innovation systems argument of joint knowledge production (Edquist and McKelvey 2000).

Even if we allow policy makers to learn from experience, the search process is partially blind because it is uncertain how successfully the particular instance of a variation will solve the policy problem that is being addressed. With time and more experience—especially when a policy field is not affected by ideas from other policy fields—this uncertainty is reduced. The reduction in blindness is, however, countered by the degree of specialization within the policy field.

Each specialization, which addresses a particular sub-problem of the field’s policy problem, has its own evolutionary process of variation-selection-retention of solutions for its sub-problem. The evolution of the overall policy alternative—equivalent to the notion of policy mixes in the innovation policy literature (Cunningham et al 2013; Flanagan et al 2011)—is the outcome of the co-evolution of the policy alternatives addressing each sub-problem. A higher number of sub-problems and the larger variety that is likely to follow the higher number of sub-problems will increase the diversity of the variation within the field.3

Second, the concept of selection is represented as two mechanisms: anticipation and trials. Selection through anticipation is closely related to Campbell’s (1987) notion of shortcuts. Shortcuts provide policy makers with opportunities to predict the outcomes of a policy alternative without direct interaction with the environment, i.e. without implementing the policy alternative. Examples of selection by anticipation include when a policy alternative is rejected by a policy maker—or a policy researcher—because it violates existing regulation, because it is in conflict with results from research or policy evaluations, or because the ideological rationale behind the policy alternative does not match the ideology of key decision makers in the policy process. Selection by trials is through direct interaction with the environment, which means that a policy alternative has been implemented in order to try to solve a policy problem. An example of

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3 We will go into more details about the mechanisms for the diffusion of this variety in the next section when we model the co-evolution of policy fields.
selection by trial for a policy alternative concerned with the funding of university-industry centers would be to allocate the funds and evaluate the performance of the policy alternative through reports about how many publications were written, how many patents granted or how many doctoral students were trained.

Selection by anticipation and by trial are related, because in order to be put to trial policy alternatives have to be selected by anticipation—in other words, if a policy alternative is rejected by anticipation it will not be implemented. With increasing growth of knowledge in policy making the number of shortcuts available to policy makers will increase, some of them associated with the increasing number of sub-problems. Furthermore, once a policy alternative is implemented it affects the anticipative selection of other policy alternatives because of their potential interaction. The combined effect is that selection by anticipation will play a larger role as knowledge grows, reflecting the increasing path-dependency of the evolutionary trajectory.

Third, the concept of retention is represented by two mechanisms: subjective retention and objective retention. Subjective retention mechanisms refer to the ability of humans to remember and repeat action and relies on individuals that are active in policy organizations. This includes both cognitive aspects, such as memory, but also more tacit elements of knowing embodied in skills. Objective retention mechanisms include symbols, artifacts or structures that guide human action. First, symbols include information used to codify how a policy alternative should be performed—research paper describing abstract ideas or written procedures describing a particular policy instruments being implemented—including criteria for participation, type and level of support, method of evaluation, etc. Second, artifacts are created to support or automate the implementation of a policy alternative, e.g. information systems that help the administration of the process of receiving, evaluating and monitoring applications for funding. Third, a policy alternative can be partially encoded through structure, e.g. organizational structure or technical infrastructure with defined roles and responsibilities. These structures can sometimes become
policy organizations in their own right, like the organization around the smart specialization platform (S3P) in the European Union.

Retention mechanisms preserve the policy alternatives that have been selected and support their repeated use and diffusion across policy organizations. Retention mechanisms differ to what degree they constrain the evolution of policy alternatives. Retention by symbol is the most flexible as can be easily modified and can be used to retain information about abstract ideas behind policy alternatives without any information about implementation. Artifacts and structure are embodiments of an implementation of a policy alternative and are more difficult to, especially organizational structures and technical infrastructures. Hence, structures become an important part of the selection environment, both for selection by anticipation and selection by trial.

Let us now turn to how policy fields evolve. At any point in time, a series of events have created an evolutionary trajectory, which is characterized by the population of policy alternatives that have been selected for addressing the field's policy problems. The evolutionary trajectory occurs at multiple levels, from local to global. At the local level, which is the basic level of selection, the trajectory expresses the population of policy alternatives that are floating around or being implemented in the local policy organization. At the global level, the trajectory expresses the population of policy alternatives that are selected by many policy organizations that have little in common except the same problems and some professional norms and values. For example, cluster innovation policy is one set of innovation policies which has diffused widely globally, but are implemented differently in different countries and time periods (Nauwelaers and Wintjes 2008).

Having specified the basic evolutionary mechanisms of a policy field, we have addressed one of the two aspects of the growth of knowledge as an evolutionary process—learning and adaptation within an existing specialization.
4.3 Co-evolution between policy fields

The next step is to address the second part—learning and adaptation through new specializations. As we have already briefly touched upon, a key aspect of the second part is how policy fields co-evolve, which also has implications for how policy alternatives addressing sub-problems within the same policy field co-evolve.

We propose that the evolutionary trajectory of one policy field, i.e. the trajectory of the population of policy alternatives intended and used to solve a specific class of problems, affects the evolutionary trajectory of another policy field through two basic processes: exaptation and niche construction. The former is mediated through variation and the latter through selection (Figure 2).

\[\text{Figure 2. Co-evolution between policy fields.}\]

Let us consider exaptation and niche creation as key ideas in co-evolution. Recently, there has been an increasing interest in two unconventional forces in evolutionary theorizing - exaptation (Bonifati 2013; Gould and Vrba 1982) and niche construction (Odling-Smee et al 2003). These concepts are believed to help explain the generation of novelty in economic systems and challenge the common conception of the market as an independent selection mechanism.
(Andriani and Cattani 2016; Dew and Sarasvathy 2016). In this paper, we integrate these views into our conceptual model of the growth of knowledge in innovation policy making.

Based on Gould and Vrba (1982) we define exaptation as the situation when policy alternatives that are being selected for solving a particular class of problems have their origins in other policy fields. In other words, they have emerged and evolved in relation to one class of problems, before being tried out as an alternative for a different class of problems. Thus, exaptation is based on the introduction of variety that is not connected to previous experience in a policy field, i.e. is not an adaptation to experience from the application of existing policy alternatives to a policy problem. Such variety is more likely to bring new abstract ideas that represent a more fundamental change in how problems are formulated and solved in a policy field than is possible through an evolution of a single field. For example, in the case of innovation policy, the foci of user-driven ideas in social innovation—which originated from a policy field focused on supporting civil society — has questioned the previous predominance of science policy in innovation policy and generated new types of policy instruments (Miettinen 2014).

Based on Odling-Smee et al (2003), we define niche creation as the process by which a part of the selection environment of a policy field (the affected field) is affected by the population of policy alternatives from another policy field (the affecting field) and thereby modifying selection pressures for policy alternatives in the affected field. Selection pressures arise primarily through the competition for scarce of resources. Policy makers can only attend to limited number of policy alternatives due to cognitive limitations and only a limited number of policy alternatives can be implemented due to budget constraints. We assume that the primary mechanisms for mediating the influence from the population of policy alternatives in the affecting policy field to the selection mechanisms in the affected field is in terms of the availability of resources, or the reduced need for resources. For example, a policy alternative in a neighboring policy field may diffuse widely making it attractive for imitation. Thus, policy makers may be able to secure resources for experimentation, in which case normal selection
pressures do not apply—at least initially. Another example is the case where an abstract idea behind a policy alternative in a neighboring field provides a much more effective framing of policy problem and introduces new criteria of fitness that change the prioritization and selection of alternatives for solving the field's policy problems.

Taken together exaptation and niche creation have the potential to renew policy fields and create new ones. Exaptation provides the blindness required to move beyond the constraints posed by localized search and structures guiding the recurrent use of existing policy alternatives, and niche creation provides the protective selection environment needed for initial survival and adaptation. When a policy field is renewed, the frequency of policy alternatives introduced by exaptation in the population of alternatives for solving the field's class of policy problem increases at the cost of policy alternatives that were previously used, similar to Schumpeter's (1942) process of creative destruction. When a new policy field is created it can have its origins in a sub-problem within an existing field—for example, when industrial policy becomes a separate policy field instead of being a sub-problem of economic policy—or it can result from the integration of one or more policy fields or sub-problems—as in the case of innovation policy which aims to integrate number of policy fields or sub-problems, such as industrial policy and science and technology policy. In both cases the original sub-problems or policy fields may continue to exist in parallel, even within the same system of policy organizations, at least for some time after the creation of the new field. Furthermore, the field may exist for some time, and policy alternatives suggested without ever being implemented.

Because resource availability and resource needs are different across policy organizations, the effects of exaptation and niche construction will vary across policy organizations. Thus, one would expect a difference among policy organizations in terms of if, and how fast, policy fields are renewed and new policy fields created. Looking at innovation policy, some countries, e.g. Sweden, very early on separated innovation policy from traditional industrial and competition policy by creating special policy organizations at the national level such as Sweden's Innovation Agency (VINNOVA). In this way, a niche was
created where policy alternatives belonging to that new field where assigned specific resources and did not need to compete with policy alternatives in a selection environment that promoted traditional alternatives.

In summary, exaptation and niche creation lead to renewal and speciation in the affected policy field. When niche construction is weak—no special resources are allocated to experimentation—exaptation is unlikely to reformulate existing policy problems or create new sub-problems. In this case exaptation will lead to competing policy alternatives that may, or may not, substitute existing alternatives depending on how well they compare using existing selection mechanisms. When niche construction is strong—special resources are allocated to experimentation—exaptation is more likely to reform existing policy problems, create new sub-problems, or integrate existing problems or fields, opening up for speciation, i.e. the emergence of new policy fields that address policy problems that are specific to those fields.

5 Discussion and conclusion

In this paper our purpose is to propose a conceptual model of the growth of knowledge in innovation policy making. We explicitly draw upon evolutionary economics in order to conceptualize learning as an evolutionary process of the growth of knowledge about policy problems and their solutions. By this, we focus upon the dynamics of learning; understand organizational routines in complex contexts; and pay special attention to self-organizing systems undergoing transformation. Our model points to the central role of the variation and selective retention of policy alternatives and contributes to the current debate about how to build policy capacity through mission-oriented innovation policies, to address grand social challenges. We argue that capacity building and the associated growth of knowledge comes about through two complementary processes: First, the increasing number of knowledge specializations—policy fields—and the corresponding increase in the complexity of coordination managed by policy organizations. Second, knowledge grows through processes of variation and selective retention of policy alternatives within each policy field. We characterize policy alternatives as organizational routines and also as the
units of selection. The co-evolution of policy fields creates the possibility of self-transformation—the renewal of existing policy fields and the creation of new ones—through the processes of exaptation and niche-creation.

One important application of this general model of evolutionary innovation policy is to further understand, develop, and implement mission-oriented innovation policies. First, the primary focus of our model is on policy learning and adaptation. Our model thus provides a conceptualization of the policy learning process, which is postulated to play a central role in mission-oriented innovation policies as means to build the necessary knowledge within policy organizations to direct and coordinate private and public actors. Second, our model uses an evolutionary approach to characterize top-down direction with bottom-up experimentation, which is also a key characteristic of mission-oriented policies (Mazzucato 2017). Our model assumes that policy problems exist at the top, but explains how bottom-up processes the organization to develop capacity to solve these problems through an evolutionary competition among policy alternatives. Third, our model provides an analytical tool to address a key question of interest to the mission-oriented approach, namely how to enable a system-wide transformation across multiple sectors based on various forms of partnerships (private, public, third sector, civil society) and across the innovation chain (Mazzucato 2017). Our model does so by contending that policy alternatives include complex organization of heterogeneous actors that can span various form of partnerships, and also by contending that policy organizations—the organizational context for suggesting, discussing, selecting and implementing policy alternatives—can also be composed of similar set of actors and partnerships. In this way, our model can be applied to more explicitly account for the inclusion of multiple stakeholders when setting the policy agenda, e.g. prioritizing societal challenges and associated missions, as well as when developing solutions and sharing the risks and benefits of their implementation across society. Hence, our model offers analytical tools to better promote smart, inclusive and sustainable growth.

Future research areas are outlined below, and they are directly related to our contributions in developing an evolutionary model of innovation policy.
First, our model can contribute to the current debate on how to build innovation policy capacity to address grand social challenges and obtain smart, inclusive, and sustainable economic growth (Foray et al 2012; Geels 2001; Mazzucato 2016; Schot and Steinmüller 2016). By identifying the complementary aspects of the growth of knowledge, our model conceptualizes the introduction of a new class of policy problems—radical transformation of complex systems to address grand social challenges and obtain smart, inclusive, and sustainable economic growth—as the emergence of a new policy field that will develop its own evolutionary processes of variation and selective retention and co-evolve with other policy fields. Currently, some authors have identified this new policy field for transformative change as Innovation Policy 3.0 (Schot and Steinmüller 2016). Our view is that within this policy field, mission-oriented innovation policies represent an emerging set of policy alternatives competing with existing sets of policy alternatives which are based on attention to market and systems failures. Thus, our model can help to formulate questions about how to build the innovation policy capacity within this emerging policy field and explain the evolution of this capacity. For example, what selection mechanisms are appropriate for selecting policy alternatives? How can we ensure learning through exaptation and niche creation? To ask such questions is an important first step, but further development of the model is needed to help us answer them.

Second, our model has the potential to explain persistent similarities and differences in innovation polices across countries, e.g. between European Union, Sweden and the United States. To do so, we need to pay attention to the complementary processes of the growth of knowledge—adaptation through new knowledge specializations and adaptation through experience within existing knowledge specializations. In the language of our model, we propose that a new policy field has emerged out of traditional industrial and competition policy, built around the concept of innovation systems. Context and evolutionary processes matter, in that its influence on the population of policy alternatives used in the European Union and in the United States differs greatly. Furthermore, we propose that in the European Union, but not in the United
States, the new policy field transformed existing innovation related policy fields through the process of exaptation and niche creation. This means that the new class of policy problems introduced by the new policy field lead to a new set of policy alternatives being put in use and selectively retained through the organizational structures constructed for their implementation. In the particular case of Sweden, the establishment of a specific organizational structure built around ideas emerging from innovation systems research (Carlsson et al. 2010) is an interesting example of niche creation because it allowed for the experimentation with new policy alternatives and the bypassing of competition with traditional policy alternatives in traditional selection environments. Further research is needed to empirically test these propositions and to investigate how the model can improve our understanding of trans-national transfer and diffusion of policy alternatives.

Third, our model connects previous research on innovation policy learning and strengthens its evolutionary foundation. By combining insights from the innovation policy history stream (Carlsson et al. 2010; Martin 2012; Miettinen 2014; Mytelka and Smith 2002; Schot and Steinmüller 2016; Sharif 2006) and innovation policy capacity stream (Borrás 2011; Karo and Kattel 2016; Nauwelaers and Wintjes 2008), we are able to conceptualize the self-transformation potential of the policy making process. By this, we mean that our model pays more attention to fundamental aspects of the evolutionary process of policy making than previous evolutionary accounts (Karo and Kattel 2016; McKelvey and Saemundsson 2017; Witt 2003). In particular, we specify the unit of selection (policy alternatives) and level of selection (policy problems in policy organizations). Further work can contrast how selection in policy making differs from market-based selection usually studied by evolutionary economics. Finally, our broad networked-based conceptualization of policy organizations allows us to move beyond the traditional government agencies and a fixed number of policy learning levels (Borras 2011; Nauwelaers and Wintjes 2008). Our model can be further developed to address the more complex governance structure that are increasingly being used by various forms of innovation-related policy instruments, including both private and public actors and spanning regional,
national and supra-national levels (Borrás 2011; Malik and Cunningham 2006; Nauwelaers and Wintjes 2008). Hence, additional research is needed, both conceptual and empirical, on how the evolution of policy organizations, including the emergence of new organizational forms, is linked to the variation and selective retention of policy alternatives. Such research is highly relevant for research on mission-oriented innovation policies, because the emphasis put on system-wide transformation requiring new, and more complex, forms of policy organizations.

On a final note, one can ask why it is relevant—as we have done in this paper—to conceptualize the innovation policy making process given the normative orientation and context specificity of policy making. More specifically, how is it helpful to develop conceptual models of policy making, given that evolutionary trajectories are uncertain and not easily predicted? In the spirit of Campbell (1987) and Vincenti (1990) we view conceptual models as problem-solving tools—e.g. shortcuts—that allow us to increase the speed of variation and selective retention of knowledge through indirect interaction with reality. Thus, conceptual models—especially if they can be further developed into more formal models—can help us to formulate problems, suggest alternative solutions, and select solution to be tried out in practice. Improving the problem-solving tools available to policy makers, we believe, can increase the rate and quality of policy learning and capacity building, which is of central importance for mission-oriented innovation policies and other policies striving to address societal challenges and support smart, inclusive, and sustainable economic growth.

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