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A holistic approach to the evolution of an entrepreneurial ecosystem: An exploratory study of academic spin-offs

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ABSTRACT

Borrowing nomenclature and concepts from ecology and evolutionary biology, we apply descriptive exploratory methods to extend our understanding about the complex dynamics of an entrepreneurial ecosystem. We take a holistic approach to ecosystem analysis, and we analyze the evolution of multiple activities (i.e., entry, exit, growth, and survival) within an entrepreneurial ecosystem and the interactions of these activities with the ecosystem actors and resource providers. Applying our approach to nearly the entire population of academic spin-offs in Norway from 2000 to 2015, we generate a number of important findings. By characterizing the dynamics of an entrepreneurial ecosystem, we take a major step towards theorizing the ecosystem perspective. Our findings have important implications for public policies targeted to promote academic entrepreneurship.

1. Executive summary

The entrepreneurial ecosystem (EE) perspective has become a popular topic among scholars, policy makers, and practitioners to describe the complex interdependencies of various actors and activities that result in entry, growth, and exit of new ventures. However, there is substantial discrepancy between conceptual framing and empirical studies to date. EEs are conceptualized as complex systems with dynamic processes, numerous interactions among actors, and interdependencies among activities. Notwithstanding, empirical studies fall behind these conceptual advances because they do not consider the dynamic interactions, mainly focusing on static examination of individual elements of an EE. Consequently, the full potential of the ecosystem perspective in entrepreneurship research is far from realized.

In this study, we take a holistic approach to analyze the evolution of the Norwegian academic spin-off (ASO) EE. We concurrently explore firm entry, exit, growth, and survival, and we analyze how ecosystem services and resource endowment associate with these activities. By doing so, we identify dynamics, nonlinearities, and outliers within the Norwegian ASO EE. To carry out our research, we utilize concepts from ecological ecosystems, and we adopt an exploratory quantitative approach to inductively recognizing patterns

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within the EE. Our methodological approach is novel and appropriate to the context because conventional statistical methods and their underlying assumptions are ill-suited to examine the nonlinearities of an EE as a complex system. Our data constitutes nearly the entire population of Norwegian academic spin-offs over a long period as the core of an EE combined with other ecosystem actors and services.

Our research has several important contributions to EEs literature and their governance. First, by invoking nomenclature from ecological ecosystems and adopting a holistic approach, we extend the EE perspective that helps better theorizing EEs. This approach also helps elucidate important findings that would otherwise have remained unknown. Second, our exploratory methodology that has minimum modeling restrictions allows identifying complex dynamics of an EE. It also allows identifying interrelationships among and co-evolution of various elements of an EE. This methodology helps better design future studies, illuminate new research questions, and inform hypotheses. Finally, our study provides important implications to policy and governance of EEs by providing empirical evidence on how components of an ASO EE affect its development.

Our results are rich and detailed, and we offer deep explanations regarding how an ASO EE evolves. To provide some examples, we show that there is a tightly knit EE with collaboration and knowledge spillover. Many ASOs have extensive relationships with multiple resource provider organizations. Public grants play an important role in driving the number of entries and exits. Many ASOs that received grants are non-productive and fail to survive when competition for resources intensifies. Regulatory changes introduce uncertainties and have unintended consequences that disrupt the equilibrium of the ecosystem. Combining public grants with VC support appears to help create or shape a small number of outlier ASOs that make a disproportionately large economic contribution to the ecosystem. On the contrary, by insulating ASOs from market pressure, incubators do not seem to increase viability and productivity in the long run. Our findings provide evidence that a top-down policy approach to EEs does not seem viable.

2. Introduction

The entrepreneurial ecosystem (EE) perspective is used extensively by scholars, policy makers, and practitioners to describe the complex interactions of numerous actors striving to enhance entrepreneurial activity and convert it into positive outcomes (e.g., Acs et al., 2017; Autio et al., 2018; Spigel, 2017; Audretsch and Belitski, 2017; Kuckertz, 2019; Stam, 2015). The complexity of the system, the interdependencies, and the complementarities among various actors and activities make the ecosystem perspective particularly attractive (cf. Acs et al., 2017; Adner and Kapoor, 2010; Brown and Mason, 2017; Feldman et al., 2019; Godley et al., 2019; Jacobides et al., 2018; Kapoor, 2018; Stam, 2015). However, while conceptual advancement has been extensive, empirical EE studies to date fall short of examining many of the dynamic processes most central to the development of the natural ecosystems from where they draw their inspiration. In particular, studies of EEs have predominantly focused on static examination of entry into the system using conditional means analysis (e.g., linear regression) to the exclusion of crucial ecosystem dynamic processes like exit, growth and development, and survival (Autio et al., 2018; Brown and Mason, 2017). This has limited our ability to accurately evaluate the effect of policies or assess the health of an ecosystem, and as a result, the full potential of the ecosystem approach to entrepreneurship is far from realized.[1]

The value of exploratory quantitative research has been recently noted (Anderson et al., 2019), and in this study, we apply exploratory methods to a multitude of activities (e.g., entries, exits, growth, and survival) so to identify dynamics, capture nonlinearities in and interactions among variables, and to pinpoint policy-relevant outlier firms (i.e., high-growth firms that have a disproportionate contribution to the ecosystem). We also explore essential ecosystem processes that have hitherto received limited attention in the EE literature. These include changing *carrying capacity* (i.e., the maximum number of firms that can be sustained), *disturbances* (i.e., unexpected disruptive events), *succession* (i.e., the subsequent adaptation after a *disturbance* event), and firm *fitness* (i.e., the ability of firms to survive and be productive). In carrying out this research, we examine nearly the entire population of academic spin-off (ASO) in Norway from 2000 to 2015.

In this study, we also examine how different forms of resource provision (e.g., resource munificence, regulations, VC support, and incubation) associate with entry, exit, and health of the ecosystem. By capturing dynamics, outliers, and nonlinearities, we uncover conceptual as well as policy-relevant issues. For instance, it appears that despite substantial public grants and incubation programs, the Norwegian ASO EE only produces a handful of firms with substantial sales or employment. For the most part, these successes receive grants and VC backing. Despite the small number of successes, these grants and VC investments may be important because these outliers contribute disproportionally to the overall success of the ASO EE. This finding would potentially be missed had we applied conditional mean analysis, which has problems accounting for outliers.

We make several contributions to the literature. First, we extend the ecosystem perspective by utilizing the ecological ecosystem nomenclature and applying a holistic approach to the analysis of the ecosystem. Doing so, we elucidate fundamental ecosystem processes that have hitherto remained unexplored within the EE literature. To give an example, the decline of government grants represents a source of resource endowment, which seems to reduce the EE's *carrying capacity*. Subsequently, entries decrease and exits increase, with the weakest firms going under. Such findings are consistent with theorizing about natural ecosystems but remain unexplored in the EE literature.

[1] Take for example an analysis of the effect of governmental grants on entry. Grants typically have a positive effect on entry. However, absent analysis of factors like firm growth and exit, it is difficult to assess overall economic impact. Greater entry may simply reflect entry of less viable firms and increase competition for scarce resources. For example, a dynamic approach was used by Söderblom et al. (2015) who examined the effect of grants awarded to firms less than one year old and the effect on equity, sales, and employees in the seven subsequent years, showing that the positive effects of the grants actually increased over time.

Second, we apply exploratory quantitative methods (Singer and Willett, 2003; Johnson et al., 2019) with minimum modeling restrictions (Murnane and Willett, 2011) that are novel to the context. This approach aligns with the conceptual literature stressing the complexity and nonlinearity of entrepreneurial ecosystems (e.g., Daniel et al., 2018; Jacobides et al., 2018; Kapoor, 2018; Roundy et al., 2018). Typical empirical approaches, like linear regression, are not ideally suited to capturing such complexity (Berger and Kuckertz, 2016; Lichtenstein, 2000; McKelvey, 2004). Moreover, our approach can complement other techniques. For instance, our findings can be used to provide parameters for simulation studies, select correct functional forms for regression analyses, identify appropriate lag relationships for dynamic panel models, or uncover policy-relevant outliers. Further, consistent with what has been highlighted in prior research (Anderson et al., 2019; Van de Ven et al., 2015), this descriptive exploratory design can help generate new research questions or "illuminate new hypotheses" (Anderson et al., 2019).

Third, we provide empirical evidence about how components of an ASO EE such as VC funding, incubation and public grants (Clayton et al., 2018; Fetters et al., 2010; Good et al., 2019) affect growth and survival of ventures in an EE. For instance, our results call into question whether incubation has a positive effect on ventures in the EE. While such findings are in line with broader ecosystem theories, they run counter to mainstream scholarly and public policy assumptions (cf. Brown and Mason, 2017; Fuerlinger et al., 2015; Mason and Brown, 2014).

3. Theoretical framework

3.1. Review of research on entrepreneurial ecosystems

The notion of ecosystems was first introduced to the management literature in the 1990s because of increasing interdependencies occurring within economic activity, and the fading lines between industries (Moore, 1993, 1996). It has become increasingly popular within entrepreneurship (e.g., Acs et al., 2017; Autio et al., 2014; Spigel and Harrison, 2018), including reviews of the literature to date (e.g., Alvedalen and Boschma, 2017; Brown and Mason, 2017; Cavallo et al., 2018; Malecki, 2018; Stam and Spigel, 2018). The ecosystem concept is rooted in ecology and biology, in which the interactions of living organisms with each other and their environment takes center stage (Auerswald, 2015; O'Connor et al., 2018).

Research on EEs brings context to the fore, as it influences behavior, choices, and performance (Autio et al., 2014). Entrepreneurial activity is influenced by industry/technology, social, institutional/policy, and organizational contexts (Autio et al., 2014; Autio and Levie, 2017). EEs have a spatial dimension because interconnection and interaction are facilitated by proximity and agglomeration (Audretsch and Belitski, 2017; Stam and Van de Ven, 2019; Wennberg and Lindqvist, 2010). However, flows of knowledge and networks of cooperation within EEs are not delimited to specific locations. Therefore, useful spatial boundaries can range from the local to the regional and national (Daniel et al., 2018). EEs differ from related concepts, such as industries, business ecosystems, or clusters (see Autio et al., 2018 for details regarding how EEs are similar to and differ from other related concepts). For example, resource sharing and knowledge spillover/sharing center around starting-up and scaling-up of new ventures rather than specific products or processes; collaboration crosses industry boundaries, is horizontal rather than vertical in the value chain, and is typically not guided by contractual arrangements; and EEs involve several types of actors in addition to new ventures, such as venture capitalists and business incubators (cf. e.g., Jacobides et al., 2018; Kapoor, 2018).

Following the existing literature, we conceptualize an EE as a dynamic, self-organized community of different types of actors facilitating the entry, growth, and exit of new ventures (Roundy et al., 2018; Stam and Van de Ven, 2019). EEs can be defined in terms of focal venture types (here, ASOs), types of new venture support systems (here, primarily universities, TTOs, and policy initiatives), and geographic and socio-cultural characteristics (here, Norway) (Audretsch et al., 2019; Roundy et al., 2018). EEs are not closed systems, yet have distinct boundaries making it possible to define which actors belong to the EE and which do not (cf. Roundy et al., 2018).

3.2. Notable discrepancies between the conceptual and empirical literatures on EEs

Conceptual advancement of EEs has outpaced empirical research on EEs. For example, the conceptual literature notes that EEs are fundamentally dynamic, because the population of new ventures changes due to entries, exits, and growth, as do interactions with the other ecosystem actors and the environment (Spigel and Harrison, 2018; Stam, 2010). Moreover, the conceptual literature posits numerous interactions, interdependences, and complementarities among EE components (Brown and Mason, 2017; Daniel et al., 2018; Kapoor, 2018).

Despite such dynamic and integrative characterizations of EEs, most empirical studies to date have focused on static examinations of individual components or identifying elements of the system with less attention paid to the dynamic interactions among components (the following papers make this observation: Brown and Mason, 2017; Daniel et al., 2018; Haarhaus et al., 2020; Isenberg, 2016; Malecki, 2018; Spigel and Harrison, 2018). The few papers that apply a longitudinal lens support the importance of dynamism, suggesting that history, culture, and institutional setting affect EEs over time (Mack and Mayer, 2016), that EEs have lifecycles (Auerswald and Dani, 2017) and go through stages of development (Rong and Shi, 2014). Many processes also take several years to unfold (Mack and Mayer, 2016), and are best analyzed with longitudinal approaches (Autio et al., 2014; Brown and Mason, 2017). Therefore, in order to study the evolution of an EE, using a longitudinal sample both with clear spatial boundaries and a rich set of variables that represent the salient features of an EE has been encouraged (e.g., Acs et al., 2014; Autio et al., 2014; Stam and Van de Ven, 2019).

In terms of suitable dependent variables, the conceptual EE literature calls for the consideration of broader outcomes such as contribution to economic and societal welfare (Audretsch et al., 2019; Stam and Spigel, 2018), or concomitant concern for entry, exit, survival, and growth of the entrepreneurial population (e.g., Autio et al., 2018). It has been suggested that EEs cannot be understood by examining entries alone but require a more holistic approach that also considers growth, survival, and exit (Autio et al., 2018; Brown and Mason, 2017; O'Connor et al., 2018; Roundy et al., 2018). Despite this, it appears that the empirical literature to date focuses predominantly on new firm entry as the dependent variable (e.g., Audretsch and Belitski, 2017; Ghio et al., 2019; Miller and Acs, 2017), to the exclusion of growth, survival, and exit. The importance of how entry, exit, growth, and survival interrelate has been acknowledged (Autio et al., 2018; Brown and Mason, 2017; Hoetker and Agarwal, 2007; West, 2017). For instance, the exit of ineffective ventures releases their knowledge and resources which can be transferred into other new ventures and assist in the growth of the EE (Hoetker and Agarwal, 2007; Knott and Posen, 2005). For example, it has been suggested that the high failure rate in Silicon Valley may help explain why it excels in successful entrepreneurship (Bahrami and Evans, 2011; Engel, 2015; Kenney, 2000).

Actors within the entrepreneurial ecosystem are not limited to new ventures. The study of entrepreneurship under an ecosystem perspective benefits from the inclusion of other actors in the institutional context, such as venture capitalists, business incubators, public agencies, and other entities with which new ventures interact (Acs et al., 2018; Van de Ven, 1993; Autio et al., 2018; Ritala and Gustafsson, 2018).

3.3. Understanding entrepreneurial ecosystems using natural ecosystems nomenclature

Several authors discuss the constituent parts of EEs. Interestingly, categories proposed often have little to do with nomenclature from the broader ecosystem literature. Instead, various categorizations not rooted in any particular theory or conceptualization of ecosystems have been proposed. For example, Isenberg (2010) suggests that an EE consists of 50 components in six different domains: markets, policy, finance, culture, support, and human capital. Others have focused on a variety of attributes (e.g., regulatory framework, education, and training), actors (e.g., venture capitalists), or resources (e.g., human capital or financial resources) within EEs (Mason and Brown, 2014; Spigel, 2017; Spigel and Harrison, 2018; Stam and Van de Ven, 2019).

Given the long history and extensive theorizing related to ecosystem, we believe it is fruitful to infuse nomenclature from that broader literature into the EE domain (cf. Auerswald, 2015; Isenberg, 2016). The drivers of change in EEs — such as birth (entries), growth, survival, and death (exits) — seem to be like those of other ecosystems (e.g., biological, urban, ecological).

We apply concepts and nomenclature from the ecology and evolutionary biology literature. This helps clarify how the relevant components of the ecosystem interact with the new ventures. Concepts such as *carrying capacity*, *disturbance*, *succession*, *habitat* are helpful for understanding interactions between context and new ventures. The concept of *fitness* is useful for evaluating the performance of ventures that the EEs produce and for assessing whether the EE may achieve policy objectives.

Carrying capacity of a population is the number of organisms that can be sustained in a particular ecosystem. The *carrying capacity* of an entrepreneurial ecosystem depends on the absolute level of resources that firms compete for, the total number of firms (density) in the ecosystem, and the resource requirements of each individual firm (Hannan and Carroll, 1992; Specht, 1993; Staber, 1997). As the resource availability of an ecosystem changes, so does the *carrying capacity*, which has direct implications for firm entry, exit, and growth.

A '*disturbance*' is an uncommon and often unexpected event that causes abrupt structural changes in an ecosystem by disruption of the structure, existing arrangement, and equilibrium state of the ecosystem (Bengtsson et al., 2000; Chapin et al., 2002; Sousa, 1984). Examples of *disturbances* in natural ecosystems include, e.g., fires, flooding, or earthquakes. Depending on the extent of the *disturbance* and the vulnerability of organisms, the magnitude of the impact of a *disturbance* can vary greatly (Sousa, 1984; Turner et al., 1998). A *disturbance* can influence firm group patterns, as well as the positioning of individual firms (Zúñiga-Vicente et al., 2004). A *disturbance* disrupts the equilibrium state of an ecosystem and has immediate implications for its *carrying capacity*, resource availability, and overall composition. The *disturbance* of an entrepreneurial ecosystem — such as a policy change — would affect entry, survival, and growth.

Following a *disturbance* event, individual organisms start to adapt, which changes them as well as the nature of the ecosystem. This is known as *succession* (Bengtsson et al., 2000; Connell and Slatyer, 1977; Turner et al., 1998). Ecosystems change and evolve through *disturbances* and subsequent *successions*. Because of the instability caused after a *disturbance* event, some organisms exit from the system, and the organisms that survive start to reorganize and adapt themselves (Bengtsson et al., 2000). In the short run, *disturbances* are typically negative for the organisms in the ecological ecosystem, but that may change over time. The same likely applies to entrepreneurial ecosystems.[2]

A *habitat* is an environment in which a species of organisms forms a community (Whittaker et al., 1973). The characteristics of the *habitat*, directly and indirectly, affect the species (Beyer et al., 2010). *Fitness* describes how well-adapted an organism is to its environment (e.g., ability to survive and produce offspring) (Kauffman and Levin, 1987). For our purposes, we can think of *fitness* as a venture's ability to survive and produce positive economic outcomes, like sales and employment (Auerswald, 2015).

[2] Despite similarities in the short run, organizations, unlike organisms, can change the source of the scripts that govern their behavior by strategic reorientation, changing management, creative revision, or in general, through 'entrepreneurial pivoting' (Grimes, 2018; Hampel et al., 2020; Kirtley and O'Mahony, 2020). Therefore, organizations have more leeway to transform radically what they are about compared to organisms that their DNA only changes by natural selection over long periods.

4. Research design, data and variables

4.1. Studying the dynamics of EEs

A complex adaptive system (CAS) approach has been advocated (Auerswald and Dani, 2017; Berger and Kuckertz, 2016; Daniel et al., 2018; Haarhaus et al., 2020; Kuckertz, 2019; McKelvey, 2004; Ritala and Gustafsson, 2018; Roundy et al., 2018) to study EEs because they show attributes of complex systems, such as large number of interacting elements, nonlinearity and interdependency, emergent behavior, self-organization and adaptation to changing conditions (Daniel et al., 2018; Haarhaus et al., 2020; McKelvey, 2004; Ostrom, 2010; Roundy et al., 2018). Examining these complexities is the main objective of the ecosystem perspective. Yet, it has received little empirical following because standard statistical methods can be ill-suited to apply to the CAS approach. In particular, standard methods and their underlying assumptions fall short of explaining the complexity, nonlinearity, and dynamism proposed by CAS. Applying classic techniques to analyze an ecosystem is similar to trying to "understand running water by catching it in a basket" (Miller and Page, 2009).

However, finding useful alternatives to traditional statistical methods is a challenge. Introducing complex statistical methods may be impracticable because it is difficult to model the numerous intertwined interactions among elements of an EE. Instead, in this study, using descriptive exploratory methods, we focus on inductively recognizing patterns in the nearly entire national population of a specific subset of entrepreneurial firms -ASOs- and on empirically investigating how these patterns are associated with the actions of other actors in the ecosystem. These avoid standard assumptions used in conventional statistical methods. Descriptive methods can highlight dynamics and interdependencies so that new research questions can be identified, regression models can be better specified, endogeneity more easily recognized, and the like. Moreover, our exploratory design can complement other approaches; for instance, descriptive graphs can generate realistic values for simulation analysis. Further, this approach allows us to go beyond examining the means by empirically investigating outliers. Outlier firms are a few new ventures with high growth that account for a disproportionate contribution to the output of the entire ecosystem (Acs, 2008; Crawford et al., 2015), but create problems in standard statistical techniques. Examining means and outliers simultaneously allows us to better understand the nonlinear development of the EE.

4.2. Research design and sample

As noted in our review of the EE literature, several authors call for more dynamic approaches in empirical examinations. This includes taking into account changes over time; consideration of interactions among components; moving beyond entry into the ecosystem including also growth, exit, and survival; allowing for nonlinearity; samples with clear spatial and institutional boundaries; and representation of multiple interacting industries and technologies.

We take these considerations into account as we designed our study. Specifically, we sampled nearly the whole population of ASOs in Norway from year 2000 to year 2015. Consistent with the literature, we define ASOs as new ventures initiated within an academic setting that are either formed by a faculty member, staff member, or graduate student, and are based on the commercialization of a core technology that is transferred from an R&D institution or university (Clarysse and Moray, 2004; Link and Scott, 2005; Lockett et al., 2005; Rasmussen and Borch, 2010; Steffensen et al., 2000). This includes all entries in 2000–2012, exits through 2000–2015, and annual data on the firms. In total, the sample contains 374 firms and 2740 firm-year observations.

The population is ideal for our purposes. First, it represents the core of a well-defined and well-demarcated ecosystem. For example, specific policy initiatives, support organizations, and infrastructure are in place to support this particular population of firms. The population and associated policies are geographically bounded. Second, ecosystem interactions are salient in this population. For example, these types of firms are often VC-backed, receive government support, locate in incubators, and collaborate with universities, other organizations, and with each other. Additionally, longitudinal data allow us to capture evolutionary changes over time, and the focus on one type of firm (academic spin-offs [ASOs]), and in one small country (Norway) allows us to reduce (unobserved) heterogeneity due to the limited institutional and spatial boundaries. Notably, because we examine a population rather than a probability sample, statistical inference is a non-issue, and statistical tests do not convey any meaningful information. We therefore refrain from reporting such statistical tests.

We identified these ASOs through a national public-policy instrument called the FORNY program, which financed and promoted local support infrastructure, e.g., technology transfer offices (TTOs), at all major research organizations to promote the commercialization of academic research (Rasmussen and Gulbrandsen, 2012). The program was in place from 2000 until 2012 and kept detailed records throughout its existence.

In collecting our data, we used several sources to triangulate the information to ensure that this sample as closely as possible approximates the whole population of ASOs established in Norway over the observation period (Rasmussen and Mathisen, 2017). For example, we asked TTOs and entrepreneurship professors if they were aware of ASOs not utilizing the program. We also examined newspaper archives to search for additional ASOs. None were found through these efforts, which makes us reasonably confident that we capture the vast majority of ASOs. Merging official registers and other data sources, we generate individual histories for each of the 374 ASOs. The ASOs primarily represent the ICT, biopharma, maritime, and oil and gas sectors.

4.3. Data collection

We adopted a longitudinal research design exploiting archival data from several sources to follow ASO firms in our sample from inception until 2015. Given our interest in the ecosystem, it is critically important that we correctly register entries, growth, survival, and exits. We, therefore, matched the information from FORNY with the National Register of Business Enterprises (BRREG, www.brreg.no) using the unique company ID that is assigned to all firms registered in Norway. All companies incorporated in Norway are required to file annual accounts approved by registered public accountants. This helps us establish entry, exit, sales and employment. In terms of exits, it captures mergers, liquidations, and bankruptcies, but not acquisitions, which are another important exit mechanism (cf. Wennberg et al., 2010). To capture acquisitions, we read all letters from the board of directors, which form part of the annual statements registered by BRREG, and are therefore compulsory, as well as the Retriever database (www.retriever-info.com). Retriever is the largest media surveillance provider in the Nordic region. We constructed an individual news archive for all firms in the sample, including also information about acquisitions. In total, there were 189 exits, including 4 IPOs and 32 acquisitions during the studied period. Patent information is collected from the Norwegian Industrial Property Office (www.patentstyret.no). Finally, in order to qualify for the FORNY program, ASOs had to file business plans with Innovation Norway who granted us access to these plans. We used these plans to verify and cross-check information.

4.4. *Measures*

Ecosystem Metrics. In order to capture the dynamics of the EE, we rely on a number of different metrics that represent the dynamism of the EE. ***Active firms*** represents the total number of firms active in the ASO EE at any given time. ***Sales*** is the annual sales revenue in million Norwegian kroner (mNOK) and represents the size of the firm. ***Employees*** is the annual number of employees, representing another measure for firm size. Annual changes in sales and in number of employees represent ***Growth***. ***Entry*** and ***Exit*** are the other indicators that we study, which respectively represent the number of firms entering and exiting the ecosystem in one specified calendar year.

Ecosystem Services and Resource Endowments. ***Public grants*** represent public funding awarded to ASOs by various Norwegian support organizations including the Norwegian Research Council, Innovation Norway, and Skattefunn (tax deduction scheme for innovation projects). The amount of public grants is also measured in mNOK. It reflects the munificence of resources within the EE. ***VC Investment*** measures whether or not the firm has received outside investment made by venture capitalists or business angels. In their annual reports, Norwegian firms must disclose the names of any owner owning 5% or more of the stock in the company. We matched the names of owners with the names of the founders as indicated by the Brønnøysund register and/or the ASOs business plans, thereby establishing outside ownership. We then matched the names of the investors with the names of known venture capitalists and business angels, thereby excluding other investors, such as friends or family members. This variable is dummy coded 0/1 depending on whether the firm has received any VC funding. Similar to public grants, this variable captures ecosystem resource endowment. ***Incubation*** reflects if a firm has ever been located at an incubator, accelerator, or science park coordinated by the Industrial Development Corporation of Norway (SIVA). Incubation is captured by matching the unique firm registration number with the full population of incubated firms from SIVA, and coded 0/1.

5. The Norwegian academic spin-off entrepreneurial ecosystem (ASO EE)

5.1. *Origin and main actors*

The origin and development of the Norwegian ASO EE closely follows the development of the FORNY program. It was initiated by the Research Council of Norway (RCN) and implemented by allocating resources to the TTOs, which selected and followed up commercialization projects. The FORNY program became independent within the RCN from 2000 and operated until 2012. It was intended to create infrastructure to move Norway towards a knowledge economy and to provide public support promoting commercialization of science originating at universities and research institutes (Borlaug et al., 2009; Rasmussen et al., 2013; Rasmussen and Gulbrandsen, 2012). It aimed at establishing a robust ecosystem to "encourage and contribute to increased cooperation between research communities, entrepreneurs, investors, industry and commerce, and public authorities" (Rasmussen and Mathisen, 2017). Over the duration of this program, different mechanisms and schemes were implemented to promote interaction and collaboration among a diverse range of actors to mobilize resources supporting the entrepreneurial ecosystem (Borlaug et al., 2009).

Other related public agencies included Innovation Norway (IN) and the Industrial Development Corporation of Norway (SIVA). IN ran multiple programs to promote entrepreneurship and innovation in Norway offering support to firms (e.g., financial support, training). SIVA supported science parks and incubators and also provided soft infrastructure like knowledge networks (Borlaug et al., 2009). FORNY worked with these agencies, TTOs, incubators, universities, and research institutes to facilitate the commercialization process of research (Gulbrandsen and Rasmussen, 2012). Hence, a community of different stakeholders was created in Norway. As we show below, there was a high degree of interaction and collaboration among these actors, suggesting that these ASOs and the affiliated stakeholders (e.g., TTOs, universities, incubators, policy programs, public agencies) constituted an EE with clear boundary conditions (cf. Clayton et al., 2018; Fetters et al., 2010).

5.2. *Collaboration and knowledge spillover within the ASO EE*

Knowledge spillover in an EE can take many forms but is primarily horizontal and is typically non-contractual (e.g., Autio et al., 2018). Therefore, it is difficult to measure knowledge spillover directly. To study the potential for knowledge spillover, and to address interaction within the EE more generally, we examined the extent of cross-ownership. Using annual reports, we constructed Table A1 in Appendix A. It shows examples of the complexities of the ownership of the ASOs. Several types of investors simultaneously owned shares in the ASOs. To complicate matters further, some TTOs established VCs to secure seed capital for ASOs and some owner/managers simultaneously worked at TTOs having ownership stakes in their businesses. This intertwined network of ownership among the ecosystem stakeholders suggests that there is ample opportunity for collaboration and knowledge spillover.

A different way of examining ownership is to instead follow the investors. Table A2 in Appendix A shows examples of different types of investors (private company, incubator, VC, TTO and individual) and their ownership. For example, a TTO invests in 23 ASOs (6% of the population of ASOs) across 9 different industries, whereas an incubator made 17 investments (4.5% of the population of ASOs) across 8 industries. What is interesting about these figures is that because the ASO population is relatively small (374 firms), some investors can invest into a relatively large proportion of the whole ecosystem, and they invest across a wide range of industries. This potentially facilitates broad knowledge spillover.

Another aspect of ownership associated with knowledge spillover is acquisitions. A total of 32 ASOs were acquired during the 16 years that we studied. Out of those, 8 were international and 24 domestic. The acquiring firms were typically large established firms. We did not find any examples of acquisitions by other ASOs. Thus, acquisitions represent knowledge spillover outside the ASO EE.

Next, we examine how key personnel moves among the ASOs in the EE. In knowledge-based industries, transfer of employees represents an important mechanism for knowledge spillover. While it would have been interesting to examine many different types of employees, we only had consistent access to the names of the CEOs across years. In other words, we were only able to examine the extent to which CEOs in one ASO later became the CEO of another ASO. We identified the CEO names of ASOs from Norwegian National Registry Database (Brønnøysund Register Centre). We identified 55 CEOs who moved from one ASO to another. These 55 individuals were CEOs of a total of 130 ASOs. In other words, over 1/3 of all ASOs were managed by a CEO that also managed another ASO. These CEOs, the number of ASOs in which they worked, the industries, and technological domains are listed in their entirety in Table A3 in Appendix A. No less than 42 out of these 55 CEOs moved across industries. Among the 13 CEOs who did not, 6 moved across technological domains, and only 7 remained within the same technological domain. Additionally, in some cases, academic founders started multiple ASOs in diverse industries. These findings show that human capital often moved between ASOs across different industries, indicating possible linkages among them. This extensive fluidity of CEOs opens up the possibility of extensive knowledge transfer. For example, Autio et al. (2018) note that the development and transfer of new business models is an important aspect of an EE. This is no easy task. That CEOs extensively move between ASOs and particularly across industries within the EE suggests that the possibility for such transfer should be extensive within the Norwegian ASO EE. This finding also suggests that individuals working in the ASO EE seem to develop unique competencies which makes them suitable to move between different EE actors. This provides validation to how we delineate the ASO EE.

5.3. Changes by calendar year

Fig. 1 shows the dynamic development of the ecosystem by overlaying annual changes in our central variables, viz. entries and exits, total population of firms, total employment, patent applications, patents granted, total sales and total government grants received. Thus, apart from showing simultaneously the development of these variables, these plots allow us to reflect upon potential covariation among them. While visual display of covariation indeed does not imply causation, it provides cues about development patterns and factors that may drive these developments. The figure shows how the EE develops by chronological year from 2000 up until 2015, thereby covering a period of 16 years.

As seen in Fig. 1, the total population of firms grows steadily from 2000 up until 2010 when it reaches a total of 248 ASOs. The growth rate then drops off from 2010. Specifically, the number of ASOs in the EE increases by over 450% in 3 years from 2000 to 2003, and the number is 600% larger in 2005 than in 2000.

The pattern of entries and exits explains the development of the overall population of firms. Entries by year fluctuate somewhat over time. Initially, a rapid increase is noticeable over the first four consecutive years. The number of entries declines after 2003, increases in 2006, and then there is no clear trend until after 2010 when the relative number of entries start to dwindle. Conversely, the average number of exits is initially low but increases from 2010. Overall, this suggests an initially healthy and growing population that starts struggling towards the end of the studied period. Given that the population increases and then drops off, it suggests that the EE reaches its maximum number of firms over the period.

Interestingly, sales and employment do not follow the same development. Employment initially grows rapidly and is more than 5 times higher after 3 years and about 20 times higher at the end of the period compared to the beginning. Sales is slower to take off. It remains relatively low until 2005, when it rapidly increases. Sales in 2015 is about 7 times larger than in 2005. For these variables, there is no distinct downward trend towards the end of the period. Instead, both grow steadily until 2014 when there is a small dip in employment. A few interesting conclusions can be drawn based on this.

First, the difference in development for the number of active firms compared to total sales and employment of the population indicates that overall firm size increases over time - surviving firms grow, adding both new employees and sales volume, while the smallest firms are the most likely to exit, indicating that the least viable firms are the most likely to exit. This suggests that resources are freed up from the less productive firms and shifted to the more productive that put them into more productive use. Increased productivity is further supported by total sales increasing at a more rapid rate than total employment towards the end of the period, suggesting that sales per employee increases. Further, the temporal lag between employment and sales growth suggests that employment growth drives sales growth rather than the reverse.

In terms of intellectual property, patent applications grow steadily until 2009–2010, when there was a sharp drop off, coinciding with the start of the decline of the population. It seems that patent applications follow the number of active firms relatively closely. For obvious reasons, there is a delay until patents are granted, and we don't see any decline during the studied period.

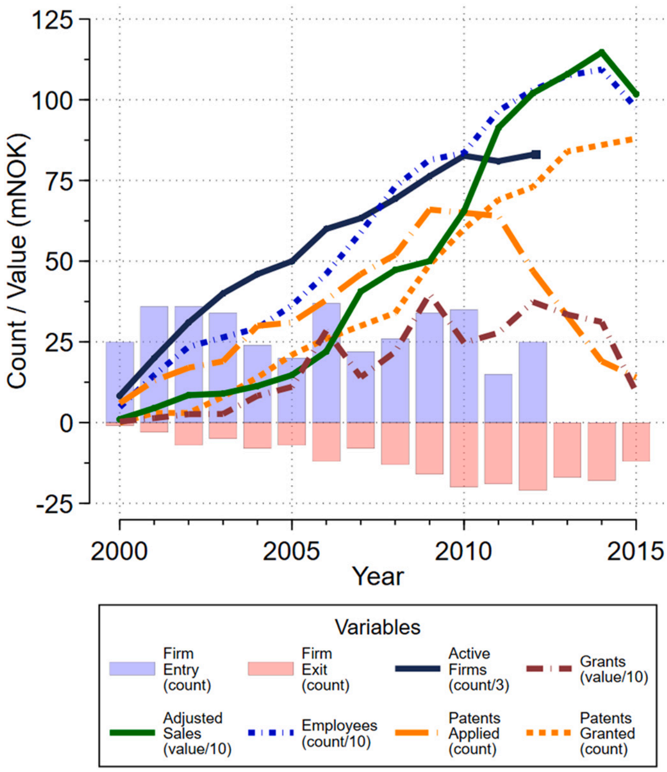

Fig. 1. The population of firms and its development by calendar year.

Government grants peak in 2009 and decline from there onwards. Specifically, in Fig. 1, we can see that the reduction of public grants after 2009 coincides with the reduction in entries and increased exits in the subsequent years, leading to a shrinking population. This seems to indicate that the amount of public grants underpins the *carrying capacity* of the EE and their decline in 2009 onwards may drive exit.[3]

5.4. Changes by firm age

Fig. 2 is similar to Fig. 1, but instead shows the development of the same variables by firm age. These two types of plots (Figs. 1 & 2) reveal different things, i.e., they focus on period and age effects, respectively (Cook and Campbell, 1979).

The figure reveals that all ASOs collectively receive about 400mNOK in public grants during their first year, and that the numbers drop off somewhat as they age, just as the number of firms goes down. Exits are initially low but pick up as ventures hit the age of three to six years (see Fig. 2).[4] From age 4, the amount of grants reduces in proportion to the number of remaining firms, suggesting that the average grants per firm remain relatively constant. This indicates that public grants drive exits, reinforcing the role they play in determining the *carrying capacity* of the EE.

The graphs examining patent applications and granted patents are interesting. Around 70 firms file for patents in their first year of existence. An additional 142 firms file for patents at ages 2 and 3 years. That is well over half of the firms in the sample. This suggests two things. First, it indicates that the ASOs are research-intensive and continue developing intellectual property after founding, rather than exploiting technology that was developed prior to inception. Second, it says something about the stage at which these firms are launched. Rather than building on technology that was fully developed within the university, it seems that these ASOs are launched relatively early in the process of developing their core technology, operating for one or two years beyond founding before being at a stage where the technology is patentable. This is further supported by the fact that hardly any patents are granted during the first year of existence, and patent granting only picks up very slowly. Thus, it seems that substantial exploration goes on also after the businesses are launched.

[3] In 2010 and 2011, FORNY receives funding from three Norwegian ministries down from six ministries a few years before that (Gulbrandsen and Rasmussen, 2012). Further, the number of eligible TTOs to receive funding from FORNY reduced from 14 in 2008 to 8 in 2011 due to strategy changes and assessment programs (Gulbrandsen and Rasmussen, 2012). These facts provide evidence that the supply of public grants was mainly driven by macro-level policy changes and distribution mechanisms rather than the demand from prospect ASOs.

[4] From Fig. 2 we see that, in line with prior research (Wennberg et al., 2011), approximately half of all new ASOs exit after 5–6 years.

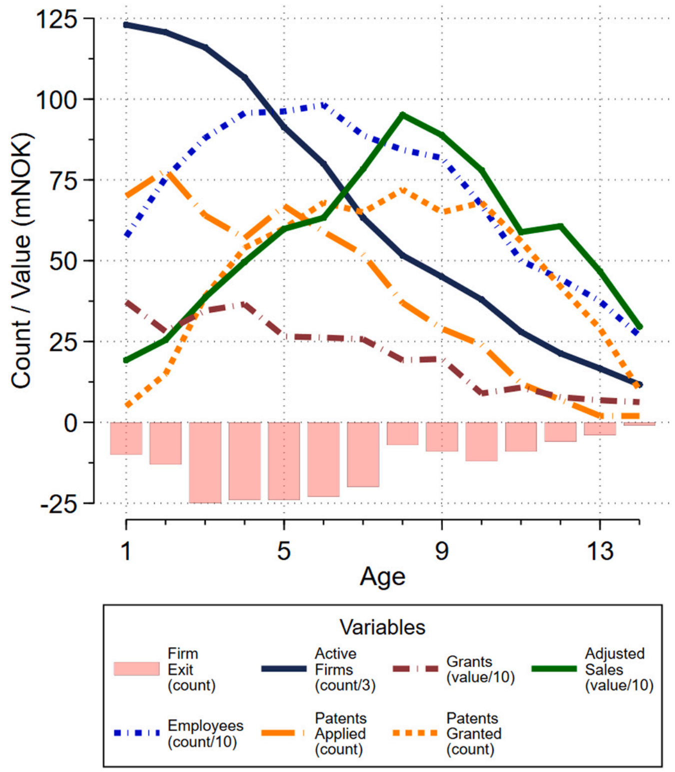

Fig. 2. The population of firms and its development by age.

5.5. *Disturbance and succession*

In 2003, a legal change was implemented in Norway, specifically targeting universities. Until 2003, inventions made by university employees belonged to the inventor rather than the institution (called the professor's exemption). In 2003, the ownership of patent was transferred from the inventor to the institution, placing universities on equal footing with other legal entities (Borlaug et al., 2009; Rasmussen et al., 2013). The change was implemented to stimulate universities to invest more in science commercialization (Rasmussen et al., 2013). The idea was that technologies that were earlier patented by the ASOs should instead be patented by the university and then licensed to the spin-off. This specific institutional change caused significant uncertainty in the EE, including a decline in the number of new ASOs. Actors started to adapt including universities reorganizing commercialization activities (Borlaug et al., 2009). The policy had several unintended consequences. It affected patenting behavior of ASOs—26% of ASOs founded before 2003 applied for a patent at some point over their period of existence as compared to 19% of firms founded post-2003, while licensing activity of universities increased after the 2003 legislation. Further, total patenting in the entire Norwegian ASO ecosystem declined 50% and some suggest that the mean quality of patents, as measured by citations, declined significantly (Hvide and Jones, 2018). These are certainly unintended consequences of the legal change. In ecosystem terms, it seems that this legal change could be viewed as an example of a *disturbance* of the ecosystem with subsequent *succession*. It is also an illustration of the potential consequences of interventions into nonlinear complex systems (cf. the introductions of rabbits, foxes, and cane toads into Australia).

5.6. *Sectoral and geographical differences*

To provide more fine-grained information, we repeated these plots grouped by three sectors (‘biopharma’ [74 ASOs], ‘software’ [145 ASOs], and ‘others’ including oil, gas, offshore, and maritime [154 ASOs])[5] and by eight locations. Comparing sectors, it seems likely that sales in biopharma would be slowed to take off due to longer development lead-times (see Figs. B1 & B2 in Appendix B). However, despite a 16-year window, we don't see the sector taking off – the increase in patenting towards the end of the period suggests that it may be necessary to study this industry for *even longer* time periods to reach any conclusions.

[5] Five ASOs that belonged to both biopharma and software sectors and had marginal sales were dropped from these plots.

Additionally, we identified eight locations for ASOs in Norway (see Figs. B3, B4 & B5 in Appendix B for map and plots). These plots show that in the three locations of Oslo, Trondheim, and Kjeller[6] which are industrial-academic hubs, a higher rate of economic activity is clearly noticeable. This indicates that geographical proximity to stakeholders and higher concentration of resources in regional EEs likely increases entrepreneurial dynamism and the subsequent number of entries and growth.

5.7. Outliers and firm fitness

Here we evaluate the ecosystem's ability to produce fit firms. Our earlier analyses suggest that firms in the ecosystem were becoming more 'fit', as both size and productivity increased over time. To examine this further, we plot the untransformed sales (mNOK) and employment trends for all firms using Lowess plots (see Fig. 3). The left panel shows growth in sales and the right panel growth in employment. Doing so helps identify outliers and nonlinearities in the data (Crawford et al., 2015).

First, it seems that much of the growth in overall sales and employment that we observed in Fig. 1 can be attributed to only a handful of firms. Only six firms ever surpass 50 mNOK and only five surpass 40 employees. Moreover, two of the firms that surpass 50 mNOK experience a decline in sales in the 2012–2015 period. Second, as smaller and less viable firms exit (as seen in the 2009–2015 period in Fig. 1), it is possible that resources are freed up from these less productive firms and shifted to the more productive ones, which subsequently grow (see the increase in sales growth in 2009 onwards in Fig. 1 and 'productive' outliers in Fig. 3).

The pattern for employment growth is similar with a few distinct differences. First, employment growth takes off earlier, suggesting that employment growth drives sales growth rather than the reverse. Second, although a few firms stand out, a larger number of firms appear responsible for overall employment growth. Third, a few of the firms that take off and exhibit extensive growth later substantially contract.

More details are included in Appendix C, which includes outlier firms that reached 100mNOK of sales (3 firms), 50 mNOK of sales (3 firms), or did an IPO (4 firms). The table is useful in that it succinctly shows the diversity of these highly successful outlier firms. It seems that they were founded at different times, in many different industries, and received VC investments at different phases of their development. Perhaps the most consistent findings are that (a) all but one received VC investments (b) all but one received public grants at multiple points in time and (c) all but two were located at the three main hotbeds (Oslo, Kjeller and Trondheim). Thus, more than providing definite answers regarding what makes a firm an outlier, the table raises questions.

A different kind of outliers is firms that grow substantially, but then later retrench. We identified 5 ASOs that reached the 95th percentile in sales, but then exhibited reduced sales in the two subsequent years. All those firms received public grants, but only one VC-backed. Also, it appears that one ASO was retrenched because of exogenous factors (falling oil prices), whereas the others appear to be shrinking due to some aspect of lack of *fitness* (e.g., poor business model, overextending internationally).

5.8. Health of the ecosystem: survival and growth

We also conducted *group mean* comparisons over time, where we group the firms based on public grants, VC investment, and incubation, which may potentially be aspects that differentiate successful ASOs from less successful ones. We show the means for those groups in longitudinal bivariate plots. For exit, we generate hazard plots using the Kaplan-Meier (KM) estimator that represents the probability of exit at a given point in time. This estimator shows the relationship between variables without imposing any specific functional form on the hazard. We analyze growth in sales and employment using the logged *group mean*. We also examine outliers to better understand nonlinear development of the EE in relation to these variables.

5.8.1. Public grants

We noted earlier that public grants help shape the EE's *carrying capacity*. The public grants were allocated to ASOs over their life cycle at different ages (see Fig. 2). Fig. 4 shows mean hazard rates for firms receiving zero, low, or high amounts of public grants (split at the median). The figure shows that on average, firms receiving high grant funding exhibit lower exit hazard. Moreover, on average, firms receiving low grants have an initial survival advantage compared with those receiving no grants (5% vs. 12% in year 3). However, their survival rates converge by year 7, which may indicate that small grants bolster survival but only until the money runs out—on average, small grants do not appear to enhance long-term viability.

Next, we analyze how public grants are associated with sales and employment growth, using the same three categories (see Fig. 5). We find that, on average, grants are associated with greater sales and employment growth. Although all three sales lines tend upwards, higher grant funding associates with steeper growth over time, which suggests that, on average, the effect of public grants on sales

[6] Kjeller hosts several large research institutes, including in energy and military. Oslo is the capital and the largest population center with multiple headquarters and universities. Trondheim is home to NTNU, the only university of technology in Norway) and of SINTEF, one of Europe's largest technical research institutions. These three regions represent Norway's largest research hubs.

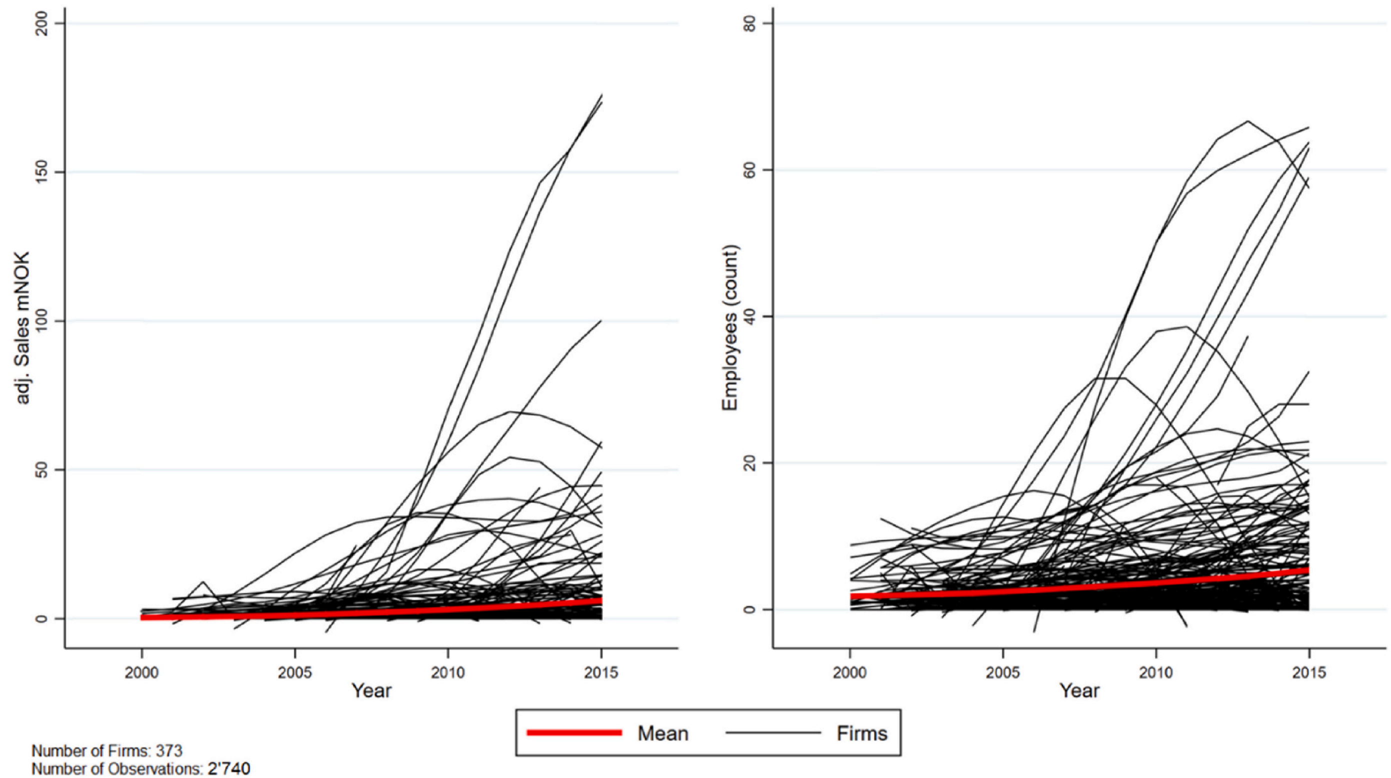

Fig. 3. Size of firms based on sales and number of employees. The left panel illustrates the Lowess (locally weighted scatterplot smoothing) curves of changes in adjusted sales for each individual firm, and for the mean, by year. The right panel illustrates the Lowess curves of changes in number of employees for each individual firm, and for the mean, by year.

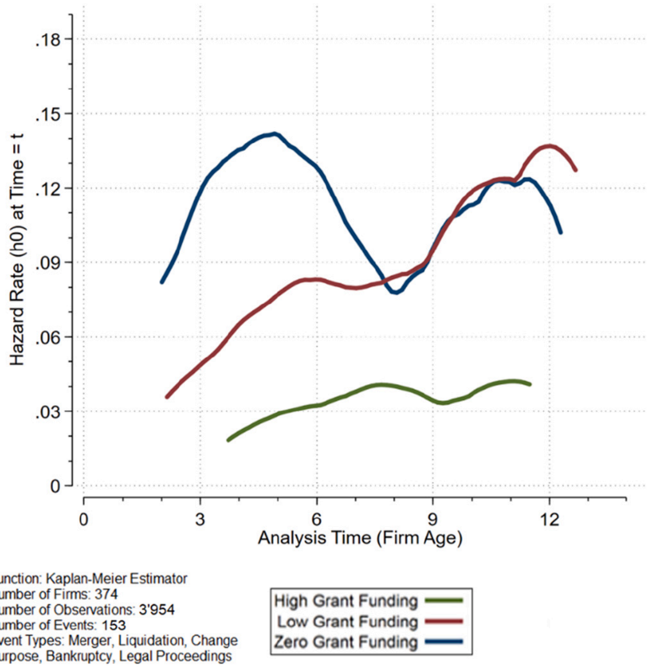

Fig. 4. Grant funding and exit hazard. It illustrates the probability of failure for ASOs as they age, grouped by the level of access to public grant funding.

growth materializes over time (see left panel of Fig. 5).[7] The pattern for employment growth is different. Assessing group averages, ventures receiving high grant funding add employees rapidly, while as a group, those with low or no grants grow at a much more modest pace. For example, at the end of the period, the average size of ASOs receiving large grants is 1.71 times larger than the average size of those receiving small grants and 2.44 times larger than the average size of those receiving no grants. Overall, it seems that at the population level, public grants are positively associated with both survival and growth, emphasizing its importance for the *carrying capacity* of the EE.

5.8.2. VC funding

Next, we conduct similar analyses for VC funding. We separate ventures receiving VC funding from those that don't and display hazard rates in Fig. 6. On average, ASOs receiving VC exhibit substantially lower hazard rates throughout the whole period studied. This would suggest that as a group, firms funded by VC are more viable. Examining growth, however, we find a different image (Fig. 7). On average, there are virtually no differences in terms of sales growth. In terms of employment growth, the average VC-backed ASO starts out larger, but actually grows less than the average ASO not receiving VC. These findings appear to be in contrast with the general view of VCs backing high-growth firms, pulling the plug if they don't perform to expectation. Based on examining averages, the conclusion would be that VCs neither pick the winners, nor guide them towards extraordinary growth. However, it also points to the problem of examining means (which most statistical techniques do). When we discussed outliers before, we found that all firms that reached 50mNOK or more were VC-backed (see Appendix C). Three out of the four firms that went public were VC-backed. In addition, all those outliers receiving VC support had zero to very marginal sales and only a few employees one year before the first VC investment. Given that only about 38% of the firms received any VC, this suggests that VCs may be able to pick and/or nurture winners among the Norwegian ASOs.[8]

5.8.3. Incubation

Finally, we examine the implications of incubation. Incubators offer new ventures access to resources such as space and advice for

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[7] Gimmon and Levie (2020) show that early sales has a significant positive impact on long-term performance of Israeli high technology new ventures. In order to explore the potential importance of how early sales and receiving public grants may influence the fate of our Norwegian ASOs, we ran a series of regressions. We examined the impact of *time to first sales* on *receiving public grants*. It appears there is no association between *time to the first sales* and *receiving public grants*. We also examined the impact of *receiving public grants* on *receiving VC investment*, and the impact of *time to receiving first public grants* on *time to the first VC investment*. Although there seems to be a positive association between *receiving public grants* and *receiving VC support*, early public grants does not influence timing of VC support (Appendix D).

[8] VCs scout potential high-growth firms better than other investors, and they also coach firms through provision of additional competencies and resources (Colombo and Grilli, 2010).

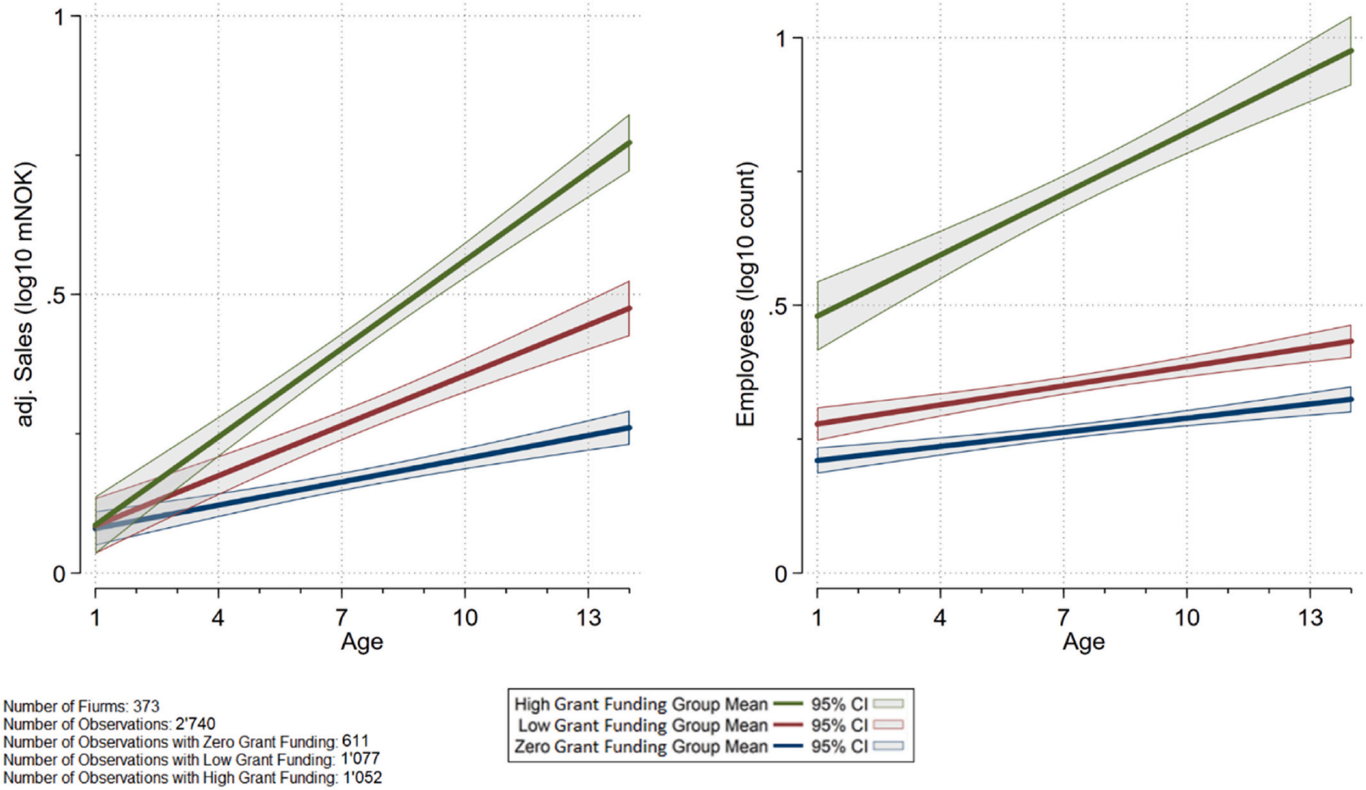

Fig. 5. Grant funding and growth. The left panel illustrates the mean of changes in adjusted sales (log10) of ASOs by age, grouped by the level of received public grant funding. The right panel illustrates the mean of changes in the number of employees (log10) of ASOs by age, grouped by the level of received public grant funding.

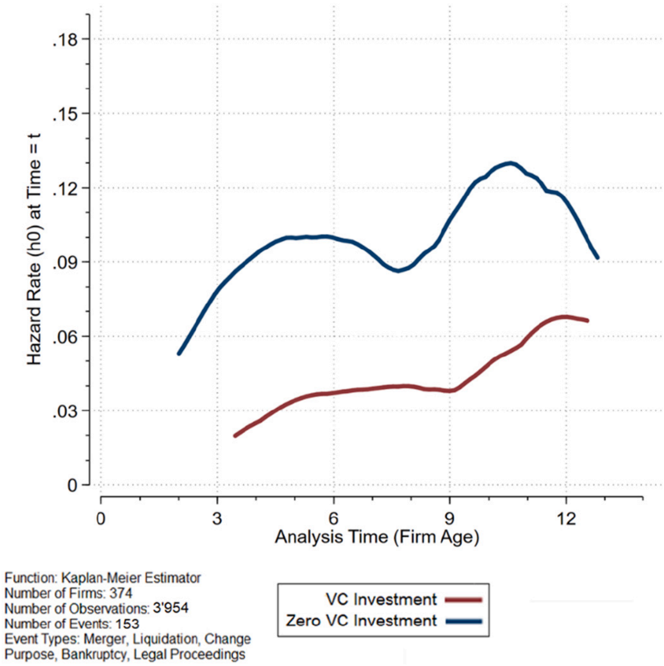

Fig. 6. VC investment and exit hazard. It illustrates the probability of failure for ASOs as they age, grouped by whether or not they are VC-backed.

free, or at reduced costs, access to management training; they also help new ventures establish relationships with VCs and other resource providers (Bruneel et al., 2012; Knopp, 2007; McAdam and McAdam, 2008). They support fledgling firms to survive the initial development stages, mainly because new businesses are at a disadvantage relative to their established counterparts due to lack of legitimacy, knowledge, and resources (Flynn, 1993; Singh et al., 1986; Stinchcombe, 1965). Incubation has been a popular policy instrument aimed at stimulating the feasibility of nascent ventures through creating a resource-munificent context (Amezcua et al., 2013; Amezcua et al., 2020; Mian, 2016). This sponsorship is created through two main mechanisms; provision of resources by shielding the venture from the external environment (i.e., buffering), and provision of targeted connections to the external environment to promote ventures' social capital, resource endowment, and legitimacy (i.e., bridging) (Amezcua et al., 2020; Flynn, 1993; Wiklund et al., 2010). Thereby, incubators represent ecosystem protected *habitats* by creating niches that offer munificent conditions for ASOs. Fig. 8 shows the hazard plots for incubated and non-incubated firms. The lines cross each other in several places, suggesting that, on average, incubation does not offer a consistent survival advantage.

Fig. 9 displays growth plots. On average, incubated and non-incubated firms exhibit virtually identical sales growth, whereas on average, incubated firms exhibit slightly faster employment growth. This may suggest that, on average, incubation does not increase firm *fitness* in terms of being productive and generating output. Again, as with VC, examination of averages does not tell the whole story. If we examine the ten outliers that exhibited extraordinary growth or went public, we find that 6 out of 10 were incubated. Since around half of all ASOs were incubated, it is hard to draw any conclusions regarding incubation based on this information. In sum, our analyses suggest that incubation only has marginal effect on the ASOs, if any.

6. Discussion

The conceptual application of the ecosystem perspective has gained popularity in recent years. From an empirical standpoint, scholars have not fully adopted the complex ecosystem view. As a result, many issues regarding dynamic change and evolution remain unresolved (Stam, 2015; Acs et al., 2017). In the current paper, we utilize the ecological ecosystem nomenclature and take an exploratory holistic approach to the analysis of the ecosystem—investigating concomitantly the dynamic development of entry, exit, survival, and growth of new ventures. Doing so, we gain a more complete understanding of how an EE evolves and the factors influencing its evolution (e.g., public grants, VC, incubators). We also illuminate new research questions worthy of further study. We include a table summarizing what we believe are the most important future research questions (see Appendix E).

We apply this approach to the Norwegian ASO EE. Using ecosystem nomenclature and reflecting on our findings, we believe with some confidence, we can summarize the most important insights as follows: Norway, like many other European countries, explicated its intentions to transform into a knowledge economy and it established the FORNY program to achieve this goal (Rasmussen and Mathisen, 2017). This signaled munificent entrepreneurial opportunities, which encouraged entry (Delacroix and Carroll, 1983). Soon other mechanisms (e.g., VCs, incubators, etc.) developed to support the ecosystem. Initially, the *carrying capacity* of the ecosystem exceeds the quantity of resources required by the individuals inhabiting the ecosystem. This creates room for entries of new ASOs as well as growth of existing ASOs. It also provides sufficient resources to less competitive firms, leading also to low exit rates (Aldrich and

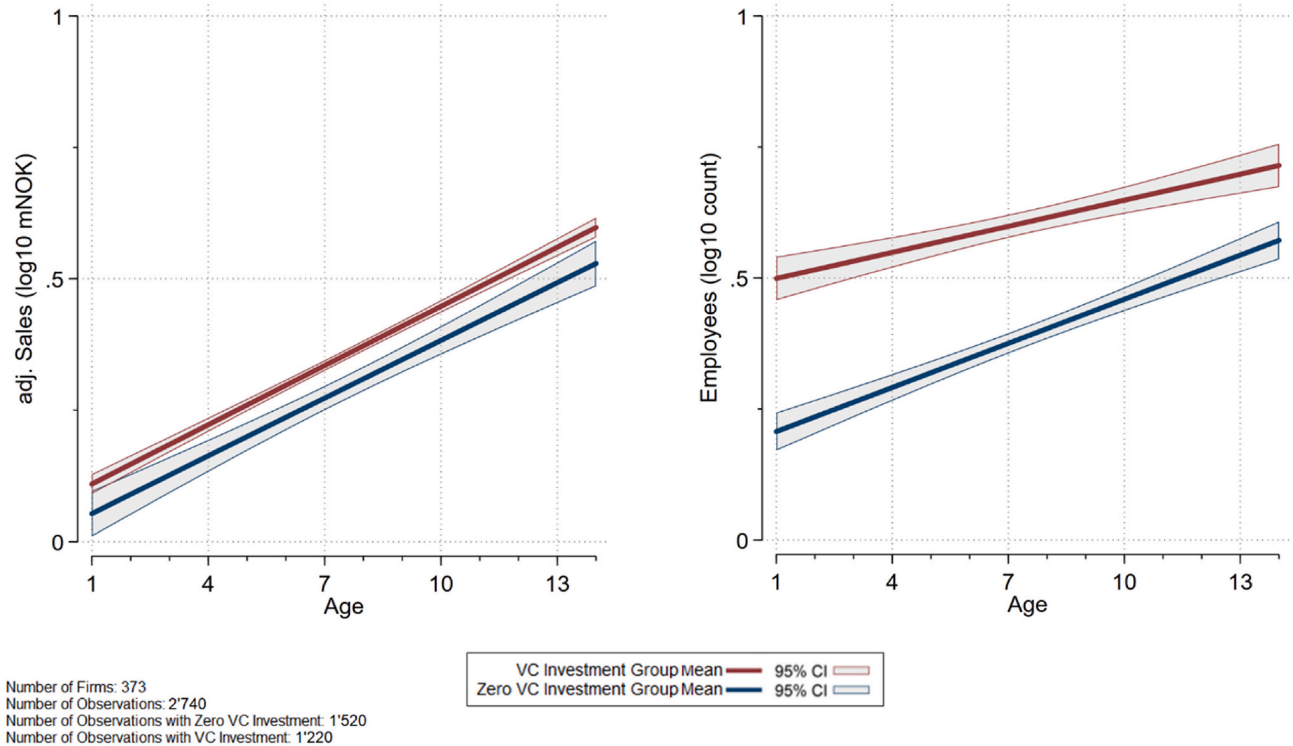

Fig. 7. VC investment and growth. The left panel illustrates the mean of changes in adjusted sales (log10) of ASOs by age, grouped based on whether or not they received VC investment. The right panel illustrates the mean of changes in the number of employees (log10) of ASOs by age, grouped based on whether or not they received VC investment.

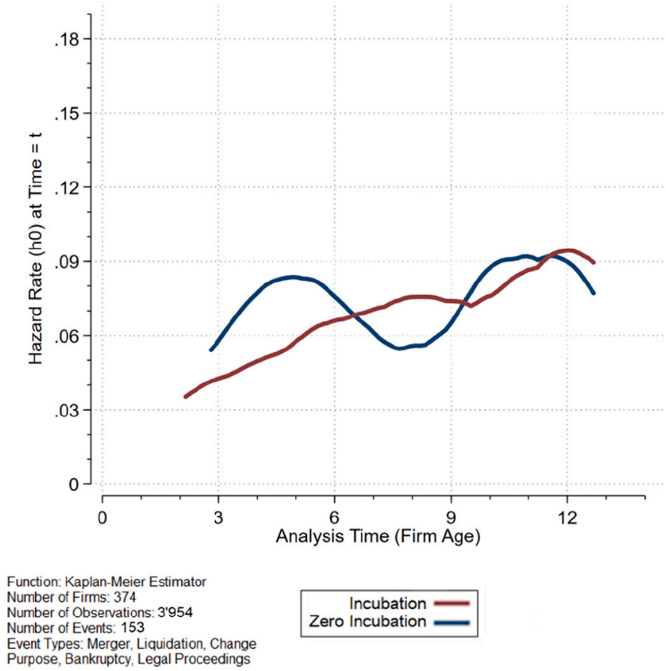

Fig. 8. Incubation and exit hazard. It illustrates the probability of failure for ASOs as they age, grouped by whether or not they are incubated.

Wiedenmayer, 1993). As the *carrying capacity* of the EE contracts, due to the reduction in public grants relative to the total number of firms, the competition among firms to access grants increases, and the less viable firms exit (Agarwal et al., 2002; Lomi et al., 2005) as expected. The smaller *carrying capacity* also resulted in relatively fewer entries into the ecosystem. The organizations that survive can continue to grow, because they can create their resources internally, or they can absorb the resources, such as competent employees, equipment, and patents, made available by exiting firms. As evidence, we observe the average of both firm sales and employee count increases.

We find that the institutional *disturbances* disrupt existing trends of entries and exits in the ecosystem. For instance, the policy shifting patent ownership from the inventor to the university had a profound effect on the EE. Entry fell but rebounded quickly as universities adapted to the change and began to license technology to ASOs (*succession*). However, such a *disturbance* can have unintended consequences. After the policy change, academics had less incentive to develop patents, and the quantity and quality of ASO patents declined (cf. Hvide and Jones, 2018).

We also explored the impact of incubation on the EE. Our findings indicate that an incubator represents a protected *habitat* that insulates firms from the selection pressures of the market. As expected, incubation increases the near-term probability of survival; however, it does not appear to enhance long-term survival or growth, suggesting that, on average, incubation does not increase firm *fitness* both in terms of viability and productivity. This supports recent creatively named evolutionary theorizing, which holds that more intense selection pressure leads to greater viability (i.e., "Red Queen Competition" [Barnett, 2008]; and "Trial-by-Fire" [Swaminathan, 1996]).[9] For non-incubated ASOs, the pattern of the hazard rate seems consistent with "trial-by-fire" — non-productive firms die when they exhaust their initial resources and the more fit firms survive, while the hazard pattern of incubated ASOs seems more consistent with Red Queen Competition — lack of exposure to competition reduces longevity and long-term productivity. VC is another important element in an EE (Spigel, 2017; Stam and Van de Ven, 2019). Our results indicate that VC investments associate with lower exit rates. We also find that the 'winners' in the sample, i.e., those that exhibit the greatest growth and those that go public for the most part were VC backed. This suggests that VC plays an important role in the Norwegian ASO's EE by both taking a punt on potential future winners and actively shaping them. This finding is aligned with some prior claims regarding the importance of VCs for growth and development of ASOs (cf. Colombo and Grilli, 2010; Mathisen and Rasmussen, 2019; Miozzo and DiVito, 2016).

6.1. Contributions to the EE literature

We make several contributions to the EE literature that have important implications for the EE research agenda. First, we extend the EE perspective by invoking the ecological ecosystem nomenclature and taking a holistic approach to examine elements of the ecosystem's evolution, namely entry, growth, survival, and exit, and how the external context influences them. We also demonstrate the

[9] As an auxiliary analysis, using Poisson regression, we tested the association between *time to the first sales* and *incubation dummy*. The results shown in Appendix F indicate that incubated ASOs take longer to have their first sales than non-incubated ASOs.

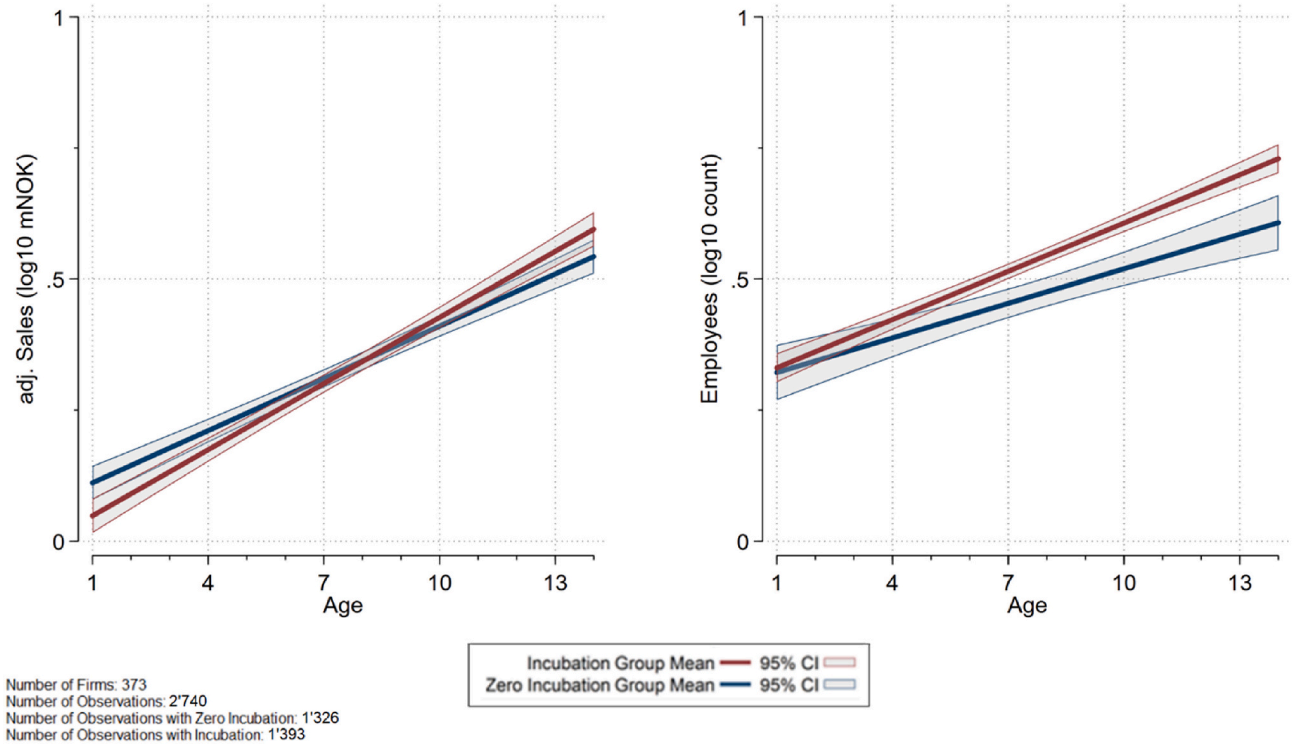

Fig. 9. Incubation and growth. The left panel illustrates the mean of changes in adjusted sales (log10) of ASOs by age, grouped by whether or not they are incubated. The right panel illustrates the mean of changes in number of employees (log10) of ASOs by age, grouped by whether or not they are incubated.

usefulness of applying concepts and nomenclature derived from ecology and evolutionary biology, such as *carrying capacity*, *habitat*, and *disturbance* effects. We show that these processes are clearly important to the EE. For example, *disturbances* such as changes to public grants, or changed IP legislation seem to have profound effects on the population in the EE. Our approach aligns with the conceptual literature that discusses these dynamic interrelationships and evolutions and calls precisely for the kinds of integrative and dynamic analyses that we conduct here (Auerswald, 2015; Autio et al., 2018; Berger and Kuckertz, 2016; Bruns et al., 2017; Good et al., 2019; Jacobides et al., 2018; Karatas-Ozkan et al., 2014; Malecki, 2018; Roundy et al., 2018). When we concomitantly discuss these processes and their interrelationships, we gain insights that would not be possible using traditional approaches. The first section of our discussion provides such an example.

Second, we apply exploratory quantitative methods (Singer and Willett, 2003; Johnson et al., 2019) with minimum modeling restrictions (Murnane and Willett, 2011) to the EE context. Doing so aligns with our holistic approach to examining the EE and enables us to better capture the complexities of EE evolution (e.g., Daniel et al., 2018; Jacobides et al., 2018; Kapoor, 2018; Roundy et al., 2018). Our empirical results provide insights into the evolution of an EE, which interrelationships appear important, and how to better design future studies. For example, the ASO EE appears to produce only a few successful outliers. To the extent that this can be seen as a policy success, then future studies of similar EEs should take this nonlinearity into account. Again, focusing on mean effects may obfuscate important findings related to the distribution of outcomes. For instance, an effective EE may have a high failure rate, but produce some large firms (outliers) that have the potential for sustained sales and employment growth, and potentially international prominence, particularly for a small country like Norway. As such, blindly applying classical statistical methods and their underlying assumptions falls short in explaining nonlinear dynamics and evolutionary nature of EEs. The results from this study can also be used to generate parameters for future stochastic (e.g., agent-based modeling) or probabilistic simulations (e.g., dynamic network modeling). Simulation methods like agent-based modeling assume that agents exhibit stochastic nonlinear behaviors and change over time through adaptive improvements and are therefore particularly useful in contexts such as EEs.

6.2. Policy contribution & discussion

Our analysis of findings has implications pertinent to policy and governance. Perhaps, the most important insight is that if we accept that EEs represent dynamic, nonlinear, interrelated systems (which is the consensus in the conceptual literature on which we build our research) that follow a polycentric governance of resources (cf. Ostrom, 2010), then policy needs to follow suit. Essentially, it becomes difficult to successfully implement large-scale top-down policies in support of EEs because it is hard to foresee what the outcomes will be, and unpredictable adaptations can emerge in response to such policies as the result of dynamic patterns of behaviors. As such, not considering the full scope of interrelationship in an EE inspires misguided policies. One example of this would be the change in IP rights' regimes. Our findings indicate that these changes likely had unintended and largely unforeseeable consequences, such as causing uncertainty, which can lead to a decline in the number of new ASOs (cf. Borlaug et al., 2009), and the drop in the quality and quantity of patents (cf. Hvide and Jones, 2018). Thus, the goal should be nudging EEs or building EEs that are capable of learning from failure and subsequently improving their support mechanisms iteratively with a bottom-top approach, rather than designing or creating impeccable EEs with a top-down approach. Another insight from our findings is that EEs are quite sensitive to institutional change (*disturbances*). Given that it is difficult to foresee the outcomes of such changes (e.g., because of complexity), the best advice is probably to leave existing policies alone and refrain from constant social reengineering. This is likely advice that will receive little heed because the politically elected typically want to show boldness and action in order to be reelected (Acemoglu and Robinson, 2013; Arshed et al., 2014).

In terms of specifics, it seems that the initial provision of public grants paired with VC investment can be a way of establishing a viable EE. Of course, we do not know the counterfactuals, i.e., if these resources could have been used even more effectively in other ways and/or if the ASOs would have developed equally well or better if no grants had been provided. However, it is reasonable to conclude that the FORNY program led to the establishment of an ASO EE and that VCs helped grow several viable firms. Whether the generation of 975 jobs, four IPOs, and three firms with over 100 mNOK of sales after sixteen years is a sufficient return on investment is for others to decide. Over the period of study, public grants totaled 2947 mNOK while total sales (adjusted) of the ASOs totaled 7923 mNOK, just less than three times the public grant total. So, the relative total amount of grants appears very large compared to the value created. The outcome of such investments on science commercialization process can, however, unfold indirectly and over time (Fini et al., 2018). As a case in point, a total of 32 ASOs were acquired, almost exclusively by large established firms. In several cases, human, physical, and intellectual capital of the ASOs were fully integrated into the acquiring firm. As a consequence, it appears as if those ASOs show little activity post-acquisition. In fact, they generated much value to the economic welfare, but this value is hard to capture as it is no longer directly attributable to the ASO (cf. Audretsch et al., 2019). Such indirect, nonlinear, and long-term impacts may also provide some justification for the value of the FORNY program.

Also, despite their popularity, it seems that the relevance of using public funds to start and support incubators may need assessment. We find little evidence to suggest that incubators have been essential in the establishment and growth of the Norwegian ASO EE. However, the impact of incubation on survival can potentially be interpreted in two different ways. First, incubators create an artificial *habitat* preventing ASOs from feeling competitive pressures and inevitably exit. With such an interpretation, incubation as a policy tool seems inefficient. The second interpretation would be that incubators provide a set of support mechanisms within a *habitat* that allows new ventures that would otherwise not have been started or would have exited to survive the initial stages to develop more fully over time. If so, even if incubators don't produce more viable firms, on average, they may still provide value.

6.3. Implications for the EE research agenda

In this section, we highlight several issues for the EE research agenda. First, researchers evaluating EE outcomes need to be aware that blindly applying traditional statistical approaches may lead to biased conclusions. For instance, examining mean revenues or mean employees is not indicative of whether the EE produces successful firms. Therefore, we call on researchers to pay attention to the entire distribution in their samples prior to applying conventional statistical models. Our approach can help provide a holistic picture of the whole EE, which can complement other statistical approaches, lead to better identification of relevant research questions, capturing possible institutional *disturbances* and their effects, recognizing possible endogeneity, evaluating modeling assumptions, correctly specifying functional forms for regression analysis, and discovering unexpected patterns and alternative explanations.

Second, to evaluate the effect of a policy on an EE, researchers also need to engage closely with their context and determine what constitutes success. For instance, a small country like Norway may need only a few large, internationally competitive firms to develop from the EE for a public grant policy to be considered a success. Not studying these outlier firms properly leads to forgoing important and valuable findings, so it is vital to identify them (Aguinis et al., 2013). It may be more appropriate to model the probability that an EE creates a successful firm than to model raw indicators of success, such as revenues. By combining our exploratory method with knowledge of the context, researchers may be able to identify more appropriate variable coding and empirical specifications to enhance the usefulness of classic statistical methods.

Third, we urge EE researchers to further explore the interrelationships between typical outcome variables like entry, survival, growth, and exit. Take exit as an example—future research could explore if exits alleviate intra-ecosystem competition and allow fit firms to grow? Are resources sufficiently released and reallocated efficiently as firms exit? Do other actors, such as government, VCs, financial institutions, facilitate healthy exit, or do they impede it to boost survival at the expense of healthy growth? Further research in this direction can expand our understanding of EE health and potentially surface useful and actionable policy recommendations.

Fourth, our findings suggest that successful startups from our EE context receive both grants and VC backing. Further research is needed to evaluate whether public grant programs have a positive treatment effect. Future research might ask if these grants provide the capital necessary for startups to develop enough to garner VC consideration, hence both grant and VC funding are essential complements, or do grants substitute for early VC funding, with grants representing a transfer of risk from VCs to the public.

Finally, the findings in our context raise further questions related to incubation that EE should explore. Our analyses don't show any positive performance implications of incubation, yet it is hard to assess the treatment effect of incubators. To understand whether they are an effective mechanism, scholars need to pay more attention to the dual selection effects—what drives incubators select startups and startup founders to consider incubation. Because the potential quality of a startup entering incubation is latent, future research could examine founders' motivation for entering incubators and whether access to incubators encouraged entrepreneurship. Moreover, learning during incubation could have a positive effect beyond the initial startup. For instance, if the incubated firm fails, do founders' training and network access help them to start new ventures? Is there any link between receiving incubation support and serial entrepreneurship? Undercovering these dynamic effects can broaden our understanding of incubator effectiveness. Also, we would encourage scholars to take a more critical approach to incubators. Our reading of the literature suggests that scholars don't sufficiently consider alternatives to incubation and whether they represent money well spent.

6.3.1. Links to other theories & perspectives

Our findings also have implications to future theory development. First, based on the real options perspective (McGrath, 1999; Rasmussen and Mathisen, 2017), our findings have theoretical implications for future investments made by different stakeholders within an ASO EE. ASOs are based on novel technologies, and they face highly uncertain growth prospects and long developmental cycles (Mathisen and Rasmussen, 2019). Considering their long developmental paths, they require substantial resources to survive and become commercially viable (Mustar et al., 2006; Wright et al., 2006). In this line, considering the very few numbers of outliers in an ASO EE (in the population of firms), and given the non-normal distribution of return outcomes, the real options perspective can provide a better understanding for expectations of possible opportunities of future investments.

Second, although EEs and business ecosystem research differ in their focus, there may be much to gain by considering both in tandem. Future research could explore how belonging to a common EE influences the firms' interactions when they belong to the same business ecosystem. In terms of theoretical connections, although ecological metaphors have been used in the business ecosystem literature (e.g., Iansiti and Levien (2004) focus on a "keystone species"), they have been mostly absent from recent theorizing. We believe theory development in the business ecosystem literature may benefit from engaging with the ecology and evolutionary biology nomenclature as we have done here. For instance, researchers might assess the *carrying capacity* of a platform ecosystem (e.g., Apple's iOS) so to understand what factors affect entry, exit, and complementors' value capture. Doing so can add to the growing literature examining the performance of business ecosystem participants (Kapoor and Agarwal, 2017; Miller and Toh, 2020).

Third, through shared incubation, common investors (see Table A2 in Appendix A), and employee mobility (see Table A3 in Appendix A), we expect that firms embedded in EEs will benefit from horizontal knowledge spillovers (Acs et al., 2009; Autio et al., 2018). Understanding which of these channels is most likely to produce beneficial knowledge flows, how the type of knowledge might differ across channels, or how these knowledge flows benefit the *habitat* is worthy of further study.

6.4. Research limitations

Like all research, ours has limitations. First, identifying the underlying dynamics of an EE as a complex adaptive system (CAS), theoretically, asks for data about all the interactions of all existing agents, patterns across all networks, process variables, incentives of the interacting agents, and so. This requires an 'order-of-magnitude' deep data collection. Such a data collection might be unrealistic. Further, modeling an empirical dataset that fully represents the actual system requires a detailed model which is probably as hard to understand as the real system. Considering these issues, in this paper, we believe that effectively simple descriptions of the outcome variables of the system can help us to understand, synthesize, and predict an EE. That is mainly aligned with the goal of the paper to provide a holistic picture, which could not be possible otherwise. This holistic picture can help us raise new questions or develop new hypotheses that can be investigated in future studies (cf. Anderson et al., 2019), from which future EE research can benefit to the extent that their data allows. Notwithstanding, we acknowledge that the limitations of our analytic approach, our data constraints, or the fact that our variables are concerned with the outcomes of an EE rather than the detailed interacting agents, might not capture all core underlying structures, or might not tease out all alternative explanations.

Second, as we suggested in the previous section, we suspect selection issues in the identified patterns. For example, prior research shows that incubators have reasons to respectively admit a firm, and the incubatees have reasons to apply to an incubator (Hackett and Dilts, 2004). In this line, we believe that our analytic approach and visual display of covariation provide important information regarding development of patterns and the factors that may drive these developments. However, we fully acknowledge that the visual display of covariation indeed does not imply causation. Therefore, the findings should be interpreted with caution.

Third, we caution against the overgeneralization of our results given our single country context. Without information on how a country and EE-specific factors compare with Norway's, we cannot accurately project how our policy implications might directly map to different contexts. However, we speculate that our policy implications will most likely generalize to countries of similar size and with similar economic traits, such as Nordic countries, the Netherlands, Belgium, and New Zealand.

CRediT authorship contribution statement

Hooman Abootorabi: Conceptualization, Methodology, Software, Formal Analysis, Investigation, Writing – Original Draft, Writing – Review & Editing, Project Administration, Visualization.
Johan Wiklund: Conceptualization, Investigation, Writing – Original Draft, Writing – Review & Editing, Supervision.
Alan R. Johnson: Methodology, Software, Formal Analysis, Data Curation, Visualization.
Cameron D. Miller: Writing – Review & Editing.

Declaration of competing interest

The named authors have no conflict of interests.

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Appendix A. Collaboration and knowledge spillover within the ASO EE

Table A1
Examples of ASOs with multiple EE investors.

Number	Description of ownership structure
1	The ASO (9e) in 2001 is owned by an engineering firm (38%), and two separate TTOs (34% and 28%).
2	The ASO (0k) in 2000 is owned by a TTO (13.2%), an incubator (9.4%), a publicly listed company (8.6%), a private company (5%), and seven different individuals (ranging from 16% to 6.3%).
3	The ASO (0v) in 2010 is owned by three distinct TTO each 20%, a public institution (20%), a VC (12.1%), and an incubator (7.9%).
4	The ASO (1h) in 2008 is owned by an incubator (54.1%), a VC (16.7%), a public institution (7.6%), and five individuals (ranging from 5.8% to 1.8%).
5	The ASO (1o) in 2002 is owned by three founders (ranging from 46.9% to 15.6%), a private company (10.9%), and a VC (10.9%).
6	The ASO (9a) in 2010 was owned by a TTO (39.5%), a VC (36.8), and three individual founders (ranging from 16.6% to 3.6%).
7	The ASO (9c) in 2006 is owned by an institutional VC (18.4%), a TTO (5%), a private company (11.6%), a holding company (2.8%), and six individual owners.
8	The VC N is created by a TTO to secure capital for their portfolio companies. The TTO is partly owner of the VC, and the VC is associated with another company who is a founder personal company, owning shares in multiple ASOs.
9	The VC names P is created by a TTO to provide seed capital to ASOs.
10	S is the CEO and owner of a private holding company owning shares in two ASOs. He also ran other companies, worked at a TTO, and before that, he worked at a university as an assistant professor.
11	A is the founder of an ASO. Before starting his business, he worked at a TTO. He left his company in 2009 and went back to the TTO. In 2012, he started another company.

Table A2
Examples of types of investors investing across industries.

Owner ID	Type of investor	Total number of ASOs invested	Industry codes of ASOs (NACE 2-digit)
R	Private company	2	58, 72
F	Incubator	17	26, 72, 58, 26, 100, 32, 71, 62,
I	Institutional venture capital	9	62, 72, 28, 58, 71
N	TTO	23	74, 72, 71, 70, 100, 28, 62, 21, 25,
P	Individual owner	2	72, 62

Table A3
CEOs of academic spin-off who moved across different ventures.

#	Role	No. of ASOs	Corresponding industries (NACE 2-Digit)	Corresponding technological domains
1	Founder & CEO	2	Publishing Activities (50), Scientific Research & Development (72)	ICT, Material Science/Nanotechnology
2	Founder & CEO	2	Other (100)	Electronics, Other
3	CEO	5	Computer Programming (62), Agricultural & Engineering Activities (71), Office Administrative, Office Support & Other Business Support Activities (82), Scientific Research & Development (72), Other (100)	ICT (Med/Bio), Medtech/Pharma, Biotech/ Nutrition, Marine/Aquaculture, Other
4	CEO	2	Scientific Research & Development (72)	Medtech/Pharma
5	CEO	2	Scientific Research & Development (72)	Medtech/Pharma
6	Founder & CEO	4	Scientific Research & Development (72), Mining Support Service Activities (09)	Medtech/Pharma, Biotech/Nutrition, Oil/ Gas/Offshore
7	Founder & CEO	2	Scientific Research & Development (72)	Medtech/Pharma
8	CEO	3	Fishing & Agriculture (03), Computer Programming (62), Architectural & Engineering Activities (71)	Marine/Aquaculture, ICT (Maritime/ Energy), Oil/Gas/Offshore
9	Founder & CEO	4	Other Manufacturing (32), Scientific Research & Development (72)	ICT, Marine/Aquaculture, Other, Biotech/ Nutrition
10	CEO	4	Wholesale Trade, Except of Motor Vehicles and Motorcycles (46), Scientific Research & Development (72), Publishing Activities (58), Other Professional, Scientific & Technical Activities (74)	Marine/Aquaculture, ICT (Med/Bio), ICT
11	CEO	4	Wholesale Trade, Except of Motor Vehicles and Motorcycles (46), Agricultural & Engineering Activities (71), Scientific Research & Development (72), Computer Programming (62)	Marine/Aquaculture, Medtech/Pharma, ICT
12	CEO	2	Computer Programming (62), Manufacture of Machinery & Equipment N.E. C. (28)	ICT (Med/Bio), Material Science/ Nanotechnology
13	CEO	2	Office Administrative, Office Support & Other Business Support Activities (82), Scientific Research & Development (72)	Medtech/Pharma, Biotech/Nutrition
14	CEO	2	Scientific Research & Development (72), Agricultural & Engineering Activities (71)	Biotech/Nutrition, Medtech/Pharma
15	CEO	2	Scientific Research & Development (72), Other Manufacturing (32)	Medtech/Pharma
16	CEO	3	Scientific Research & Development (72), Other Professional, Scientific & Technical Activities (74)	Biotech/Nutrition
17	CEO	5	Scientific Research & Development (72), Manufacture of Food Products (10), Architectural & Engineering Activities (71)	Biotech/Nutrition, Medtech/Pharma
18	Founder & CEO	2	Scientific Research & Development (72), Publishing Activities (58)	ICT (Med/Bio), ICT
19	CEO	2	Wholesale Trade, Except of Motor Vehicles and Motorcycles (46), Computer Programming (62)	Oil/Gas/Offshore, ICT (Maritime/Energy)
20	CEO	2	Wholesale Trade, Except of Motor Vehicles and Motorcycles (46)	Oil/Gas/Offshore, Material Science/ Nanotechnology
21	CEO	2	Manufacture of Machinery & Equipment N.E.C. (28), Manufacture of Basic Pharmaceutical Products and Pharmaceutical Preparations (21)	Material Science/Nanotechnology
22	CEO	2	Other Manufacturing (32), Publishing Activities (58)	Medtech/Pharma, ICT (Med/Bio)
23	CEO	2	Manufacture of Machinery & Equipment N.E.C. (28), Manufacture of Fabricated Metal Products, Except Machinery & Equipment (25)	Environmental/Renewables, Material Science/Nanotechnology
24	CEO	2	Scientific Research & Development (72)	Medtech/Pharma
25	CEO	2	Manufacture of Machinery & Equipment N.E.C. (28), Computer Programming (62)	Maritime, ICT
26	Founder & CEO	2	Scientific Research & Development (72), Other Professional, Scientific & Technical Activities (74)	ICT (Maritime/Energy), ICT
27	Founder & CEO	2	Computer Programming (62)	ICT (Maritime/Energy), ICT
28	Founder & CEO	2	Manufacture of Basic Pharmaceutical Products and Pharmaceutical Preparations (21), Scientific Research & Development (72)	Medtech/Pharma
29	Founder & CEO	2	Agricultural & Engineering Activities (71), Other Professional, Scientific & Technical Activities (74)	Biotech/Nutrition
30	CEO	2		Biotech/Nutrition

(continued on next page)

Table A3 (*continued*)

#	Role	No. of ASOs	Corresponding industries (NACE 2-Digit)	Corresponding technological domains
			Agricultural & Engineering Activities (71), Scientific Research & Development (72)	
31	Founder & CEO	2	Scientific Research & Development (72)	Medtech/Pharma
32	Founder & CEO	2	Other Professional, Scientific & Technical Activities (74)	Other
33	Founder & CEO	2	Activities of Head Offices (70), Other Manufacturing (32)	Other, Medtech/Pharma
34	Founder & CEO	2	Other (100), Manufacture of Machinery & Equipment N.E.C. (28)	Environmental/Renewables
35	CEO	2	Scientific Research & Development (72), Publishing Activities (58)	Medtech/Pharma, Other
36	CEO	3	Publishing Activities (58), Architectural & Engineering Activities (71), Other Professional, Scientific & Technical Activities (74)	Other, ICT (Materials Science), Material Science/Nanotechnology
37	Founder & CEO	2	Manufacture of Machinery & Equipment N.E.C. (28), Computer Programming (62)	Environmental/Renewables, ICT
38	CEO	2	Publishing Activities (58), Scientific Research & Development (72)	ICT (Maritime/Energy), Medtech/Pharma
39	Founder & CEO	3	Computer Programming (62), Architectural & Engineering Activities (71)	ICT, Material Science/Nanotechnology
40	Founder & CEO	2	Other Professional, Scientific & Technical Activities (74)	ICT, ICT (Med/Bio)
41	Founder & CEO	2	Agricultural & Engineering Activities (71)	Maritime, Environmental/Renewables
42	Founder & CEO	2	Agricultural & Engineering Activities (71)	Maritime, Environmental/Renewables
43	CEO	2	Agricultural & Engineering Activities (71), Scientific Research & Development (72)	Medtech/Pharma
44	CEO	3	Manufacture of Food Products (10), Computer Programming (62)	Biotech/Nutrition, ICT (Med/Bio), ICT
45	Founder & CEO	2	Computer Programming (62), Scientific Research & Development (72)	ICT, Electronics
46	CEO	3	Architectural & Engineering Activities (71), Scientific Research & Development (72)	Medtech/Pharma, Other
47	CEO	2	Other Professional, Scientific & Technical Activities (74), Scientific Research & Development (72)	Electronics, Medtech/Pharma
48	CEO	2	Other Professional, Scientific & Technical Activities (74), Architectural & Engineering Activities (71)	Electronics
49	CEO	2	Architectural & Engineering Activities (71)	ICT (Materials Science), Electronics
50	CEO	2	Manufacture of Computer, Electronic & Optical Products (26), Other Professional, Scientific & Technical Activities (74)	Electronics
51	Founder & CEO	2	Wholesale Trade, Except of Motor Vehicles & Motorcycles (46), Manufacture of Machinery & Equipment N.E.C. (28)	Material Science/Nanotechnology, Environmental/Renewables
52	CEO	2	Activities of Head Offices (70), Scientific Research & Development (72)	Medtech/Pharma
53	Founder & CEO	2	Wholesale Trade, Except of Motor Vehicles & Motorcycles (46), Computer Programming (62)	Oil/Gas/Offshore, ICT
54	Founder & CEO	2	Architectural & Engineering Activities (71), Activities of Head Offices (70)	Oil/Gas/Offshore, ICT
55	CEO	2	Architectural & Engineering Activities (71), Scientific Research & Development (72)	Environmental/Renewables, Medtech/Pharma

Appendix B. Sectoral and geographical differences

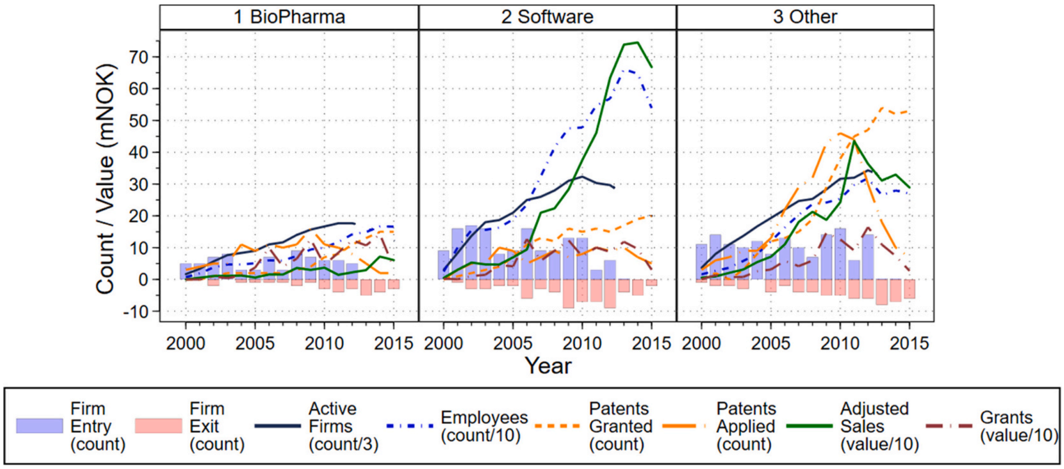

Fig. B1. The population of firms and its development by year, grouped by sectors.

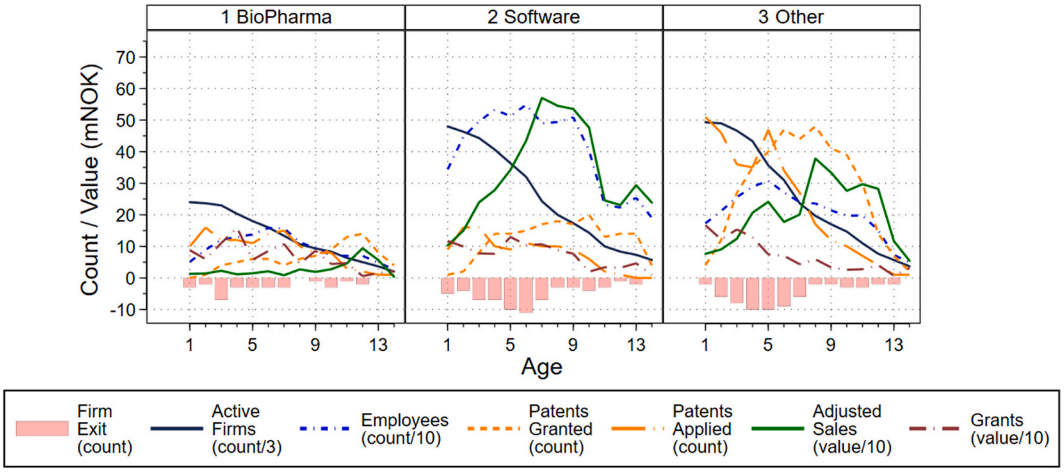

Fig. B2. The population of firms and its development by age, grouped by sectors.

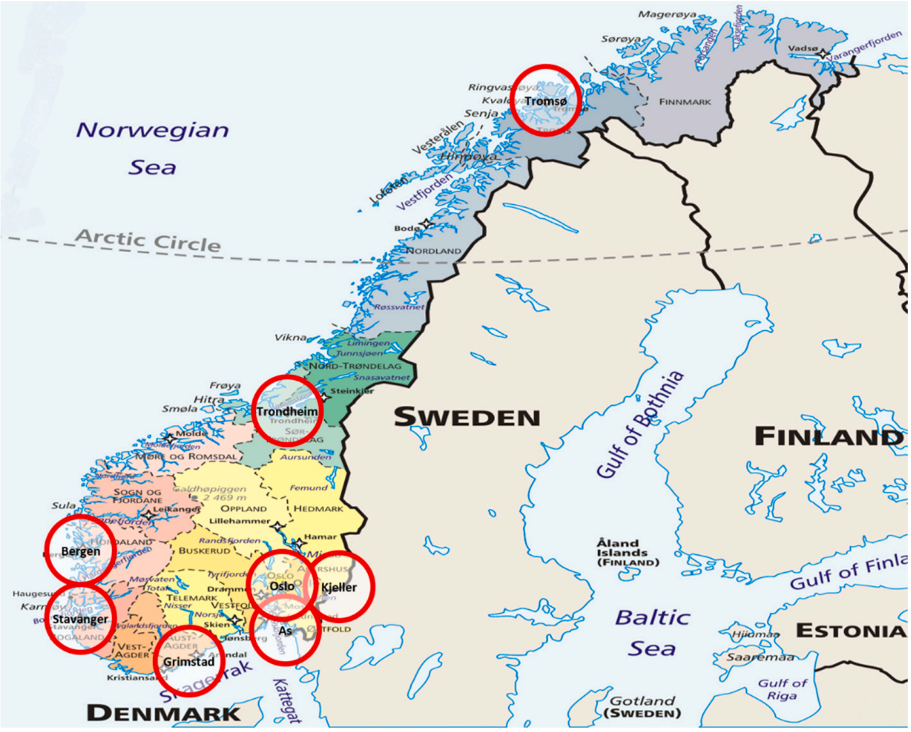

Fig. B3. Map of Norway illustrating the eight geographical locations of ASOs.

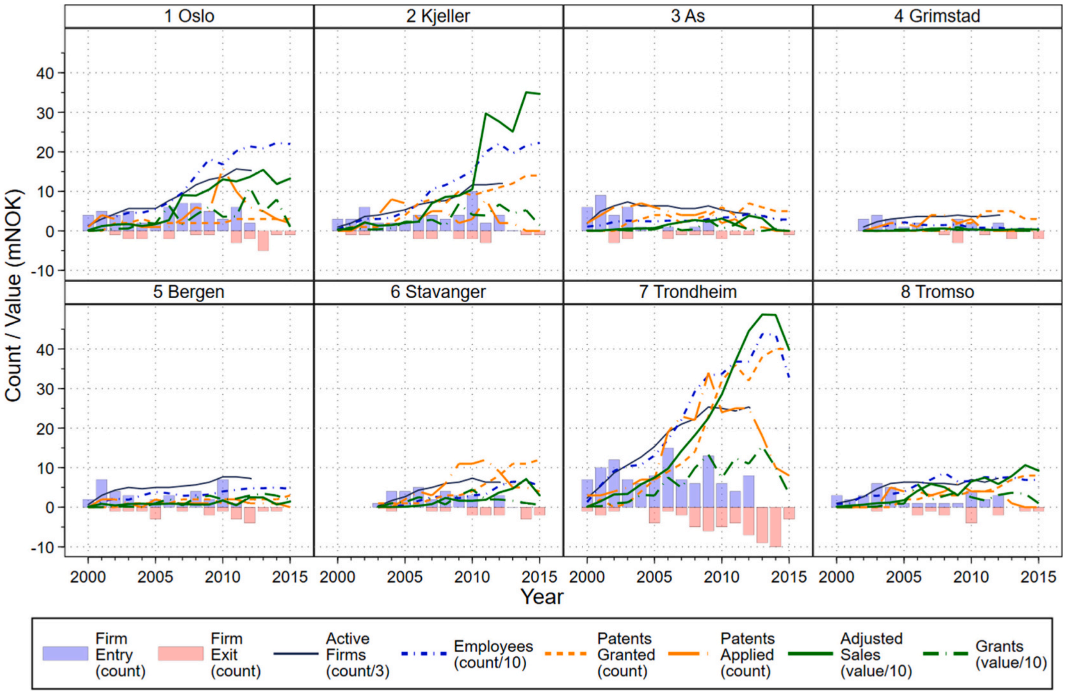

Fig. B4. The population of firms and its development by year, grouped by locations.

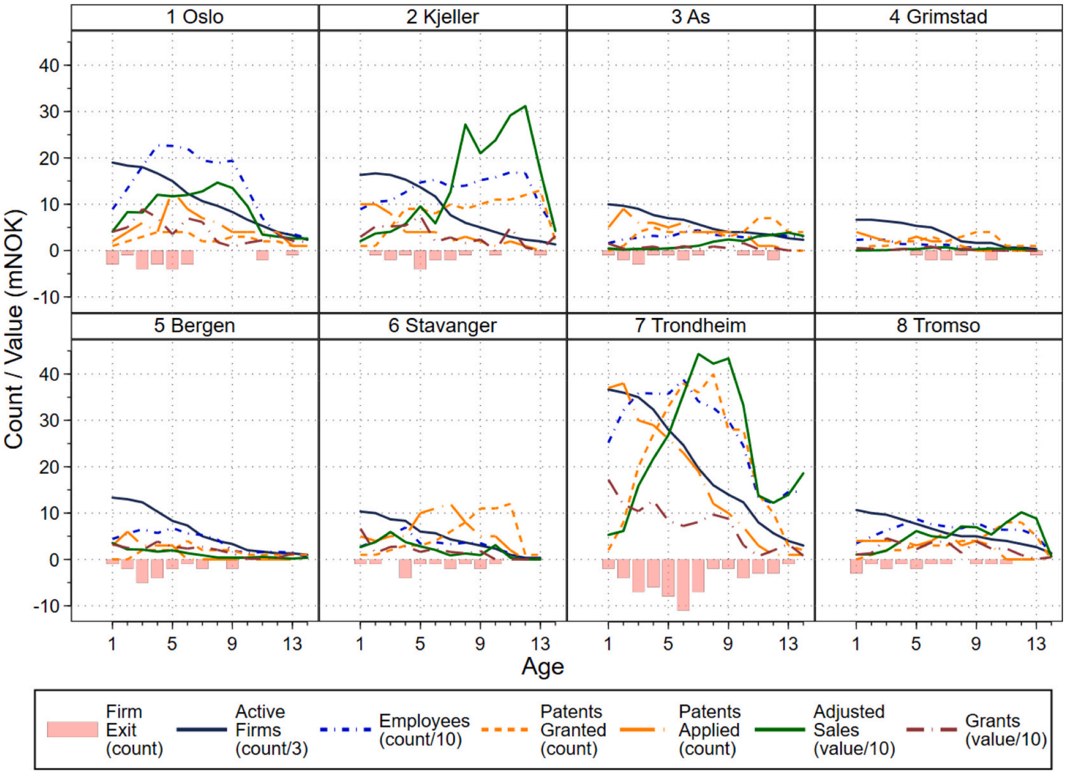

Fig. B5. The population of firms and its development by age, grouped by locations.

Appendix C. Detailed description of outlier ASOs

Appendix D. Regression analysis testing the association between grants, VC investment, and time to the first sales

ID	Type of outlier	Start year	Year @ first significant sale or contract	Max sales (mNOK)	Year @ max sales	VC support	Year of first institutional VC investment	Sales @ first VC investment	Sales @ first VC investment – 1	# Emp @ max revenue	# Emp @ first investment	# Emp @ first investment + 1	Incubation	Public grants	Year(s) received grants	Industry (NACE-2)	Tech domain	Location
1	100 M	2002	2006	103.5	2015	Yes (>50)	2005	0	1	58	7	7	Yes	Yes	2003–05, 2007–11, 2013	Computer Programming (62)	ICT (Maritime/ Energy)	Kjeller
2	100 M	2003	2007	188.9	2015	Yes (100)	2007	3.5	0	68	8	2	Yes	Yes	2005, 2007–10, 2012, 2014	Manufacture of Machinery & Equipment (28)	Maritime	Kjeller
3	100 M	2005	2008	185.7	2015	Yes (<80)	2005	25.5	0	68	21	6	Yes	Yes	2005–08, 2010–12, 2014	Scientific Research & Development (72)	Oil/Gas/ Offshore	Trondheim
4	50 M	2005	2006	83.5	2013	Yes	(2014)	61	83.5	63	67	63	No	Yes	2005–06, 2012	Computer Programming (62)	ICT (Med/ Bio)	Oslo
5	50 M	2000	2002	77.8	2014	Yes (<60)	2002	0.6	0	69	12	0	Yes	Yes	2001, 2004–9, 2012–13	Computer Programming (62)	ICT	Trondheim
6	50 M	2005	2008	80.1	2012	Yes (<78)	2007	0	0	25	15	3	Yes	Yes	2005–12, 2014	Scientific Research & Development (72)	Maritime	Trondheim
7	IPO (2005)	2002	2002	101	2010	Yes (<35)	2005	0.258	2.3	43	10	4	No	Yes	2002, 2005, 2009–10	Scientific Research & Development (72)	Medtech/ Pharma	Bergen
8	IPO (2007)	2003	2008	9.9	2008	Yes (<36)	2003	0	–	33	0 (Excl. Founders)	–	No	Yes	2003–06, 2009–10, 2012, 2014	Mining Support Service Activities (09)	Oil/Gas/ Offshore	Stavanger
9	IPO (2013)	2009	2011	–	–	Yes (<19)	2010	0	0	5	0 (Excl. Founders)	0 (Excl. Founders)	Yes	Yes	2009–12, 2014	Scientific Research & Development (72)	Medtech/ Pharma	Oslo
10	IPO (2015)	2008	2008	0.059	2013	No	–	–	–	1 (Excl. Founders)	–	–	No	No	–	Scientific Research & Development (72)	Medtech/ Pharma	Oslo

Appendix E. Examples of future research questions outlined in the paper concerning an ASO EE

Dependent variable	Model 1 (Logit regression)	Model 2 (Logit regression)	Model 3 (Poisson regression)
	Public grants (0/1)	VC investment (0/1)	Time to the first VC investment (by year)
Time to the first sales	−0.090	–	–
Public grants (0/1)	–	1.238***	–
Time to the first received grant (by year)	–	–	−0.460
Constant	−0.845	−0.920	0.502
Observations (number of firms)	223	342	118
Log likelihood	−140.406	−204.138	−199.932
Pseudo R2	0.086	0.125	0.131

All models are estimated with robust standard errors, and we controlled for industry (NACE 2-Digit), location, and academic affiliation (type of academic institution of origin).

*** $p < 0.001$.

Appendix F. Poisson regression analysis testing the association between incubation dummy and time to the first sales

Number	Example of research questions	Overall categorization
1	How do future studies have to take into account the entire distribution of outcome variables, and the outlier firms?	Methodology
3	How to explore the interrelationships between outcome variables?	Methodology
4	Does exits alleviate intra-system competition?	Ecosystem specific
5	Are resources of exited firms reallocated efficiently to surviving firms?	Ecosystem specific
6	What is the role of government, VCs, and financial institutions in either facilitating healthy exits or boosting survival at the expense of healthy growth?	Resource availability
7	Is there a complementary or substitute effect between VC funding and government grants?	Resource availability
8	To what extent and how incubators are necessary in emergence and developing an EE? If incubators encourage entrepreneurship, what is their long-term value to the whole EE?	Support service
9	Is there a link between incubation and serial entrepreneurship?	Support service

Dependent variable	Time to the first sales (age)
Incubation (0/1)	0.214*
Constant	0.472*
Observations (Number of Firms)	240
Log Pseudolikelihood	−407.292
Pseudo R2	0.013

The model is estimated with robust standard errors, and we controlled for industry (NACE 2-Digit), location, and academic affiliation (type of academic institution of origin).

* $p < 0.05$.

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