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Innovation lives in ecotones, not ecosystems

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ABSTRACT

Researchers tend to rely on metaphors to gain initial comprehension of complex systems. However, literature offers little guidance for this strategy. This paper presents criteria for using metaphors responsibly in this arena by applying them to evaluate ecological metaphors related to innovation systems. We develop the idea of *innovation ecotone* as the boundary between the knowledge ecosystem and the business ecosystem. We demonstrate why this ecotone better meets the criteria for a valuable metaphor for understanding innovation systems than the "innovation ecosystem" metaphor. This novel approach resolves many ambiguities and provides new implications for policymakers, particularly regarding the nature of innovation policy agencies.

1. Introduction

In decades past, when reductionist, single-discipline science was the norm, scientists were taught to be suspicious of reasoning by analogy (Brown & Salter, 2010; Simanek, 2010). Now, however, the objects of our investigations are more challenging, and our approaches to investigation are often more holistic. We face complex social and organizational systems the detailed behaviors of which appear unpredictable (Cowan, Pines, & Meltzer, 1999). In such systems, where forecasting and control cannot be modeled easily because of the plentitude of interactions, developing new, appropriate approaches for proper understanding of design, management, uncertainty and risk at a system level is of paramount importance (Christensen, 2008). For this reason, the Hungarian mathematician, John von Neumann, emphasized the need for a "theory of non-elephants" when approaching non-equilibrium or complex systems (Christensen, 2008).

In this context, Devezas (2005) remarks, "The more complex and intangible the system, the more useful is the resort to metaphors." Analogies and metaphors have thus regained respectability in the study of complex social and organizational systems. In particular, engineers have become more aware of biological systems' efficient interactions, and technological innovations have made a remarkable shift toward biomimetics and bio-inspired design. However, the soundness and usefulness of these metaphors vary. Whereas some of them may feature as theoretical building blocks in organization theory, most of them function simply as tools to better understand complex systems (Cornelissen & Kafouros, 2008).

This paper offers a list of criteria for the responsible use of metaphors in complex system studies. We focus particularly on innovation (eco-) systems, which amply display the characteristics of complex adaptive systems (Leydesdorff, 2006). We argue that the "innovation ecosystem" can mislead policymakers and business strategists. Furthermore, our studies show that by definition, innovation occurs in the conjunction area between business and knowledge ecosystems, and that is where writers using the "innovation ecosystem" metaphor try to fill the gap.

Following Adner (2006), many scholars have studied different aspects of innovation ecosystems. When we look at biological systems as the source of inspiration for such analogies, the area between two ecosystems is denominated "ecotone," with features partially different from those of the separate ecosystems. Thus, this article introduces a better metaphor that could offer more transparent implications for business activists and policymakers. To reach this end, we review the pertinent literature of ecological metaphors as they are applied to innovation, particularly the "innovation ecosystem" and its offspring. Lastly, we conclude that "innovation ecotone" is the metaphor that best meets the criteria for an apt and useful positioning of innovation systems.

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1.1. Metaphors

Metaphors play two leading roles in the scientific context. First, they help the public to better understand scientific concepts, and help researchers to more easily talk about the concepts. For instance, we all use metaphorical personification, such as "it reads," "catches viruses," etc., to describe and understand the complexities of computing technologies. Second, metaphors have stimulating effects on scientific and technological development by providing new ideas, strengthening existing concepts, helping scientists to communicate more efficiently and legitimizing research projects to financial supporters (Afshari-Mofrad, Ghazinoory, Montazer, & Rashidirad, 2016). Particularly in recent decades and because of the turbulent and changing environment of organizations and societies, use of biology-inspired metaphors for insights, theory, and perspective has increased dramatically (Mars, Bronstein, & Lusch, 2012). However, "metaphors are often improperly used, their potential left unrealized" (Von Ghyczy, 2003). If we are to use metaphors in science, it should be in as disciplined a manner as possible. First, in terms of the rationale for the chosen metaphor:

- Its advantage over other analogies and comparisons should be well established.
- Its valuable points of comparison with the phenomenon under study should outnumber comparison points that are untrue or might mislead.
- The metaphor should provide rich insights. It should open avenues toward plausible hypotheses, as well as improved tools, data collection, or policy action.

Second, the most rigorous possible correspondence rules between elements of the metaphor and elements of the phenomenon under study should be established. (This was the problem with efforts to apply the chaos theory of physics to business organizations [see Phillips & Su, 2013]).

Third, the limitations of the metaphor should be presented clearly. In what ways does the metaphor potentially mislead? What are exceptions to the comparison? Where does it fail? Mars et al. (2012) described misleading similarities between organizational systems and biological ecosystems.

Fourth, the metaphor should motivate a young researcher to comment, e.g., "Business systems can be like ecosystems? How interesting – I would like to research that in more depth."

Finally, it should be well understood that the metaphor is only a first approximation to be left behind as our understanding of the object at hand progresses. It was a helpful initial conceptualization, for example, to say that an electron orbits a nucleus "like" the Moon orbits the Earth. However, the comparison was abandoned as physics advanced to deal with spin, energy/orbital levels, and quantum uncertainties.

Using metaphors in business journals dates back to the early 1980s when (Lakoff & Johnson, 1980) viewed the metaphor as a phenomenon of thought and language. They defined metaphor as a mapping across domains, with ontological correspondences between entities in source and target domains (Skorcynska, 2001). Plenty of such metaphors have been applied to business research, such as cultural metaphors for computing technology in the U.S. (Denny & Sunderland, 2005), metaphors for competitive advantage (Hunt & Menon, 1995), marriage metaphors in buyer–seller relationships (Celuch, Bantham, & Kasouf, 2006), and metaphors as tools for enhancing adoption intentions (Bertele, Feiereisen, Storey, & van Laer, 2020). Moreover, Silaški (2011) investigated animal metaphors in the business realm by introducing the metaphor of *fat cats* to describe executives who earn unreasonably high salaries and bonuses. In this metaphor, people resemble animals (cats) that consume more than an appropriate amount of food (money), thus becoming grossly overweight, suggesting the luxurious lives of *fat cats*.

1.2. Innovation

Leydesdorff, Wagner, Porto-Gomez, Comins, and Phillips (2019) leave behind the biological metaphor in precisely the way described above, treating information exchanges among the three social sectors while keeping "triple helix" as a handy shorthand term. Jacobides, Cennamo, and Gawer (2018) do likewise, attempting a theory of *product ecosystems,* i.e., the collection of complementary and interacting companies that supported the value chains of the IBM360, the iPhone, and Uber – again using "ecosystem" as a convenient handle but not as a metaphor. Oddly personifying the ecosystem ("ecosystems…help coordinate interrelated organizations that have significant autonomy"), Jacobides, Cennamo, and Gawer justifiably omit mention of the leadership and facilitating organizations that are central to *regional and national innovation systems* (Lundvall, 2010), which we emphasize, are different from product ecosystems.

Dedehayir, Mäkinen, and Ortt (2018) equate the *innovation ecosystem* with the product ecosystem, citing some of the same products as Jacobides et al. (2018) and separating the innovation ecosystem from the *entrepreneurial ecosystem* just as we do in this paper. However, we disagree with their implied equation of innovation and productization. Though many definitions of innovation abound (see Taylor, 2017), we see innovation as the translation of a discovery or a new creative idea into tangible technology or a new method. This translation occurs within what we call the *innovation ecotone.* Many hurdles stand between a technology and a salable product or service – supply chain development, packaging, customer testing, form design, advertising message, etc. Overcoming these hurdles is the responsibility of the product ecosystem, sometimes called the business ecosystem.

To recapitulate, our premise is that the three stages of (1) creativity/discovery, (2) innovation, and (3) productization, while they feed each other, are primarily sequential and distinct, and our argument centers on the second stage. We demonstrate that innovation stands between discovery and productization and that there is crosstalk among the three.

1.3. Natural systems as metaphors for innovation systems

Systems of innovation is one of the fields rife with natural system analogies and bio-inspired metaphors. Innovation activity is "glocal," with concentrations of innovation actors and industrial clusters in metro areas and with worldwide connections and knowledge exchanges. Biological metaphors applied to these systems include the Triple Helix (Leydesdorff, 2006), ecosystems (Adner, 2006), rainforests (Kiuchi, Shireman, & Shireman, 2002), and coral reefs. We find that these metaphors were outlined in the literature with thin rationales at best, with little regard for their semantic connotations, and with no discussion of their limitations.

Each metaphor – triple helix, ecosystems, rainforests, and reefs – presents particular shortcomings in these regards. However, they all share a naïveté about teleology. Technological innovation is purposive, aiming to create resilient, ongoing streams of new products, services, and jobs (Phillips, 2014). Species in natural ecosystems (at least those minimally influenced by humans) evolve so that their members expend minimum energy, subject to requirements for defense and procreation. This continuous re-optimization should not be mistaken for an overall evolutionary purpose.

Before discussing these four metaphors, we consider "genetic algorithms" (Goldberg & Holland, 1988) as a fifth example of a constructive but limited biological metaphor. Built on the metaphor of mutating DNA, genetic algorithms mimic some but by no means all of the known behaviors of biological genes, producing innovative improvements in mechanical design and other areas. In his lectures, John Holland was scrupulous in noting the limitations and the advantages of the metaphor.

According to Leydesdorff (2006), the Triple Helix model emerged from a 1994 workshop aimed at "crossing the boundaries between institutional analysis of the knowledge infrastructure, on the one hand,

and evolutionary analysis of the knowledge base of an economy, on the other." The Triple Helix phrase strongly suggested the inter-twining and the co-evolution of academic, industry, and government actors in creating innovation and the innovation environment and allied itself with the double helix of DNA. Though also a helpful metaphor, it was limited: Industries evolve, for example, but their counterparts in DNA (the "side rails" of the double helix) do not. Moreover, the metaphor confuses genotype with phenotype. There are more than three important actors in different innovation systems – for example, the press, church, NGOs, and international agencies – as evidenced by subsequent academic papers on quadruple and quintuple helices.

The ecosystem metaphor produced offspring: knowledge ecosystems (Van der Borgh, Cloodt, & Romme, 2012), innovation ecosystems (Adner, 2006), entrepreneurial ecosystems (Isenberg, 2011), and business ecosystems (Moore, 1993). However, the parent metaphor's implications have not been thoroughly explored. In the natural world, for example, some species are ephemeral, while others (e.g., dinosaurs) persist for millions of years. In business, as in nature, larger entities tend to be longer-lived, though companies' tenure on the Fortune 100 has been shrinking, a phenomenon that seems not to have a parallel in natural ecosystems.

Indeed, ecology addresses the evolution of species – the analogy would seem to be to industries – and not to individual organisms, which in the ecosystem metaphor would be individual companies. While the survival of industries can be a responsibility of state and national governments, the actors in "business ecosystems" appear to concern themselves primarily with the growth and success of particular, local firms (Anggraeni, Den Hartigh, & Zegveld, 2007; Baldwin, 2012) and with attracting relocating firms. According to Leydesdorff (2006), other researchers have claimed that markets, not firms or industries, evolve. Isenberg (2016) details five more shortcomings of the ecosystem metaphor.

Following environmental calamities, some ecosystems regain a new equilibrium, as forests after a fire, while others are effectively wiped out – the desertification of the Sahara, for example, or the sinking of Thera. Though this might be asking too much of it, the ecosystem metaphor seems not to add to our ability to foresee the state of businesses following the COVID-19 pandemic.

Innovation system writers have particularized the ecosystem idea in different ways. Hwang and Horowitt (2012) and Hwang (2013) compares the entrepreneurial environment to a "rainforest" biome. The images of flowers blooming, birds singing, and fruit ripening surely make entrepreneurship sound attractive to students. However, these concepts obscure the fact that in the forest, some entities will eat, and some will be eaten. The fertile rainforest may provide all that a company needs until it fails to become a pinnacle predator and instead is eaten by one. Also, the stable environment of rainforests is not conducive to evolution.

Pogue, Thomson, French, Lorenzini, and Markman (2016) put forth the coral reef metaphor for early-stage entrepreneurship. Ecologically speaking, however, reefs are protective refuges for species, not generators of new ones. These authors make a good point that new business incubators temporarily protect vulnerable new companies. But although these firms graduate from the incubators, native fishes never leave the reef.

Whatever analogy may be used to explain the innovation system, its components and limitations must be specified to ensure that it is understood as intended and misconceptions are minimized (Brown & Salter, 2010). Unfortunately, the ecosystem metaphor for innovation has not led to a consensus on the definition, characteristics, dimensions, boundaries (Neumeyer & Corbett, 2017), players and structure. More importantly, it is unclear what implications for policymakers, academics and practitioners stemmed from adding this concept to the literature. Indeed, it seems impossible to agree on theoretical contributions when there is no agreement on definitions.

Therefore, it is striking that the ecosystem metaphor has survived through the decades in the face of continued criticism. This might be because of what Oh, Phillips, Park, and Lee (2016) called its "mimetic quality," or perhaps due to researchers' strong suspicion that "there's something there" that would become visible if we were but using the right metaphor.

Thus, this paper argues that the "innovation ecosystem" metaphor must be modified to best characterize the innovation situation. To this end, we rename it "innovation ecotone," keeping an instructive ecological comparison even as we acknowledge its limitations (for instance, the teleology issue). Ecotones form the interfaces between two disparate ecosystems and best reflect the evolutionary dynamic that innovation induces in industries. With respect to our list of criteria, we believe the ecotone idea proves most useful for "metaphorizing" innovation systems.

2. Review of pertinent literature

More extensive reviews of the metaphorical "ecosystem" literature can be found in Scaringella and Radziwon (2017), Jacobides et al. (2018), and Dedehayir, Mäkinen, and Ortt (2018). In this section, we focus on works that bear on our ecotone argument.

The notion of an ecosystem in biology was first introduced in the 1930 s. Since then, many ecologists have focused on its various aspects. Tansley (1935) was the first researcher to use the ecosystem concept, combining "eco" and "system" to denote the interaction of organisms and their environment. In the natural ecosystem, species interact with each other and with their environment, forming various types of relationships that maintain the relative stability of the system. This metaphor wended its way into human social systems.

2.1. Business, social, and knowledge ecosystems

In 1993 and later in 1996, Moore (1993, 1996) was the first scholar who brought the concept of the ecosystem into the management field and defined the business ecosystem as a socio-economic system that is based on social actors and institutions and consists of people, organizations, and governmental and regulatory institutions. Following Moore, various definitions of the business ecosystem were presented that somehow complement each other, emphasizing the communication and dynamics of the business ecosystem (Li, 2009; Zhang & Liang, 2011; Gawer & Cusumano, 2014).

After developing the ecosystem concept in different fields, Pilinkiene and Maciulis (2014) investigated the nature and central aspects of five social ecosystems, including the business ecosystem, entrepreneurship ecosystem, innovation ecosystem, digital business ecosystem and industrial ecosystem. They scrutinized the environment, players, economic effects and key factors affecting each ecosystem. They showed that these factors are similar in business and innovation ecosystems and have negligible differences with those of the entrepreneurship ecosystem. However, differences between these ecosystems and other ones, such as venture capital or start-up ecosystems, are significant in terms of players, interactions, boundaries, and purpose.

Another socio-economic ecosystem introduced in the literature is the knowledge ecosystem. Clarysse, Wright, Bruneel, and Mahajan (2014) defined it as the flow of tacit knowledge between firms and local universities and introduced research institutes as the leading players. He argued that such institutes conduct basic and applied research and act as catalysts for technological innovations through research and development collaborations, and companies use this knowledge for industrial and commercial purposes.

Accordingly, it is evident that the knowledge ecosystem is interconnected with the business ecosystem, leading some researchers such as Van der Borgh et al. (2012) to define a knowledge-based business ecosystem as an interdependent set of heterogeneous firms focused on unique resources and knowledge.

2.2. Innovation ecosystem; similarities and differences with related concepts

Among the tangled definitions of different social ecosystems, that of the innovation ecosystem is the most ambiguous. It is possible to distinguish between the business ecosystem and the knowledge ecosystem, but the indistinct definition of "innovation" has led to confusion in presenting an independent description for the innovation ecosystem. However, even "innovation ecosystem" has been described in multiple ways, some researchers having published literature review articles on the topic. For instance, after reviewing different definitions of the innovation ecosystem, Durst and Poutanen (2013) highlighted factors leading to an innovation ecosystem's successful implementation. Granstrand and Holgersson (2020) analyzed different definitions in the literature and introduced a new one.

The most important definitions and explanations of the concept of innovation ecosystem are presented in Table 1.

Table 1 shows how the discussion has matured over time. Adner focused on firms without mentioning the individuals and other institutions comprising the innovation ecosystem. Luoma-aho and Halonen applied the word "ecology" circularly to define a putative ecology. Durst and Poutanen described the system as "a specific innovation," though most system actors aim for an ongoing and profitable sequence of multiple innovations. With admirable idealism, Oksanen and Hatumaki propose a system in which innovations flow from "difficult challenges," even though today's innovation systems tend to produce solutions to easy challenges, like pizza delivery apps and "solutions that are still looking for problems."

Furthermore, several definitions in Table 1 suggest that researchers are, to a greater degree, referring to the business ecosystem rather than the innovation ecosystem. In this regard, comparing the ecosystems of innovation, business, entrepreneurship and knowledge could clarify that their definitions are ambiguous and, in some cases overlapping, making them hard to distinguish. Considering the growing literature on related fields, on the one hand, and the increasing ambiguity and fragmentation of literature, on the other, some studies in recent years illustrate the differences among these ecosystems and criticize the metaphor.

For instance, Oh et al. (2016) criticized the concept of innovation ecosystem as a theory and identified its differences with earlier models (in the literature) of S&T parks, technopoleis, science cities, regional innovation systems, or innovation clusters. They pointed out differences such as: Innovation "ecosystems" are more explicitly systemic, more oriented to digitalization and open innovation, and emphasize roles, niches, and market forces. They mentioned that "ecosystem" rolls off the tongue easily, sounds less dry than "innovation system," and is thus more attractive to journalistic coverage. They called this the "mimetic quality" of the ecosystem term, dismissing it as a superficial justification for using it.

Table 1
Timeline for definitions of innovation ecosystem.

Researcher	Year	Definition
Adner	2006	The collaborative arrangements through which firms combine their individual offerings into a coherent, customer-facing solution.
Luoma-aho & Halonen	2010	A permanent or temporary system of interaction and exchange among an ecology of various actors that enables the cross-pollination of ideas and facilitates innovation
Mercan & Gotas	2011	A combination of economic agents and economic relations as well as the non-economic parts such as technology, institutions, sociological interactions and the culture" suggesting that an innovation ecosystem is a hybrid of different networks or systems
Durst and Poutanen	2013	A set of organizations and people with interests in producing and/or using a specific innovation
Autio & Thomas	2014	A network of interconnected organizations, organized around a focal firm or a platform, and incorporating both production and use side participants, and focusing on the development of new value through innovation
Oksanen & Hatumaki	2014	A group of local actors and dynamic processes, which together produce solutions to different challenges
Granstrand & Holgersson	2020	The evolving set of actors, activities, and artifacts, and the institutions and relations, including complementary and substitute relations that are important for the innovative performance of an actor or a population of actors.

In addition, after conducting a systematic review of the literature on different types of ecosystems, Scaringella and Radziwon (2017) compared the types in terms of territory, values, stakeholders, economics, knowledge, and outcome and concluded that there are overlaps and differences between these concepts. For instance, they claimed that:

1. The territory of the business ecosystem is inherently local, and the territory of the knowledge ecosystem is its proximity, as with technological clusters.
2. The uncertainty on both supply and demand sides in the innovation ecosystem is higher than the uncertainty in other ecosystems.
3. The knowledge ecosystem is a concept that connects business ecosystems with local approaches. This concept covers cooperation and knowledge sharing and acknowledges the joint value creation between the business ecosystem and local universities.

According to these findings, Scaringella and Radziwon (2017) applied the business ecosystem as an umbrella term for innovation, entrepreneurship, and knowledge ecosystems (Fig. 1).

Valkokari (2015) investigated the components and interfaces of three ecosystems. She concluded that the three ecosystem types are interconnected, and the same actors play different roles in each ecosystem. Her study shows that what is explored in the knowledge ecosystem is exploited in the business ecosystem, and the innovation ecosystem acts as a bridge between them (Fig. 2). Her findings are consistent with Phillips (2014), who argued that the innovation system is engaging with and buffering between the knowledge and business systems.

Reviewing the literature on ecosystems of knowledge, innovation, and business revealed that few researchers studied all three of them together. It also showed that though these few researchers have been concerned with investigating the overlaps between the definitions of the ecosystems mentioned above, no actionable model of the relationships and boundaries among ecosystems has yet been developed.

On the other hand, Granstrand and Holgersson's (2020) definition of innovation ecosystem captures the full essence of the system and its dynamic evolution. That of Mercan and Goktas (2011) – "a hybrid of different networks or systems" – directly suggests that an innovation *ecotone* concept would be well worth exploring, as they explicitly approve the notion of betweenness in their definition. In addition, the Ecosystem Pie Model (EPM) introduced by Talmar, Walrave, Podoynitsyna, Holmström, and Romme (2018), which is used to map, analyze and design innovation ecosystems, implicitly acknowledges innovation ecosystem as a boundary area between research (knowledge ecosystem) and practice (business ecosystem).

3. A better metaphor: Ecotone instead of the no man's land

The ecosystem concept found its way to the field of management and other non-biological sciences, but its biological attachments have been ignored. For example, the boundaries of each ecosystem have been defined in the life sciences, but this has been overlooked in non-biological sciences, resulting in an ever-expanding set of new ecosystem concepts (national, urban, digital, university-based, advanced technology, etc.), each lacking definite boundaries.

These considerations advance the argument that "innovation ecosystem" is not an apt metaphor as it now stands, its distinction from

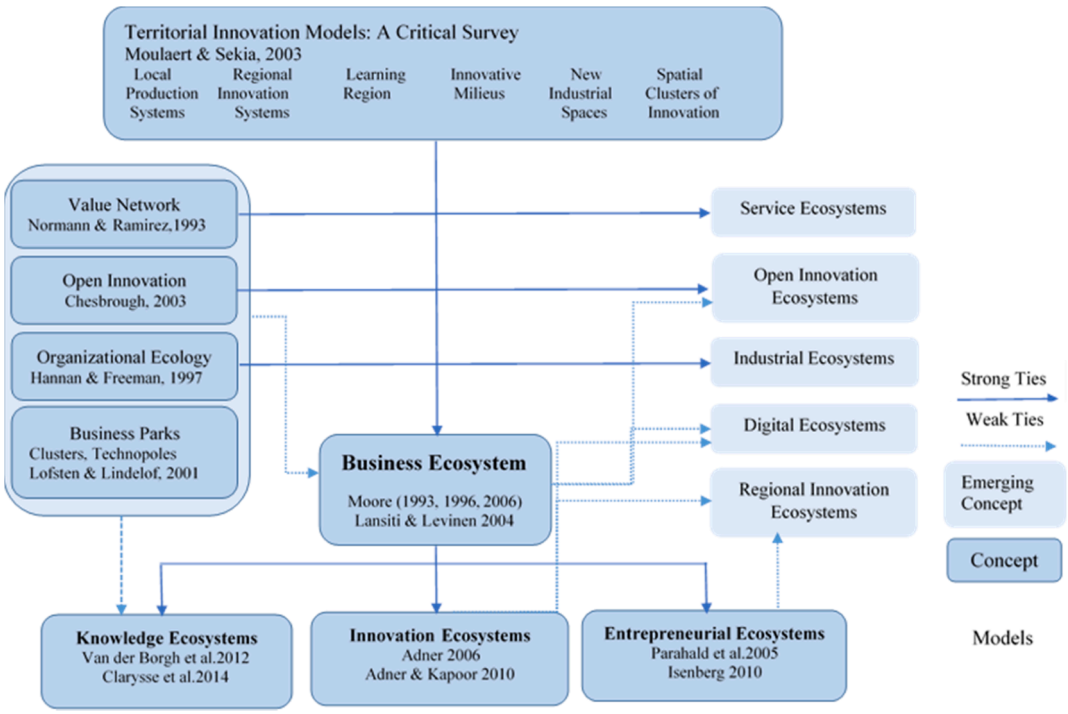

Fig. 1. Relationships among four types of ecosystems (Scaringella & Radziwon, 2017).

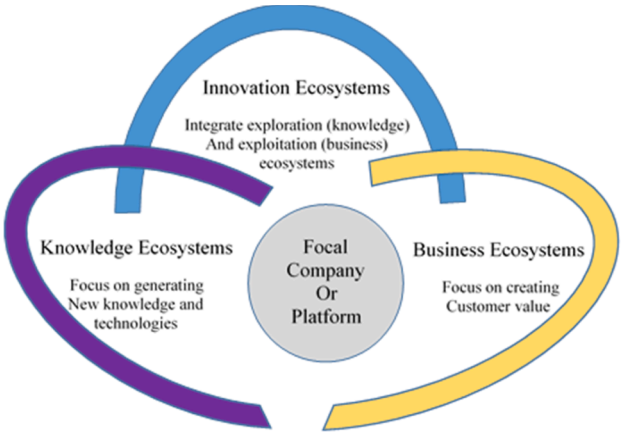

Fig. 2. Relationships among innovation, knowledge, and business ecosystems (Valkokari, 2015).

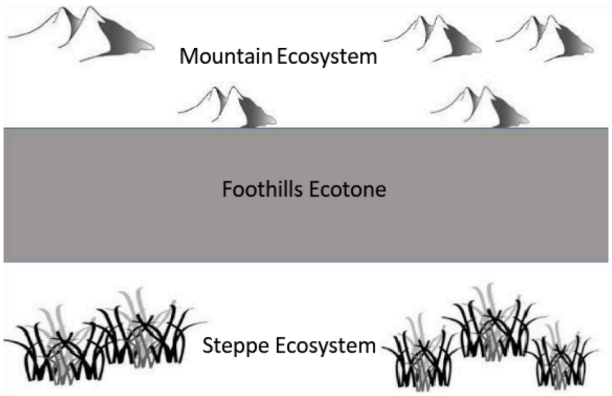

Fig. 3. A simple view of an ecotone (adapted from Spengler et al., 2013).

and overlap with the two concepts of knowledge ecosystem and business ecosystem remaining ambiguous and confusing.

Considering the importance of delineating the boundaries and transitional areas between different ecosystems, the intermediary area (ecotone) between the business ecosystem and the knowledge ecosystem is scrutinized in this section.

3.1. Biological ecotones

Moving from one biome to its neighboring biome brings gradual changes. As a result of this ecological transition, parts of the land in the borders will have the characteristics of both biomes. This section of the interstitial region is called *ecotone* (Spengler, Frachetti, & Fritz, 2013) (Fig. 3). In other words, an ecotone is a zone of transition between two ecosystems. Ecotones usually contain a larger variety of species than is found in the separate ecosystems (Seidman, 2009).

Ecotones are unstable as ecological transition zones and feature a mixture of two different types of communities. In these transitional areas, the environment is gradually changing from one ecosystem to another in terms of inanimate factors (such as climate) and living organisms (animals, plants, microorganisms) and their community structures (Sabzghabayi, Ahmadi, & Salehi, 2015).

Clements (1905) introduced the concept of ecotone for the first time. Later, Odum (1953) developed an ecological conceptual framework to study ecotones. There was considerable interest in studying ecotones among scholars until the 1970s, but then the tendency subsided because researchers concentrated on investigating more homogenous and well-defined ecosystems and communities. In the late 1980s and 1990s, the development of novel biology research areas resulted in the resurgence of studies on ecotones and their impacts on biodiversity. In the 1980s, the research on ecotones was mainly focused on the flow of materials (such as nutrients and water) into communities and ecosystem processes in these transition zones. Most researchers analyzed coastal riparian zones and wetlands, where land-water interfaces occur. Afterward, the direct impact of ecotones on biodiversity was studied in the 1990s, primarily to investigate the relationships between ecotones and processes that lead to morphological divergence, biodiversity patterns,

richness and rarity of the species, and protecting outcomes (Kark, 2013).

The ecotone is the most sensitive part of the neighborhood of an ecosystem, and because of its sensitivity to environmental changes, it plays a critical role in the biodiversity of ecosystems through harmonizing biological interactions and balancing nutrient flows.

Considering the critical role of ecotones in the conservation and successful functioning of ecosystems, diversity, flexibility, stress, and adaptation are their essential features.

Since the ecotone is an area between two adjacent ecosystems, it has similarities and differences with each. The main difference is that the ecotone does not have a definite boundary and functions as an open and interactive system. Accordingly, there are many exchanges between the species of an ecotone and its adjacent ecosystems. In his effort to facilitate the understanding of marketing in organizations, Prendergast (2000) presented the differences between ecosystems and ecotones (Table 2).

3.2. Innovation ecotones

With regard to Prendergast's ecosystem-ecotone distinction, we must note that no biological ecosystem is a closed system, as it must depend on solar or geothermal energy input. Yet, the subtle reader of this paper will notice the similarities of the natural ecotone with what was foreshadowed in the previous section about the characteristics of the innovation ecotone. In particular, the innovation ecotone depends on the *high exchange* of ideas, which is of greater quality the higher the *diversity* of inputs. Furthermore, the innovation ecotone, potentially globally networked, has *no clear boundaries.* It is *in flux,* that is, project-based, as it produces dissimilar innovations in series. This contrasts with the nature of the business ecosystem, the operations of which are generally of a more "ongoing" basis.

As *ecotone* is well known alongside the concept of the ecosystem in biology, it cannot be ignored where multiple climates or ecosystems abut. It could be a proper metaphor for what plays an interconnector's role among multiple ecosystems in non-biological fields.

Assuming that innovation itself plays a bridging role between knowledge and business, the "ecotone of innovation" could be viewed as the area between knowledge and business ecosystems. Thus, the innovation ecotone differs from what we previously knew as the innovation ecosystem.

As a real-world example, Adner (2006) stated that HD televisions were technically mature in the early 1990 s (i.e., had transferred into the knowledge system), but a number of needed complementary assets had not yet caught up, thus forcing manufacturers to postpone market entrance. In fact, Adner implicitly showed that the knowledge and business ecosystems were ready but that complementary innovations – which were gestating between these two ecosystems – were not. These innovations occur in a dynamic environment at the edges of both knowledge and business ecosystems, in what we call the "innovation ecotone." This is the bridging area between business and knowledge ecosystems that facilitates the commercialization of ideas. Alternatively, in more recent evidence, Chapman (2021) investigated the role of the "Office of Life Sciences" (OLS) in rescuing England from COVID19. He argued that the OLS, which sits *between* the business (business ecosystem) and health departments (knowledge ecosystem) –what we refer to as the innovation ecotone- helped Britain to become home to most of the world's genetic sequencing, the development of a successful jab, and its fast roll-out. He also emphasized the impact of the Vaccine Innovation Centre (VMIC) as a collaboration *between* three universities (knowledge ecosystem) and two pharmaceutical firms (business ecosystem), what we call the innovation ecotone.

4. Implications of the ecotone metaphor

This section explains the new metaphor's implications for understanding and policy.

4.1. Implications for understanding: Where does innovation live?

Isenberg's (2011) assertion that "entrepreneurship is contrarian and not innovative" suggests that we should, following Linton (2009), re-examine definitions. We view innovation as the transformation of creative new ideas into technologies or plans that can, in turn, give rise to beneficial new products and services. It is the job of the business and entrepreneurship spheres to turn technologies into products and services and market them.

Creativity, the precursor to innovation, means having new ideas – envisioning things that have never before existed. Creativity must be found in all the ecosystems we have examined here. While knowledge is clearly not the same as creativity, scientists in the knowledge ecosystem devise creative hypotheses, businesses brainstorm creative advertising themes, and (in a minor exception to Isenberg's statement) entrepreneurs develop new business models. However, the creativity of the type that underpins new technologies must reside in the innovation sphere (ecotone).

Isenberg emphasized that entrepreneurship and small (and large) business should not be lumped together conceptually or administratively. Thus, it can be inferred that the innovation ecotone abuts both the entrepreneurship ecosystem and the business ecosystem, which interact intensively as new ventures are funded by, become suppliers to, and are acquired by big businesses.

The evolution of terrestrial vertebrates is a helpful example of the ecotone's functions and its implications for innovation. The evolution occurred because of tide-induced environmental challenges at the shoreline (Kornei, 2018), the boundary between sea and land. Likewise, much innovation literature features one or more of the related concepts of "betweenness," "edge," and "flux."

Betweenness: Gulbrandsen (2011) writes of the identity anxiety of research institutes, "caught between cultures" (neither public nor private, neither academic nor commercial) as they transfer valuable knowledge from government and university to industry. Even before the age of open innovation, cross-functional project teams conducted product development within the firm. "Entrepreneurship" is usually taken to mean an undertaking, the second part coming from the French *prendre*, to take. However, the first part, *entre*, means "between." Also, Phillips and Linstone (2016) define innovation as a non-differentiable point in an experience curve: the transition point between one learning regime and the next.

Edge: Organizational innovation is said to thrive at the "edge of chaos" (Lewin, 1999; Pascale, 1999) and in "edge cities" (Choe & Roberts, 2011; Phillips, Alarakhia, & Limprayoon, 2014), where rent is cheaper than in a megalopolis, traffic is lighter, and incumbents' opposition to change is weaker. Breznitz and Ornston (2013) attribute radical innovation to "peripheral agencies." East (2019) introduces the

Table 2
Differences between ecosystem and ecotone.

Ecosystem	Self-containedSystem	Relatively stable	Active	Moderate diversity	Relatively well defined boundaries	Closed system	Low exchange of species	Within-system interactions drive change.
Ecotone	Liminal system	In flux	Interactive	High diversity	No clear boundaries	Open system	High exchange of species	Between-system interactions drive change.

Source: Prendergast (2000).

term "sociotones," highlighting the "edges of natural and human systems."

Flux: Innovation organization also implies flux and interposition. The knowledge ecosystem is known for its institutions, e.g., universities. Likewise, the business sphere has its institutions, symbolized by venerable and imposing bank buildings and Apple and Google campuses. In contrast, the innovation functions that link knowledge with business lack established institutions, viz. the more provisional terminology of U. S. university and federal laboratory technology transfer "programs" and "offices."

Unlike the other metaphors discussed above, the good fit with these three known realities of innovation justifies adopting and using the ecotone metaphor for the realm of innovation.

4.2. Implications for policy

This section draws lessons from the ecotone notion for how governments may organize to oversee national aspirations for innovation. The lessons rely on the following insights:

- Creative tension, along with the diversity of inputs, resources and interactions (Simmonds, 2018), leads to the development of adaptive mechanisms in the ecotone of innovation. Examples include university tech transfer offices and new business incubators.
- The innovation ecotone requires high institutional resilience due to the blurring boundaries, the need to maintain relationships with the neighboring ecosystems of knowledge and business, and the need to buffer the differing speeds of change among those neighbors (Phillips, 2014). These needs cause tension in the innovation ecotone and increase its creative energy.

Four policy principles that are well known from innovation ecosystem studies take on greater importance due to the ecotone characteristics of diversity, resilience, tension, intermediation, and adaptation (Baldwin & Von Hippel, 2011; Ghazinoory & Afshari-Mofrad, 2012; Rohrbeck, Hölzle, & Gemünden, 2009):

- Avoid making one-size-fits-all policies and accept diversity among individuals, industries, technologies, etc. This is an easier task in the agile ecotone than the more institutionalized and sometimes bureaucratic neighboring ecosystems.
- Support bridging institutions and brokers that mediate between the knowledge ecosystem and the business ecosystem. Along with the innovators themselves, these are the very heart of the innovation ecotone. Inhabitants of the neighboring ecosystems, and particularly legislators, find these ecotone agencies difficult to understand.
- Develop initiatives for training ambidextrous human resources and for job rotation. Agile individuals can best navigate and benefit from the fluid ecotone.
- Promote open innovation, open access to scientific articles, innovation networks and joint university-industry R&D projects, and reform intellectual property policies to incentivize collaborative innovation. These "open" entities can best hear and respond to the crosstalk among the knowledge and business/entrepreneurial ecosystems and the innovation ecotone.

Funding officials may tend to downgrade research proposals aimed at building cross-sectoral professional networks because these projects do not appear to lead directly to new knowledge. However, the ecotone notion offers assurance that the networks will indeed boost innovation.

As for national innovation oversight, it should be clear that a bureaucratic "Innovation Ministry" cannot embody the flux and adaptation the innovation ecotone requires. Yet, a weak innovation agency bears the risk of being diluted and absorbed into more powerful Ministries that oversee the surrounding ecosystems of business and knowledge. A second balancing act must also be attended to: The innovation ecotone's "adaptive mechanisms" – investment funds, incubators, etc. – cannot be allowed to multiply without limit. These mechanisms' efficacy in progressing toward the national innovation goals must be balanced against coordination costs (Freeman & Rossi, 2012).

Isenberg's (2011) remark about SMEs and entrepreneurship also applies to business, innovation, and entrepreneurship: Oversight should not fall to the same Ministry or Cabinet department. Instead, national innovation administration might best be realized via a coordinating agency staffed by the networkers and negotiators that the ecotone metaphor implies. Freeman and Rossi (2012) cite the US National Security Council as an exemplary coordinating agency in the intelligence arena.

The ecosystem metaphor emphasizes interactions *within* the innovation system. The ecotone view highlights the interactions *with* the neighboring ecosystems of knowledge, entrepreneurship, and business. Adapting the arguments of Isenberg (2011), we remark that governments and companies know how to induce parts of the innovation process. The absence of a systems view, however, leads to "a lack of clarity on [innovation] policy objectives" and "perverse consequences of piecemeal programs." These result in a waste of public funds intended to foster innovation. For example, generous government grants for medical and engineering research can clash with draconian restrictions on visas for the young foreign researchers who can best perform or assist in the research.

4.3. Limitations of the ecotone metaphor

The innovation ecotone is the interface between the knowledge ecosystem and the business ecosystem. However, it is not spatially separated, as an ecological ecotone is. Actors in the innovation ecotone go to the grocery store and the cinema; they live and work within the business ecosystem. It is not a geographical interface, and the distinction between innovation ecotone actors and players in business and knowledge ecosystems is not that easy. We have provided features such as "betweenness," "edge," and "flux" for the innovation ecotone, but introducing more definitive criteria needs further studies.

Unlike natural ecotones, the innovation ecotone takes form partially in the physical world and partially in the virtual (Internet) world. Thus, it is partly local and partly global. Such interconnection between the physical and virtual world is not justifiable using a metaphor from nature.

Though the innovation ecotone idea contributes to improved understanding and better policy action, we find the idea leads more directly to policy recommendations than to testable scientific hypotheses. It helps policymakers and strategists better understand their surrounding world, but it cannot be verified using scientific methods. However, it may help develop scientific hypotheses in future studies.

5. Summary and directions for future research

Biological and ecological metaphors are common in the innovation arena: Entrepreneurs pursue "seed" funding; they hope success is "in the company's DNA." We have put forward guidelines for using metaphors to initially comprehend complex systems such as innovation systems. We advance the "innovation ecotone" as the most rigorous ecological metaphor for innovation and its environment. We showed that it agrees with observed features of innovation practice more precisely than alternative metaphors such as "innovation ecosystem." The very language of innovation implies "edge" and interposition, reinforcing the notion of innovation ecotone. The ecotone features of adaptation, diversity, flux, openness, and between-system exchange drive specific policy recommendations with regard to administering national innovation goals. We showed that the ecotone idea best satisfies the criteria

we laid down (in §1.1) for the responsible scientific use of metaphor.

The number of multinational corporations (MNCs) in the world amply shows that business ecosystems are not purely local. In the same way, the knowledge system is worldwide; Evidence includes the steadily growing number of research articles published with multinational authorial teams. In contrast, innovation ecotones are not yet global due to parochial venture capital investors, snobbish cultures that are slow to adopt innovative components from other countries, and secretive development projects within organizations that shun open and user-generated innovation. The geographical aspect of innovation ecotones will be subject to additional research.

However, the distinction between an innovation ecotone and a regional innovation system should be clear. The current difficulties of prominent techno regions – the exodus from Silicon Valley[1] and new criticism of Austin as a relocation destination[2] – do not change the fact that innovation continues. The urgency of the pandemic accelerates innovation; pandemic-induced remote work, by lessening the serendipitous transfer of tacit knowledge, inhibits innovation.

Of interest but not explored in this paper is the fact that the knowledge ecosystem itself intermediates between the innovation ecotone and natural ecosystems. This has been true since the earliest days of agriculture, as knowledge of soil conditions and plant growth have led to (sometimes geographically isolated) community-generated agricultural innovations. The COVID-19 pandemic illustrates another connection (however unwelcome) between the natural ecosystem and the innovation ecotone. The knowledge ecosystem sequences the virus's genome and contagion characteristics, and the innovation ecotone develops quarantining regimes, vaccines and new antiviral agents. Unlike the earlier-mentioned agri-innovations, the COVID-19 innovation race is systemic and globally networked. It is what Ghazinoory, Nasri, Ameri, Montazer, and Shayan (2020) call a "problem-oriented innovation system," and Hekkert, Janssen, Wesseling, and Negro (2020) call a "mission-oriented innovation system."

We expect that researchers will refine and expand our desiderata for using metaphors in approaching complex systems. Ultimately, our understanding of innovation systems will advance beyond the need for metaphors. This paper has argued that until that time, metaphors should be used responsibly and with maximum possible rigor. Meanwhile, additional innovation system research will more rigorously specify the innovation ecotone's dimensions of diversity, flux, resilience, etc.

In addition, future studies could focus on embedding the innovation ecotone concept in the context of digital technologies such as innovation ecotone in smart cities or the role of innovation ecotones in the transformation to industry 4.0. Another vital line for future research is the importance of innovation ecotone in health-related phenomena such as future pandemics. As mentioned earlier, the role that British science played in the COVID-19 pandemic and the effect of the "Office for Life Sciences" in England, which sits *between* the business and health departments (what we refer to as innovation ecotone), could be a source of inspiration for future efforts to prevent or overcome pandemics.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

[1] https://www.bloomberg.com/news/articles/2020-08-18/the-silicon-valley-tech-exodus-could-be-a-plus.

[2] https://www.businessinsider.com/moving-california-austin-texas-10-things-i-wish-i-knew-2021-1.

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