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Innovation ecosystems as structures: Actor roles, timing of their entrance, and interactions

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ABSTRACT

Despite their importance little is known about how innovation ecosystems come into existence. We address this gap through an historical case study of Herceptin, a revolutionary drug developed for the treatment of ovarian and breast cancer, and the innovation ecosystem that emerged around this drug between 1978 and 1998. Through qualitative content analysis of a broad scope of archival documents (2474 in total), we define a cast of roles and determine their timing of entry onto the stage of ecosystem emergence, and in turn describe the interaction of these roles that govern emergence. We find that the locus of ecosystem emergence shifts gradually from discovery, resource provision and commitment, to the formation of connections and trust, and finally to complementarity and value creation. These activities are facilitated by specific roles that gain significance at various points in time. We additionally witness shifts in interaction dynamics, from individual level interactions early on, to interactions across levels, and finally to interactions at the organisational level. We synthesize these findings to propose a framework of a processual understanding of how innovation ecosystems come into existence.

1. Introduction

In many industries, competition is increasingly moving away from the level of single firms to the collective level of innovation ecosystems, due to greater interconnectedness of value creation in the contemporary business environment (e.g. Pierce, 2009; Adner and Feiler, 2019). The innovation ecosystem refers to a heterogeneous constellation of actors that create value through collaboration in bringing about innovations (Adner, 2006; Adner and Kapoor, 2010; de Vasconcelos Gomes et al., 2018). At its core, ecosystem thinking urges firms to account for the value actors beyond traditional, linear pathways (e.g. complementors) ought to deliver for the firms' value proposition to materialise, in addition to the value delivered by actors within traditional chains. By widening the viewing lens in this manner, firms increase their capability to design collaborative structures more effective in realising intended value (Adner, 2012), while controlling for transaction costs associated with collaborative activity (Lee and Kapoor, 2017).

The salient and overarching question posed in this paper is: How do innovation ecosystems come into existence in the first place? Understanding the emergence of innovation ecosystems is crucial for focal firms that invest resources into their initial construction and how they can dynamically control ecosystem development (Dattée et al., 2018; Hannah and Eisenhardt, 2018). Through this understanding, firms can anticipate and resolve trouble spots that threaten to dissolve the volatile network, while concurrently aiding decision making concerning whether and when they should join the ecosystem (Scaringella and Radziwon, 2018). At the same time, from a policy perspective, a better understanding of the mechanisms that bring about new ecosystems, and the role of national, regional, or sectoral governance in ecosystem creation, can greatly assist policy formulation to spur ecosystem emergence and growth (Overholm, 2015; Oh et al., 2016; de Vasconcelos Gomes et al., 2018).

A systematic search of the innovation ecosystem literature yields a limited number of scholarly contributions addressing this issue. Within this collection, the recent work of Sandström (2016) exploring the 3D printing ecosystem, and Lepoutre and Oguntoye's (2018) examination of money ecosystems in Kenya and Nigeria provide insightful narratives on the emergence process. Notwithstanding these valuable contributions, there remains a need for a model of innovation ecosystem emergence that focuses on ecosystem constituents (e.g. actors), their structural

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positions and interactions, and temporal dynamics (Phillips and Ritala, 2019). Such a framework, which models how the ecosystem comes into being through the complexity and multiplicity of actors and interactions would complement existing frameworks, such as that proposed by Dattée et al. (2018), which explain the "creation" of an innovation ecosystem by the strategic actions of a focal firm. To address this knowledge gap, we anchor our conceptualisation of 'emergence' on the four properties laid out by Martin and Sunley (2012) in their treatise of emergence of economic landscapes such as industry clusters. We first recognise that the innovation ecosystem is a higher-level phenomenon, whose "patterns and properties emerge from the organisation and interactions of lower-level component parts, but are not simply the aggregations of those lower-level components and properties" (Martin and Sunley, 2012, p.340). Hence, the higher-level properties of the innovation ecosystem are 'supervenient' on the interactions and properties of lower-level components. Second, the innovation ecosystem is irreducible, whereby it cannot merely be explained by the aggregation of lower-level components. Third, innovation ecosystems are self-organizing in the sense that patterns and structures of the latter emerge from the actions and interactions of lower-level components. And fourth, we acknowledge downward causation such that the innovation ecosystem, as an emergent higher-level phenomenon, "causes, determines, regulates or influences lower level properties and parts, either in those component entities or in their interactions" (Martin and Sunley, 2012, p.340).

Following these properties, our paper aligns with the ecosystem-as-structure perspective proposed by Adner (2017), and focuses on lower-level components whose actions and interactions are responsible for the emergent structures of the innovation ecosystem (Battistella et al., 2013; Adner, 2017; Jacobides et al., 2018). The industry clusters literature provides guidance to our endeavour, underscoring a number of actors (i.e. lower-level components) that enable cluster emergence (Powell et al., 2012). These include entrepreneurs, qualified labour, universities and research organizations, governments, established firms (e.g. anchor organizations), new ventures, and venture capital firms (Fiol and Romanelli, 2012; Brenner and Muhlig, 2013; Li, 2018). Interactions of actors additionally point towards mechanisms driving the emergence process, such as the accumulative interaction of the local knowledge pool and firm growth, new industry branching from existing industries, spin-off activities that lead to new venture creation, external knowledge inflow, knowledge sharing, network building among local actors, and policy interventions to facilitate these activities (e.g. Perez-Aleman, 2005).

Nevertheless, actors identified in the emergence of different kinds of organisational collective (e.g. Chiles et al., 2004; Robinson et al., 2007; Isaksen, 2016) are often case specific and therefore cannot be generalised without difficulty. To overcome this limitation and make progress towards at a more generalizable framework that defines the constituents of innovation ecosystems and their dynamic interconnectivity, we focus on the 'roles' enacted by actors (Jacobides et al., 2018; Ozcan and Santos, 2015) rather than on the actors themselves. In so doing, we follow the lead of Dedehayir et al. (2018) whose systematic review of the literature has identified a number of roles enacted during the genesis (i.e. emergence) of innovation ecosystems. We pose three questions that guide our investigation, centring on: (i) the cast of roles enacted by actors during innovation ecosystem emergence; (ii) the timing of entry of these roles onto the stage of ecosystem emergence; and (iii) the modes of interaction between roles throughout the emergence process. By answering these questions we ultimately aim to operationalise and validate Dedehayir et al.'s (2018) proposed ecosystem emergence framework. At the same time, our study complements earlier scholarship that has examined the emergence of organisational collectives in a broader sense (e.g. Feldman, 2001; Chiles et al., 2004), while elaborating on role definition and redefinition, which forms an important mechanism in meta-organization emergence (Valente and Oliver, 2018).

We undertake an historical case study that examines the emergence of the innovation ecosystem around Herceptin, a ground-breaking drug developed to treat ovarian and breast cancer, from the discovery of the drug's basic chemistry in 1978 until the drug's commercialisation in 1998. Our selection of Herceptin and its ecosystem for analysis is premised on its impact on the global biotech industry through the demonstration of a gene-targeted, personalised biomedical drug – which not only changed breast cancer treatment but also influenced other treatment strategies (Kukk et al., 2015; Kukk et al., 2016; Moors et al., 2018) – that established Genentech (the commercialising company) as a pioneer and one of the figureheads of the industry (Cockburn and Stern, 2010). At the same time, the interaction of firms, scientific teams and researchers, and regulatory regime organizations (Powell et al., 1996), which introduces complexity and fuzziness to the early phases of evolution (Gustafsson et al., 2016), renders the Herceptin innovation ecosystem highly informative for the development of a framework of innovation ecosystem emergence. Our study incorporates a thorough examination of a broad scope of archival documents (2474 in total) through qualitative content analysis, enabling us to analyse a chronology of 344 significant incidents (Van de Ven and Poole, 1990). Through this analysis we propose a framework that defines a cast of roles and determines the timing of their entry onto the stage of ecosystem emergence, and in turn describes the interaction of these roles that govern emergence.

2. Theoretical background

The emergent period of innovation ecosystems centres on establishing the value proposition that can satisfy the customer's product and service requirements (Moore, 1993, 1996). The ecosystem-as-structure view advanced by Adner (2017) argues that such a value proposition will materialise from the interaction of multiple actors, which allows the exchange of resources (e.g. financial, human, knowledge, and technological) that are utilised and synthesised to create value. We see the emergence of innovation ecosystems as the process of embedding and connecting of actors into an evolving ecosystem structure (Adner, 2012; Adner, 2017). This proposition follows a microfoundations logic (Coleman, 1987), whereby phenomena occurring at higher levels of analysis (i.e. the emergence of innovation ecosystems) are connected to lower level mechanisms (i.e. activities and interconnections of ecosystem actors). And in alignment with reductionist logic, which seeks to explain the causality between higher and lower-level phenomena (Felin et al., 2015), we perceive the process of innovation ecosystem emergence as resulting from lower-level activities, or the structure's microfoundations (Polyhart and Moliterno, 2011; Barney and Felin, 2013; Kozlowski et al., 2013).

As actors engage in activities at the microfoundations, we direct our viewing lens onto the roles they assume within the ecosystem structure (Adner and Kapoor, 2010). In other words, we liken innovation ecosystem emergence to a theatre production, with a keen interest in the roles that are enacted on stage rather than the individual actors that enact them. Our ambition is to work towards a generalizable understanding of ecosystem emergence that can be played out on any stage with the cast of roles necessary for this process, no matter the actors that will fill these roles.

In role theory, a role is defined as a "bundle of norms that defines the rights, obligations, and privileges of a person who occupies a particular status" (Biesanz and Biesanz, 1978, p.145). Roles refer to what social actors are expected to do or how they ought to behave, rather than what they are (e.g. Ivey and Robin, 1966; Lynch, 2007). In the context of a family, for instance, the structural foundations of role theory suggest that "father" will denote a position in the social structure, while "disciplinarian" exemplifies a generic role – norm or expectation of behaviour – belonging to that position (Galletta and Heckman, 1990). Furthermore, roles inherently exist in relation to others in the social system. For instance, the role of teacher implies the role of student, and the role of supplier implies the role of buyer (Solomon et al., 1985;

Galletta and Heckman, 1990).

The literature centring on innovation development has long acknowledged a number of distinct roles enacted by actors during the organisational innovation process (e.g. Chakrabarti and Hauschildt, 1989). These roles include the 'expert' role, defined as "the inventor, idea generator and the creative genius" behind the innovation process, the 'sponsor' role responsible for resource allocation and triggering important decision making processes, and the 'champion' connecting the aforementioned roles, bestowed by its knowledge of the organization, ability to translate the innovation's technical language to various members of the organization, and diplomatic skills that engage important individuals in the innovation process (Chakrabarti, 1974). These roles are, in turn, connected to several others engaged in the innovation process, including the 'supplier' (provides products and/or services to be utilised by downstream partners), 'user' (consumes the final product or service), 'consultant' (provides complementary technical information), 'functional manager' (carries out routine tasks of a manager positioned in organisational hierarchy), and 'opponent' (complains about an innovation) (Chakrabarti and Hauschildt, 1989). Scholars have since investigated the temporal interplay of such roles during the organisational innovation journey (e.g. Markham et al., 2010), and shown that different roles can be assumed by the same individual or that multiple individuals can assume the same role. It is also shown that the meanings of roles may change during the innovation process (e.g. Perry-Smith and Mannucci, 2017).

While roles have also been extended towards inter-organisational contexts (e.g. Rese et al., 2013), the relatively nascent innovation ecosystem literature has thus far derived a limited scope of roles that require enactment for ecosystem emergence and evolution. Perhaps the most prominent of these roles is the 'ecosystem leader'. Actors assuming this role are tasked with setting a shared, grand vision that aims to secure the cooperation of other actors to provide complementary offerings essential for the delivery of holistic value to the customer. Moore (1993) illustrates the indispensability of this role in his consideration of the birth of Apple's (and its rival, Tandy's) PC (personal computer) ecosystem in the late 1970s, which underlined the de facto leadership role of hardware companies. The importance of a central figure for the livelihood of innovation ecosystems is echoed by other scholars as well, albeit with different nomenclature. For instance, Gawer and Cusumano (2002) emphasize the governing role 'platform leaders' such as Microsoft and Intel have historically played in their respective ecosystems. Iansiti and Levien (2004) meanwhile borrow the notion of a 'keystone', a vital species in biological ecosystems, to represent the seminal role enacted by organizations that regulate the overall function of the innovation ecosystem. More recently, Jacobides and Tae (2015) refer to 'kingpins' that denote firms of significance, bestowed by their "superior market capitalization and also as being disproportionately important in terms of R&D" (Jacobides and Tae, 2015, p. 892).

Despite their ability to exert substantial power and command a greater share of overall profits (Moore, 1993), actors that enact the ecosystem leader role represent only a small biomass or population of the ecosystem as a whole (Iansiti and Levien, 2004). Constituting the larger bulk of the ecosystem are actors that likely assume a number of other roles. One of these is the role of 'niche player'. As in biological ecosystems (the analogical origin of the term), niche players have specialised functions (or a narrow sphere of expertise), which enable their contribution towards the holistic objectives of the innovation ecosystem. Niche players help the ecosystem leader expand the realms of its application. For example, Intel and Microsoft are platform leaders in the PC ecosystem because they assume great authority in the architectural design of the PC system and subsequently govern a plethora of niche players, which produce complementary, platform-specific hardware and software products (Gawer and Cusumano, 2002). One of these niche players is Nvidia, a firm that has historically specialised in the design of graphics accelerators, a PC component that enables the ecosystem to provide video game and other multimedia applications on the PC platform (Iansiti and Levien, 2004).

In their recent review, Dedehayir et al. (2018) propose ecosystem emergence to be marked by 11 distinct roles that can be grouped into four categories, namely, those associated with leadership, value creation, support, and entrepreneurial activities. Leadership roles manage ecosystem governance, partnership formation, and overall platform management. By comparison, value creation roles supply, assemble, complement and use components, supporting roles champion and act as experts in operational processes, and entrepreneurial ecosystem roles act as sponsors, regulators and entrepreneurs that help facilitate the creation of new ventures that lie at the centre of the ecosystem. However, despite recent advances, we still have very little understanding of the exact nature of these roles and how they are enacted during ecosystem evolution (Scaringella and Radziwon, 2018, Ikävalko et al., 2018).

3. Data and methods

We have undertaken an historical case study to examine the emergence of an innovation ecosystem around Herceptin between 1978 and 1998. Being recognised as the first of its kind – a gene-targeted, personalised biomedical drug – has allowed the documentation and availability of a large set of historical accounts and data throughout the years leading up to Herceptin's commercialisation. The novelty of the drug and the abundance of data has made this a lucrative case to study. Furthermore, by studying the Herceptin innovation ecosystem as a single case we endeavoured to acquire in-depth understanding of ecosystem emergence, including a refined understanding of roles, their timing of entry, and their interactions.

In studying innovation ecosystem emergence we make the assumption that roles and their activities can be studied at different levels of economic structures, ranging from individuals to institutions. This position is illustrated by Van Oorschot et al. (2013) who focus on the manifestation of team decision traps sourced from information filters, and by Bingham and Kahl (2013) who investigate how organisational groups develop a schema for addressing environmental changes. We find further evidence for our proposition in Markham et al.'s (2010) examination of informal roles assumed by individuals within the organization as the innovation is carried across the 'valley of death', a typically resource-deficient period bridging research and commercialisation activities. Commensurate with the multi-level perspective on change processes (e.g. Padgett and Powell, 2012; Kozlowski et al., 2013; Kim et al., 2016), we articulate a multi-level approach whereby the innovation ecosystem, as an institutional structure, lies at the macro-level, while individuals, collectives of individuals (e.g. team or groups), and organizations enact roles at the micro-level of the ecosystem, the so-called microfoundations.

3.1. Data

Following prior literature (e.g. Garnsey and Leong, 2008), we defined the birth phase of the Herceptin innovation ecosystem as the period spanning from the initial discovery of trastuzumab, the effective compound in the drug, until its commercialisation as Herceptin. The study of Herceptin's development allowed us to trace the sequence of multiple actors and their actions during the emergence of the innovation ecosystem.

We acquired data from retrospective, archival documents (e.g. Van de Ven, 1992; Hekkert et al., 2007), and employed a broad search and selection strategy to gather data from many different sources (e.g. Bingham and Kahl, 2013; Jay, 2013). We used three reputable business information databases – LexisNexis, ProQuest, and Factiva – as our primary sources of data, and employed the search terms "herceptin" (Herceptin's commercial name), "HER2" (Herceptin's abbreviated name), and "trastuzumab" (Herceptin's chemical name) to identify relevant documents for analysis. With their core focus on news facts and business developments, these databases offered ideal sources of data, providing accounts reported by independent news agencies and contemporaneous information (at the time of reporting) on the actors and activities involved in the emergence of the Herceptin ecosystem (see Appendix for list of news agency sources). The multiplicity of information sources (i.e. press releases) also allowed triangulating across these sources to increase validity. While interviews with key respondents can be highly informative (e.g. Moors et al., 2018), they may not allow the construction of detailed patterns of development "since interviews generally lead to information on a limited number of key events" (Negro et al., 2007, p. 928). Perhaps more importantly, we opted not to employ this method given the long duration of ecosystem development (20 years between 1978 and 1998), together with the substantial delay since these events took place and the authors' analysis, which was deemed to increase the likelihood of retrospective bias. Hence, by using archival data, we accessed real time accounts of the emergence process rather than retrospective ones.

We identified 2444 relevant documents, comprising newspaper articles, corporate reports, and scientific papers (in English only). To increase the inclusiveness of this body of literature, we conducted an additional search on the Google search engine using the same search terms. This exercise yielded 28 additional sources, including books, corporate announcements, news articles, and scientific publications, as well as videos, and links to company websites. Finally, we referred to the Web of Science database and used the search terms to retrieve further publications. With our ambition to collate all material relevant to the emergence of an innovation ecosystem (i.e. a business environment), we refined this search to publications appearing only in the business, management, and economic domains. This search protocol yielded 23 scientific papers, 21 of which focused solely on the economic implications of administering Herceptin to treat breast cancer, and which were irrelevant to enhancing our knowledge of the innovation ecosystem. The two remaining papers – Kukk et al., 2016 and Moors et al., 2018 – were added to the cohort of examinable documents. Collectively, these 2474 source documents provided a comprehensive corpus of data.

3.2. Analysis

A detailed study of this large number and scope of documents allowed us to record the chronology of incidents in the Herceptin innovation ecosystem emergence. We defined an incident as the specific activity of an actor (be it an individual, team/group, or organization), or a factor (e.g. a set of circumstances) at a given point in time, which influenced Herceptin ecosystem development. Incident related data were extracted from the documents and entered into a spreadsheet in chronological order. For news items we used the timestamp of its corresponding source (i.e. the publication date), and for other documents the information available in the text to ascertain event timing. This temporal sequence allowed us to crosscheck information about a particular timeframe, to track developments from different perspectives, and contrast the public discourse on the revolutionary cancer drug. At the same time, the chronology allowed us to note duplications of the data reported by different sources, which we recorded as corroborations. The above process was done with human coding and revealed 344 incidents for further analysis. We further conducted a machine parsing for the entire dataset to increase the reliability of our findings. This additional step counters the known human biases in content analysis, such as the provision of extra information around the actual event-identifying sentence (Bogaard et al., 2014), and general errors associated with human coding (Kolbe and Burnett, 1991). In this process, we automatically parsed the first four sentences of all documents to include subject, activity, and object (if present) as mentioned in the text. Our automatic parser coded a few alternatives for each sentence that was not recognised as a straightforward statement and hence delivered 26,201 incident candidates for the subject-activity-object description. Overall, this exercise reinforced the 344 incidents determined by human coding without any recommendation for additional incidents.

Our data analysis procedure commenced with the numbering of incidents (aligning with their chronological order), and then coding for their source (e.g. The Wall Street Journal), timestamp (i.e. when the incident took place), and source document title together with descriptive lines (i.e. textual data extracted from the source describing the event). We next coded the actor types involved, their activities, and the level at which the activity took place (i.e. individual, team/group, or organisational) directly from this raw, textual data. We also documented the types of factors that influenced drug development (e.g. exogenous shocks) and examined their effects (e.g. promoting or inhibiting progress). These coding steps provided a comprehensive and detailed set of event-based data, analysed to answer our research questions.

To answer our first research question concerning the roles enacted during innovation ecosystem emergence, we employed qualitative content analysis, which is broadly defined as subjective interpretation of text data content, using systematic classification processes of coding and theme or pattern identification. In this endeavour, textual data may be acquired from sources such as open-ended survey questions, interviews, and print media (e.g. scientific publications or news press), among others (Hsieh and Shannon, 2005). Through the employment of qualitative content analysis, we align our research with recent contributions, such as that of Maggitti et al. (2013), which studies the search and discovery process of invention, through the "qualitative, inductive, archival, content analysis of historical first-person documents and quotations of ten notable inventors" (Maggitti et al., 2013, p.91). More connected to the case at hand, our method follows that employed by Moors et al. (2018), who use qualitative event history analysis to study the processual development of the market for Herceptin and Tarceva (a personalised medicine product to treat lung cancer). In their study, the authors rely on "scientific literature, professional journals, 'grey' literature (industry reports, policy papers and books) and various websites" (Moors et al., 2018, p. 136) as data sources, complemented by semi-structured interviews with stakeholders. Qualitative event history analysis is additionally employed by Kukk et al. (2015) in their analysis of system building in the Technological Innovation Systems around personalised medicine products (e.g. Herceptin), and by Negro et al. (2007) in their analysis of the development of biomass digestion, an energy conversion technology.

We implemented a 'directed approach' to qualitative content analysis, whereby the coding process is guided by existing theory or findings of prior research, which may provide an initial set of codes that is used in the study (Hsieh and Shannon, 2005). This is distinguished from the 'conventional approach' that derives coding categories directly from the text data. Our directed approach to content analysis for the purpose of coding role categories was informed by earlier contributions (e.g. Dedehayir et al., 2018), which list a cast of roles relevant to ecosystem emergence. Using these prior research findings as a starting point, our qualitative interpretation of the text data allowed the identification of new role categories in addition to those previously proposed.

Aligning our analyses of the textual data with role theory, we defined a role in the innovation ecosystem as a set of behaviours or actions of actors. Role labels subsequently emerged from the coding of the data pertaining to the actors and their activities for each incident. We coded roles in two subsequent steps. First, three researchers coded the roles independently using the labels they deemed most appropriate. Second, the independent assessment of the researchers were compared and discrepancies reassessed to arrive at consensus in creating one overarching, unified system of roles. This triangulation with the research team increased the reliability of the data analysis and results derived from it. In this exercise we made reference to Dedehayir et al. (2018), which proposes a taxonomy of roles both within and without the organization (i.e. the entire innovation ecosystem), deemed necessary for ecosystem emergence. Given the centrality of 'innovation' in the emergence of innovation ecosystems, we additionally made reference to the role labels established by Chakrabarti and Hauschildt (1989) in their overview of the innovation management literature. While most of the roles labelled freely by the researchers in the first step were able to be categorised through consensus with the aid of these reference works, in some cases the researchers reached consensus on new role labels.

To answer our second research question concerning the timing of role entry during ecosystem emergence, we plotted the roles involved in incidents in chronological fashion. This graphical depiction allowed us to identify the varying intensity of roles enacted over time, signifying when particular roles were more likely to come to prominence. And to answer our third research question addressing role interactions, we not only assessed prominent role-pairs (i.e. pairs of roles that repeatedly act together) during the emergence process, but also the 'interaction specificity' of a particular role by calculating the number of other roles with which it interacts.

4. Herceptin and the emergence of its innovation ecosystem

Herceptin was developed by Genentech, a biotechnology firm established and based in San Francisco. It was the outcome of a large project that cost the company approximately 200 million dollars in monetary terms as well as a vast amount of time in development (Bazell, 1998). The drug was developed upon the HER-2/neu antibody, which scientists discovered and successfully cloned in Genentech's laboratories. The function of the drug rested on the generic role of antibodies – proteins that fight against bacterial and viral infection by attaching onto a specific molecule on the surface of bacteria or virus cells. In this instance Genentech's monoclonal antibody targeted the HER-2/neu protein produced by the HER-2/neu gene in breast cancer cells. Unlike previous drugs developed to treat cancer, Herceptin was a breakthrough as it was specific, targeting cancer cells, and without damaging normal tissue surrounding the cancerous region. This specificity greatly reduced side effects that were a burden of alternative drugs.

The emergence of Herceptin's innovation ecosystem was sparked by the collective endeavours of noteworthy scientists, commencing with Stanley Cohen and his colleagues' discovery of the first epidermal growth factor receptor (HER1) in 1978, quickly followed by Robert Weinberg's discovery of the HER2 gene in mice a year later. In 1984, Waterfield, Ullrich, and Schlessinger demonstrated the function of oncogenes – genes in the cell that induce cancerous cell growth. And in 1986, Axel Ullrich (at Genentech) and Dennis Slamon (at UCLA) cooperated in an effort to search for oncogenes and together discovered one connected with breast cancer, later named HER-2/neu. This oncogene would prove to be the target gene for the development of Herceptin.

The scientific work following the discovery of the HER-2/neu gene was supported by philanthropists such as Lilly Tartikoff, who in 1986, aimed to raise funds for the work of renowned oncologist Dennis Slamon (the co-discoverer of HER-2/neu). Tartikoff's efforts introduced an unlikely benefactor in Revlon – a company in the cosmetics industry and certainly not directly linked to cancer treatment – which contributed a total of 13 million dollars to UCLA's research directed towards women's cancer between 1989 and 1997. Notwithstanding the injection of financial resources, Herceptin's development faced a crucial barrier as Genentech hesitated to commit to creating a gene-based cancer drug. In fact, the company came close to terminating the HER2/neu project in 1988. This hesitation invited a series of championing efforts from individuals both internal and external to the company, which eventually won Genentech's commitment to the drug and entrenched the company into the ecosystem structure.

Following the development of the antibody-based drug, focus shifted to the verification of the drug's influence on breast cancer through phase I and II trials (lasting approximately from 1990 until 1994). The epicentre of activities also shifted downstream, away from the scientific work to those actors who must engage in experimenting with the drug in vivo. Actors that took centre stage during this period included oncologists and volunteering patients. An unexpected problem emerged in 1991, however, when health insurance companies refused to compensate the medical costs to be incurred by breast cancer patients, effectively preventing their participation in trials. This systemic hindrance was eventually resolved by the judiciary when it decided in favour of patients' rights to compensation.

The ecosystem continued to increase in size and complexity as it entered phase III trials, which lasted approximately from 1994 until 1998. Given the significantly greater number of patients that were now involved in these trials,[1] the oncologist assumed a more central position in proceedings. Interestingly, phase III trials also invited the activism of groups such as the National Breast Cancer Coalition. The primary objective of these lobbyists was for breast cancer patients to gain compassionate access to medication that was yet to be approved by the FDA (Food and Drug Administration), in the hope that patients with acute conditions would have a chance to survive.[2] They confronted Genentech on a number of occasions and won an eventual victory towards the end of 1995, when the company finally implemented a compassionate access program.

As I ecosystem's centre of gravity shifted towards conducting trials, the recruitment of patients emerged as a significant hurdle to negotiate. This problem was sourced from the oncologists' resistance to participate in the trials by not forwarding their patients to volunteer. There were a few reasons for this resistance, suggesting the partial detachment of oncologists from the ecosystem and their limited commitment to ecosystem ambitions. One concern was that patients had to be enrolled for the trial at academic medical centres or hospitals, which were often geographically removed. Transferring patients also meant that the local oncologist would lose potential income, especially given that on many occasions the conditions of the patients were deemed to be readily treatable and did not require transfer to medical institutions. Aside from practical and financial burdens, oncologists were also reluctant to enrol patients to a trial which could jeopardize their health by offering a 50 % chance of receiving the placebo regimen rather than Herceptin. A large coalition of actors emerged on the scene to remove this large obstacle to ecosystem development. Through a vast communication campaign that involved various members of Genentech, scientists, breast cancer advocacy groups, and the media, oncologists and their patients became convinced of the planned trials.

The final path-defining episode revolved around the development of diagnostic testing technology. Specifically, diagnostic testing helps identify patients who overexpress the HER2/neu gene and provide information as to the cancer patient's likely reaction to Herceptin. Two prominent companies developed diagnostic testing as a complement to Genentech, although they followed noticeably different paths to commercialising their products. The first was Oncor, a developer and manufacturer of gene-based test systems for detecting and managing cancer and other diseases. Oncor established its position in the Herceptin innovation ecosystem through its Inform Gene Detection System test, which was devised to detect the HER2/neu gene as well as determining the risk of tumour recurrence in newly diagnosed breast cancer patients. However, the company experienced a tumultuous path of development, set back by a series of regulatory dictates that required successive resolution. DAKO, the second diagnostic test provider, had a comparatively easier path to product commercialisation. The key to DAKO's success was its strategic product development collaboration with Genentech. Notwithstanding the alternative paths taken by these companies, they ultimately assumed their complementor positions in the Herceptin innovation ecosystem structure.

[1] Needing the recruitment of approximately 850 patients (and a significant number of doctors), in comparison to the previous trial phases - 15 in phase I, and 43 in phase II.

[2] These groups followed the example set by the AIDS activist coalition ACT-UP, which, through similar lobbying activity, had caused pharmaceutical companies and the FDA to reconsider their protocols.

5. Roles enacted on the stage of innovation ecosystem emergence

The emergence of the Herceptin innovation ecosystem spanned two decades (1978–1998) and hosted a great deal of dynamism as a large group of actors contributed to ecosystem development through their interactions. While the biotechnology company Genentech takes the credit for having developed Herceptin, our exploration showed that 130 different actors participated in the ecosystem that brought the drug to market. These actors assumed a number of roles as defined by their activities and interactions. Overall, our examination revealed 15 roles that came to prominence during ecosystem emergence – listed and defined in Table 1. Some of these are formal roles, such as those arising from a division of labour within the ecosystem (Stryker and Statham, 1985), while others are informal, enacted autonomously by actors in response to a set of perceived needs (Markham et al., 2010).

Several of the roles listed in the above table left particularly noteworthy imprints. Firstly, new discoveries and scientific research that drove the very early period of emergence assigned importance to the expert role. Our study indicates that a majority of actors that undertook this role were individuals or teams employed by research institutions and Genentech, with many cases of industry-university collaboration. The ecosystem leader role was also prominent, with Genentech a frequent occupier of this role. The emergence process additionally showed the salience of the regulator role, which permitted the progression of drug development at critical junctures, enacted by institutional actors dedicated to an assessment procedure (e.g. the FDA).

Table 1
Roles during innovation ecosystem emergence.

Role	Role description (i.e. characteristic behaviours)
Activist	actively opposes the actions of others, typically in the form of demonstrations
Assembler[a]	manufactures products and services by assembling components, materials, and services, and by processing information supplied by others in the ecosystem
Champion[a,b]	engages intensively with the overall goals of the project; plays a dominant role in many of the research-engineering interaction events; overcomes technical and organisational obstacles; pulls the effort through to its final achievement by the sheer force of will and energy
Communicator	reports results of research, and transmits controversies to the general public
Complementor[a]	provides specialised functions or a narrow sphere of expertise, which contributes towards holistic product development objectives
Consultant[b]	provides additional technical information and advice
Dominator[a]	acquires organizations vertically or horizontally, often to the detriment of the ecosystem's wellbeing
Ecosystem leader[a]	sets a grand vision to secure the cooperation of organizations for the delivery of holistic value to the customer; executes the vision for constructing the ecosystem for the purpose of innovation; reconstructs the ecosystem if it becomes unstable by bringing in needed resources and making necessary connections
Expert[a,b]	discovers, invents, and generates ideas
Functional manager[b]	conducts routine managerial tasks from a given position in organisational hierarchy
Opponent[b]	resists cooperation towards a proposed direction of development
Regulator[a]	makes legal decisions on contended issues; governs policies; makes independent decisions on the feasibility of the innovation
Sponsor[a,b]	raises or allocates resources, and triggers the decision making process with the intent of promoting ecosystem development
Supplier[a,b]	delivers materials, technologies, and services, to be used by others in the ecosystem in the creation of an aggregate product or service
User[a,b]	acquires and utilises an innovation for a particular purpose

[a] Commensurate with Dedehayir et al. (2018).
[b] Commensurate with Chakrabarti and Hauschildt (1989).

Somewhat counterintuitively, our study highlighted the enactment of the opponent role on several occasions, including Genentech's failure to support the Herceptin project in 1988, and health insurance companies' refusal to pay for medical procedures requested by patients in 1990. As a result, the opponent role was seminal to the emergence process, initiating some of the watershed episodes that configured ecosystem structure. And further, our examination emphasised the centrality of the champion role to ecosystem emergence, expanding our traditional understanding of championship by demonstrating that this role can be assumed by different individuals, not confined to a central actor such as Genentech. Indeed, champions from various positions in the innovation ecosystem structure engaged intensively with the Herceptin project at various times, overcoming obstacles to facilitate the emergence process.

While many of the role labels and descriptors are commensurate with prior literature (Chakrabarti and Hauschildt, 1989; Dedehayir et al., 2018), two roles emerged as new from our study. The communicator role was enacted by leading scientists who reported the results of their research, and the media which transmitted controversies to the general public. And the activist role was assumed by actors who actively and pre-emptively opposed the actions of others (by contrast to the passive resistance of the opponent role), typically in the form of demonstrations. Actors undertaking the activist role included the Breast Cancer Action group which lobbied for compassionate access to Herceptin, patients who lobbied for inclusion in Herceptin's clinical trials, and biotechnology companies which demanded faster drug approval from the FDA.

In Table 2 we provide an overview of the actors that were most active during the emergence process, together with the various roles they assumed.

The table shows Genentech as the most prominent actor, in terms of the number and variety of roles occupied, followed by the FDA, the scientist Dennis Slamon, and the NCI (National Cancer Institute). We interestingly note that actors in the innovation ecosystem can undertake multiple roles. For instance, Genentech enacted eight different roles across the emergence period, including the roles of ecosystem leader, occupied on 37 different occasions ($n = 37$), supplier ($n = 28$), opponent ($n = 7$), sponsor ($n = 4$), expert (n = 3), activist ($n = 1$), assembler (n = 1), and communicator (n = 1). At the same time, the table also shows that specific roles can be undertaken by different actors across the emergence period. The ecosystem leader role, for example, has been undertaken predominantly by Genentech, although it has not been the lone occupier of this important role, with the NCI, breast cancer advocates, and Dennis Slamon taking on ecosystem leadership at different times. Table 3 illustrates the diversity of roles enacted by most prominent actors.

The above table reaffirms Genentech's centrality in the Herceptin innovation ecosystem, not only with respect to its activity frequency, but also its role diversity. Despite their lower frequency of activities ($n = 17$), the NCI and Dennis Slamon also demonstrate impressively high role diversity ($n = 7$). This is in stark contrast to the FDA, for instance, which has expended all 26 activities throughout the emergence period in the single – and undeniably important – role of regulator.

Our analysis additionally highlights that roles can be undertaken by actors at different levels of operation, including at the individual (e.g. scientists, oncologists, and patients), team/group (e.g. research and management teams), and organisational (e.g. Genentech, Oncor, and FDA) levels (see Table 4).

As the above table indicates, organisational actors contributed the greatest share of activity ($n = 224$) during the emergence of the Herceptin innovation ecosystem. Interestingly, a significant number of roles were undertaken by individuals, with a notable portion attributed to the work of scientists, but also to the championing work required to alleviate bottlenecks throughout the development of the ecosystem. In Fig. 1 we represent the changing intensity of roles over time at various levels of activity.

The figure shows that the intensity of individual roles (as well as team/group roles) has been greatest at the early stages of the emergence

Table 2
Most active actors during Herceptin innovation ecosystem emergence (1978–1998) and frequency of their roles.

Actors	Roles																Total
	Activist	Assembler	Champion	Commun-icator	Comple-mentor	Consul-tant	Dominator	Ecosystem Leader	Entre-preneur	Expert	Functional Manager	Opponent	Regulator	Sponsor	Supplier	User	
Genentech	1	1	0	1	0	0	0	37	0	3	0	7	0	4	28	0	82
FDA	0	0	0	0	0	0	0	0	0	0	0	0	26	0	0	0	26
Dennis Slamon	1	0	3	4	0	0	0	1	0	7	0	1	0	0	0	0	17
NCI	0	0	0	1	4	0	0	5	0	2	0	0	2	2	1	0	17
Patients	1	1	0	0	0	0	0	0	0	0	0	2	0	0	0	10	14
Oncor	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	0	13
Colleagues	0	0	0	0	0	0	0	0	0	11	0	0	0	0	0	0	11
Axel Ullrich	0	0	0	1	0	0	0	0	0	5	2	0	0	0	0	0	8
DAKO	0	0	0	0	2	0	0	0	0	0	0	0	0	0	4	2	8
John Curd	0	0	5	0	0	0	0	0	0	0	1	1	0	0	0	0	7
Roche	0	0	0	0	0	0	4	0	0	1	0	0	0	2	0	0	7
Arthur Levinson	0	0	4	1	0	0	0	0	0	1	0	0	0	0	0	0	6
Oncologists	0	4	0	0	0	0	0	0	0	1	0	0	0	1	0	0	6
Lilly Tartikoff	0	0	2	0	0	0	0	0	0	0	0	0	0	3	0	0	5
Hank Fuchs	0	0	2	0	0	0	0	0	0	0	2	0	0	0	0	0	4
Revlon	0	0	0	1	0	0	0	0	0	0	0	0	0	2	0	1	4
UCSF researchers	0	1	0	0	0	0	0	0	0	3	0	0	0	0	0	0	4
BCA and ACT UP	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
Breast cancer advoc.	2	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	3
Health insurers	0	0	0	0	0	0	0	0	0	0	0	2	0	1	0	0	3
Laboratories	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
Medical centres	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
Ronald Perelman	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	3
The White House	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	3
Total	8	13	16	9	6	0	4	44	0	34	8	13	31	15	46	13	260

Table 3
Activity and role characteristics of most active actors during Herceptin innovation ecosystem emergence.

	Activity and role characteristics			
Actors	Activity frequency (number of activities)	Role diversity (number of roles)	Dominant role	Frequency in dominant role
Genentech	82	8	Ecosystem Leader	37
FDA	26	1	Regulator	26
Dennis Slamon	17	7	Expert	7
NCI	17	7	Ecosystem Leader	5
Patients	14	4	User	10
Oncor	13	1	Supplier	13
Colleagues	11	1	Expert	11
Axel Ullrich	8	3	Expert	5
DAKO	8	3	Supplier	4
John Curd	7	3	Champion	5
Roche	7	3	Dominator	4
Arthur Levinson	6	3	Champion	4
Oncologists	6	3	Assembler	4
Lilly Tartikoff	5	2	Sponsor	3
Fuchs	4	2	Champ./ Func. Man.	2
Revlon	4	3	Sponsor	2
UCSF researchers	4	2	Expert	3
BCA and ACT UP	3	1	Activist	3
Breast cancer advoc.	3	2	Activist	2
Health insurers	3	2	Opponent	2
Laboratories	3	1	Assembler	3
Medical centres	3	1	Assembler	3
Ronald Perelman	3	1	Functional Manager	3
The White House	3	1	Regulator	3

Table 4
Roles and their levels of activity during the emergence of the Herceptin innovation ecosystem.

Role	Organisational	Team/Group	Individual	Total
Expert	9	23	29	61
Supplier	56	0	1	57
Ecosystem Leader	44	0	1	45
Regulator	36	0	1	37
Champion	0	2	20	22
Assembler	13	1	6	20
Communicator	9	5	6	20
Opponent	12	2	6	20
Sponsor	14	0	5	19
Functional Manager	0	2	16	18
User	4	0	12	16
Activist	8	2	4	14
Complementor	13	0	0	13
Consultant	2	2	2	6
Dominator	4	0	0	4
Total	224	39	109	372

period, precisely when much of the scientific work was conducted. This pattern is in contrast to the involvement of roles enacted at the organisational level, which came to the foreground closer to the end of the timeframe when product development, supply, and assembly activities were undertaken by actors such as Genentech, Oncor, and DAKO, as well as assessment and approval activities undertaken by the FDA.

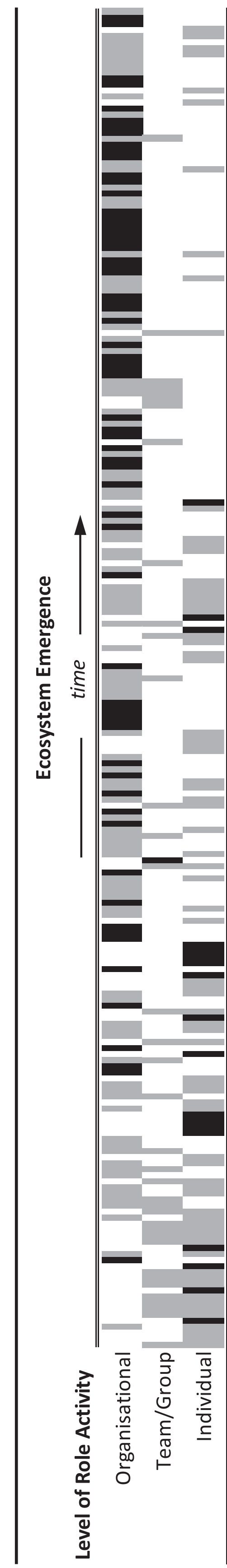

Fig. 1. Roles and their levels of activity during the emergence of the Herceptin innovation ecosystem (grey bars indicate one role, and black bars indicate two roles operating in tandem).

We also observe the intensity with which specific roles were enacted as the emergence period unfolded. Some roles entered the emergence process early, while others came to prominence later on (see Fig. 2).

As Fig. 2 demonstrates, the expert role was prominent early on, with basic and applied scientific research dominating this timeframe, as a series of discoveries established the premises upon which Herceptin would be developed. A short sequence of intense activity of the opponent and champion roles is also important to underline, immediately following the period of expert role dominance. This and similar activity sequences denote dialectical exchange between roles, which form crucial episodes of interaction.

An interesting observation is the ecosystem leader role's relatively late entrance onto the stage of emergence. This finding suggests that much of the ecosystem leadership work (i.e. setting of a vision, securing the cooperation of different actors, and constructing the ecosystem for the delivery of holistic value) could only be undertaken once fundamental components of the nascent ecosystem were put in place (i.e. a scientific and technical premise, and Genentech's commitment to the project). We additionally observe that ecosystem leadership is relatively short lived, with the intensifying contributions of the assembler, regulator, and supplier roles coming to the foreground later on. This sequence of role intensity underscores the greater necessity of ecosystem leadership during the intermediate stage of emergence when the ecosystem requires construction, and reconstruction when ties break down. Furthermore, it appears that important activities surrounding the supply and assembly of materials can start to intensify only after the innovation ecosystem has been brought to an operational state by the ecosystem leader.

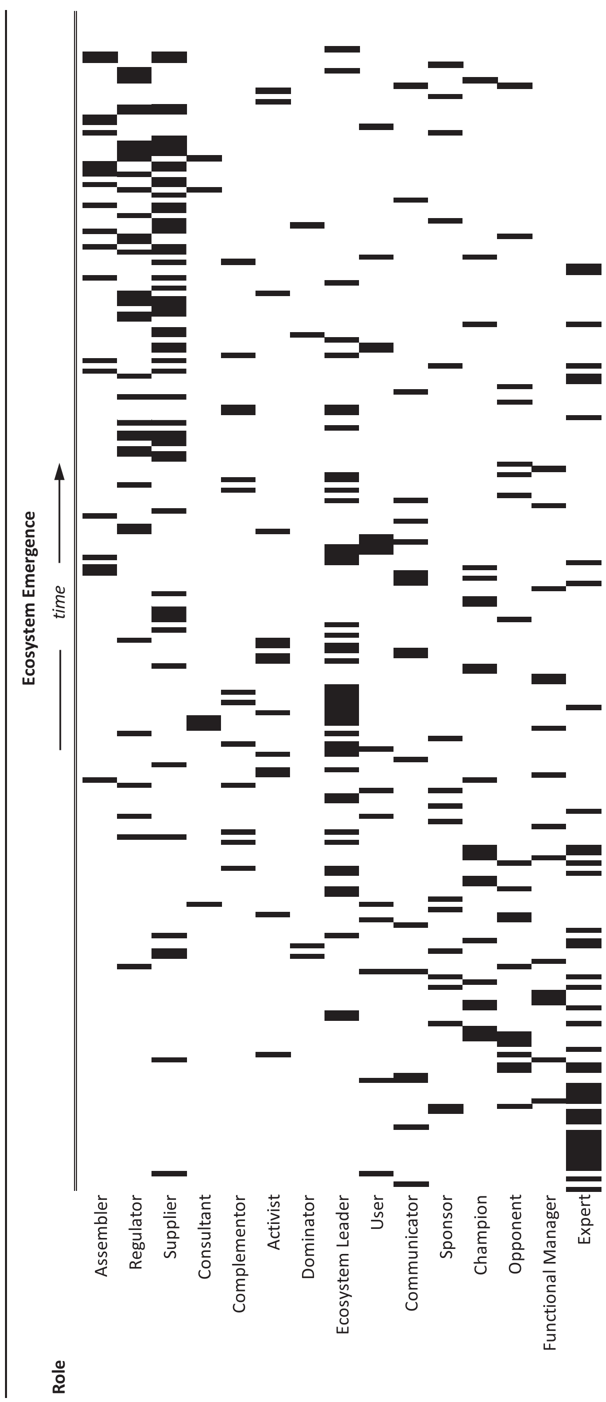

Fig. 2. Timing of role enactment during Herceptin innovation ecosystem emergence.

As in biological ecosystems that thrive through the interaction of interdependent species, the innovation ecosystem evolves subject to the interaction of roles undertaken by different actors. In Table 5 we present a summary of the interaction of roles during Herceptin innovation ecosystem emergence, as well as the interaction diversity of each role (i.e. the number of different roles with which a given role has interacted).

The table indicates that the expert ($n = 58$), supplier ($n = 45$), ecosystem leader ($n = 32$), and regulator ($n = 31$) have greatest interaction with other roles. We also observe a relatively high frequency of interaction between certain role-pairs, which indicates close interconnectivity and interdependence between these roles. One salient example is the interaction of expert roles ($n = 38$), which reflects the cooperation between different scientists and research teams during the early stages of ecosystem emergence. Other examples of closely-knit connections include the complementor's relationship with the ecosystem leader ($n = 11$), and the regulator's relationship with the supplier ($n = 15$). The table also underscores some roles to be more diverse in terms of interaction than others. For instance, the regulator interacts with 11 different roles throughout the emergence period, in fact, almost the entire cast of 15 roles uncovered in this study. This is particularly impressive when put in relation to the role's activity frequency ($n = 37$). By comparison, the expert role has less role interaction diversity ($n = 9$) despite having the highest activity frequency ($n = 61$). These differences in interaction characteristics indicate the various ways roles contribute to ecosystem emergence, with some roles assuming a relatively more specific or localised position (e.g. expert and complementor), while others assuming a more diversified position (e.g. regulator and opponent). In Fig. 3, we compare the interaction of roles with respect to the dimensions of activity frequency and interaction specificity.

This framework suggests that roles in the lower-left quadrant (activist, consultant, sponsor, and user) enter the stage of ecosystem emergence sparingly, but when on stage, interact with a relatively wide scope of roles. This contrasts with the upper-right quadrant roles (expert and assembler), which are highly visible during emergence, although quite specific in terms of the roles with which they interact. The large group of roles in the lower-right quadrant (regulator, champion, communicator, opponent, ecosystem leader, and supplier) appear on the emergence stage with a relatively high frequency, and interact with a wide scope of roles as well. Again, this is in stark contrast to the roles in the upper-left quadrant (complementor, dominator, and functional manager), which make rare appearances but often in tandem with a narrow bandwidth of roles.

6. Discussion and conclusions

In this paper we focused on innovation ecosystem emergence, and explored the roles enacted during this process. Our investigation was guided by three research questions centring on the roles, the timing of the appearance of these roles, and their interactions on the stage of

Table 5
Interaction of roles during Herceptin innovation ecosystem emergence.

Role	Expert	Supplier	Ecosystem Leader	Regulator	Champion	Assembler	Communicator	Opponent	Sponsor	Functional Manager	User	Activist	Complementor	Consultant	Dominator
Expert	38		3	1	5		1	3	5	1					1
Supplier		6	1	15	1	11		1	2	1	3		1		3
Ecosystem Leader	3	1		2		1	2	2			3	5	11	2	
Regulator	1	15	2	2	1	1		2			1	3	1	2	
Champion	5	1		1		2	1	2		2	1				
Assembler		11	1	1	2		1		1						
Communicator	1		2		1	1	4	1			3	1			
Opponent	3	1	2	2	2		1		1		1	2			
Sponsor	5	2				1		1	4		1				
Functional Manager	1	1			2					6		1		1	
User		3	3	1	1		3	1	1					1	
Activist			5	3			1	2		1					
Complementor		1	11	1											
Consultant			2	2						1	1				
Dominator	1	3													
total (bilateral)	*58*	*45*	*32*	*31*	*15*	*17*	*14*	*15*	*14*	*12*	*14*	*12*	*13*	*6*	*4*
total (unilateral)	*3*	*12*	*13*	*6*	*7*	*3*	*6*	*5*	*5*	*6*	*2*	*2*	*0*	*0*	*0*
Activity Frequency	61	57	45	37	22	20	20	20	19	18	16	14	13	6	4
Interaction Diversity	9	11	10	11	8	6	8	9	6	6	8	5	3	4	2

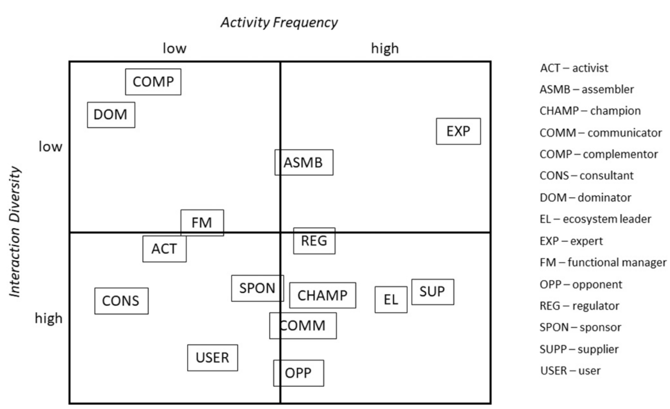

Fig. 3. Interaction behaviour of roles during Herceptin innovation ecosystem emergence.

emergence. To answer these questions we studied the case of Herceptin, a revolutionary gene-targeted drug, and analysed the emergence of the ecosystem around this drug between 1978 (discovery of the drug's basic chemistry) and 1998 (the drug's commercialisation).

Our study revealed a cast of 15 roles that facilitate the emergence of innovation ecosystems, which are enacted at the individual and team/group levels, in addition to the organisational level traditionally recognised in the ecosystem literature. While the importance of non-organisational actors has been discussed by Moore (1996), to the best of our knowledge, our study is one of only a few that empirically underscores individual and team/group level roles in innovation ecosystems (see Lepoutre and Oguntoye, 2018, and Dattée et al., 2018 for other examples). This is an important addition to the literature, which, despite borrowing the ecosystem notion to better reflect the complexity of collaborative innovation, has been reserved in its identification of a comprehensive list of roles involved (Moore, 1996; Gawer and Cusumano, 2002; Iansiti and Levien, 2004).

The importance of multiple roles to ecosystem development challenges much of the grander literature addressing a systemic, networked view of innovation, which frequently sheds its analytical lens onto a single, orchestrating role. By emphasizing the significance of orchestrators (e.g. Dhanaraj and Parkhe, 2006; Gupta et al., 2020), hub firms (e.g. Gardet and Fraiha, 2012), keystone organizations (e.g. Iansiti and Levien, 2004), platform leaders (e.g. Gawer and Cusumano, 2014), ecosystem leaders (e.g. Moore, 1993), and kingpins (e.g. Jacobides and Tae, 2015), the clusters, innovation systems, open innovation networks, and platforms scholars have inevitably left numerous roles in the periphery. And yet, these deserve analytical attention to acquire a more comprehensive perspective of how systems and networks of innovation develop (Kapoor and Agarwal, 2017).

As our study revealed, the prominence of the ecosystem leader (creator of grand vision and (re)constructor of the ecosystem for the purpose of innovation) during the critically volatile and fluid period of ecosystem emergence, in fact, materialized only after experts (discoverers, inventors, and generators of ideas; e.g. scientists) had established a pathway for innovation. Moreover, the duration of the ecosystem leader's prominence was relatively short lived as suppliers (deliverers of materials and technologies to be used by others in the ecosystem in the creation of an aggregate product), assemblers (manufacturers of products through assembly of components and materials supplied by others in the ecosystem), and regulators (makers of legal decisions on contended issues and policies) took centre stage towards the conclusion of the emergence phase. These findings contest Dedehayir et al.'s (2018) proposition that the ecosystem leader role would be prominent throughout the emergence period.

Our study also showed that other roles, besides the ecosystem leader, assumed centrally noteworthy positions during ecosystem emergence, such as the champion (resolver of technical and organisational obstacles through intense engagement with project goals). While prior literature considers champions and their activities to lie within the boundaries of the organization, our study offers an extension of this traditional view by suggesting that championing activity may be sourced from different positions within the ecosystem structure, sometimes lying outside the boundary of the organization influenced (Santos and Eisenhardt, 2005).

Concerning the timing of role entry onto the stage of innovation ecosystem emergence, our results indicated that different roles acquired prominence at different times. The expert role was noticeably active at the very early stages of ecosystem development, while the ecosystem leader role acquired significance during the intermediate phase of emergence, prior to the assembler, regulator, and supplier roles rising to the foreground in the concluding stages. This temporal pattern of role prominence offers a tool to forecast the anticipated evolution of an innovation ecosystem in its early period, while enhancing managerial and policy decision making regarding the roles that are required to be enacted for the ecosystem to successfully emerge. We further showed that the expert, supplier, ecosystem leader, and regulator roles have the greatest interaction with other roles, and that some roles (e.g. regulator) to be relatively more diverse in terms of these interactions. We also observed frequent interactions between certain role-pairs, such as between experts, complementor and ecosystem leader, and regulator and supplier. The notions of ‘interaction diversity’ and ‘activity frequency’ we have developed for ecosystem roles in this paper ultimately extend the ‘influence diversity’ and ‘influence density’ characteristics Luo (2018) has proposed to define firms' architecture of participation in ecosystems.

6.1. Theoretical implications

We synthesize our findings in an overarching, role-centric view of innovation ecosystem emergence (Fig. 4). This framework ultimately operationalizes the ecosystem-as-structure perspective advanced by Adner (2017), which “starts with a value proposition and seeks to identify the set of actors that need to interact in order for the proposition to come about” (Adner, 2017, p.41). Adner proposes four elements that underlie this structuralist perspective. The first element, ‘activities’, defines the actions required for the value proposition to materialise, while the second element of ‘actors’ refers to the executor of these actions. ‘Positions’, the third element, specifies the location of actors in the activity flow and the final element of ‘links’ pertains to the transferring of transactional content (e.g. resources and influence) between actors.

The activity-centric rather than actor-centric perspective held by the structuralist view invites roles into a conceptual framework of ecosystems, substituting for actors and their activities. In fact, we argue that focusing on roles rather than the actors who undertake these roles carries broader conceptual applicability. This is because actors, their activities and interconnections are specific to the innovation ecosystem that embeds them. Any insights about ecosystem development acquired from the analysis of the latter will thus be difficult to transfer to a broader range of ecosystem contexts. By contrast, roles operate at a higher level of abstraction and are indiscriminate of the ecosystem that embeds them. They represent sets of activities that are generically undertaken across different ecosystems, allowing scholars to produce more generalizable theorization about innovation ecosystems and their development. This logic of moving to a higher level of concept abstraction for the purpose of arriving at more generalizable conceptualisation of a phenomenon is observable in earlier contributions, including Hekkert et al. (2007), who define a set of functions to map key activities of innovation system dynamics.

The framework presented in Fig. 4 firstly shows the cast of roles that populate the ecosystem structure during the Herceptin ecosystem emergence. Following Adner's ecosystem-as-structure proposition, the framework additionally indicates the positions of roles and the links between them. The notion of position is challenging to operationalise in the context of ecosystems given their complex and non-linear structure. In our framework we propose a method of defining the position of ecosystem roles with respect: (i) to the microfoundation level of activity (e.g. individual, team/group, or organization) – in line with Phillips and Ritala's (2019) proposition of a structural dimension that considers ecosystem hierarchy and relationships across multiple levels; (ii) to time – in reference to three sequential phases of ecosystem emergence (preparation, formation, and operation) proposed by Dedehayir et al. (2018); and (iii) to other roles – commensurate with role theory which asserts that roles do not occur in isolation and are always linked to complementary roles (Bertrand, 1968). Meanwhile the connections between roles (i.e. dashed lines) represent the links that allow transfer of resources and influence.

6.2. Implications for practice and policy

Considering the implications of the proposed innovation ecosystem emergence framework on practice and policy, we make two fundamental assumptions, namely, that an operational and value delivering ecosystem is a desirable end-state of the emergence process, and that each stage of emergence needs to be successfully navigated to reach the desired end-state. Building on these assumptions, we propose that practice and policy will strategically engage with or facilitate the activities of each stage, to ensure that intended value can materialise. Such initiatives can influence the direction of change by removing bottlenecks to ecosystem development and stimulating roles and their interactions when these are lacking.

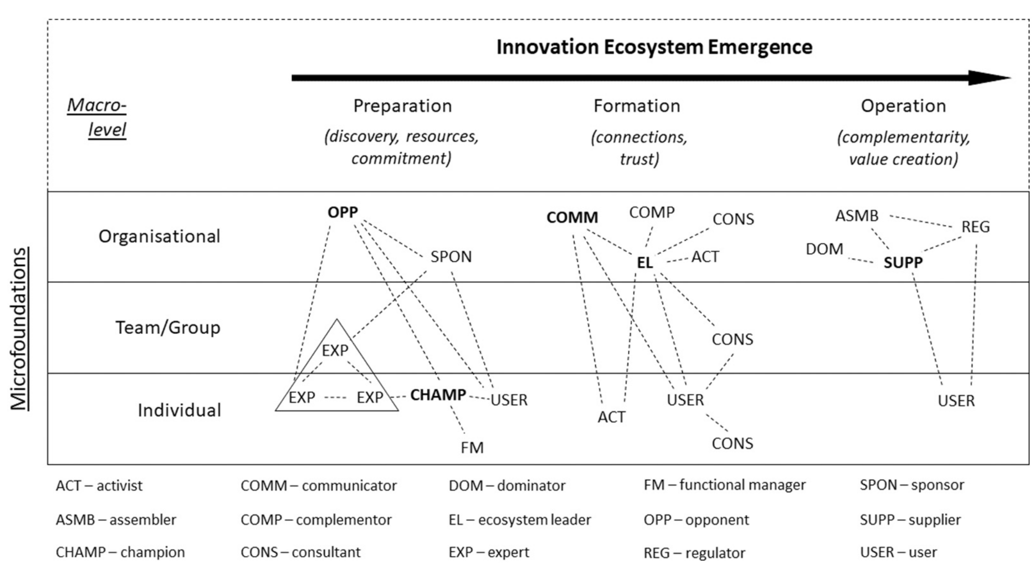

Fig. 4. Microfoundations, roles, and innovation ecosystem emergence.

In the preparation stage, focus is on the discovery and invention of fundamental technical premises, the provision of resources, and the commitment of key actors to the innovation effort (Dedehayir et al., 2018). From the ecosystem-as-structure perspective, these foci are akin to value attributes created by the ecosystem in this stage of emergence that result from the enactment of particular roles (primarily individuals and teams/groups) and their interactions. The expert role is seminal to this phase, along with the opponent and champion roles bestowed by their high frequency-high diversity characteristics (emboldened in Fig. 4). The positioning and linkage of the opponent and champion roles additionally connote tension and conflict that marks the phase of preparation, suggesting a dialectic process of change (Van de Ven and Poole, 1995) during the early period of ecosystem emergence. From a practice and policy point of view, it is important to measure how the ecosystem is performing during this early timeframe. Given the centrality of developing a technical solution in the preparation stage (to offer a solid foundation for the ecosystem's product and service offerings), stakeholders ought to monitor technological development and inject resources when needed. Furthermore, it is necessary to measure the level of commitment of actors to the emerging ecosystem, to ensure that required levels are reached for the creation and exchange of value. This period is likely to attract organizations specialising in R&D (e.g. universities) and firms that invest recourses with the goal of appropriating future value from prospective technologies.

In the formation stage, interaction between roles takes the form of a dialogue across the three levels of activity, indicating a gradual shift in activity focus from individual, to collective, and organisational processes over time (Fiol and Romanelli, 2012). This period is pronounced by the appearance of crises requiring resolution, and so focuses on the creation of connections and the strengthening of trust between ecosystem members to foster value creation (e.g. Clarysse et al., 2014). The ecosystem leader consequently takes centre stage – a role that may be enacted by practice- or policy-oriented organizations. How the ecosystem performs in the formation stage may be measured by the number of connections in the ecosystem (observable through active resource exchanges between actors), and the level of trust various actors in the ecosystem experience towards others. Through these measurements, stakeholders can take action to increase connections and strengthen trust as necessary. For firms, assuming the ecosystem leader role during this time can reap benefits as the ecosystem enters the following stage centring on commercialisation, while for policy makers, the enactment of ecosystem leadership may become necessary to drive development towards a particular goal.

Finally, in the operation stage, attention shifts to the provisioning of complementary offerings and inter-role transactions that create additional value and secure the value appropriation for the ecosystem. Interactions between roles are predominantly at the organisational level. The supplier role, characterised by its high frequency and high diversity of activity gains greater visibility during this period, in readiness for product commercialisation. How the ecosystem performs in the operation stage may be measured through the efficacy of the product or service that is provided by the ecosystem in satisfying the needs of the end-user. This is a lucrative period for firms to engage with the ecosystem as providers of products or services, and for policy makers to facilitate ecosystem development towards market-readiness of products and services.

6.3. Limitations and future research

The selection of a single case and single industry is one obvious limitation of our study. Given that the industry-specific nature of innovation mechanisms is well documented, future work should study ecosystem emergence in different domains. It is important to recognise the boundary conditions established by the Herceptin case, within which other cases might be expected to display similar role characteristics. Specifically, Herceptin is an integrated product innovation that requires a long time as well as large financial resources to develop and commercialize, while concurrently having to negotiate tight regulatory control. The emergence of ecosystems around other cancer-fighting drug innovations could be anticipated to follow similar patterns as we observed for Herceptin. How ecosystems emerge around innovations that fall outside of these boundary conditions (e.g. modular products, innovations in fast-cycle industries, and innovations in deregulated sectors), however, may not demonstrate the same role-centric processes and therefore motivate future research.

A further limitation of our study is bestowed by its scope of investigation and purposeful focus on actors, their activities and roles, and interactions during ecosystem emergence. As a result, other highly important questions centring on value creation and value capture (e.g. de Vasconcelos Gomes et al., 2018) by these actors during ecosystem emergence were not able to be addressed. The kinds of value and the mechanisms through which they are created and captured by different roles form worthy questions that can guide extensions of our present work. We also acknowledge that a more complete processual understanding of innovation ecosystem emergence requires the inclusion of other components in addition to the structural components we have focused on in our study. Valuable complements to our proposed framework include the bottlenecks that arise during emergence, and the mechanisms (as well as actors and roles) that resolve these to ensure the ecosystem evolves from a loose network to one that is tightly knit. Such bottleneck-resolution activities may additionally help identify significant milestones in ecosystem emergence that can further inform stakeholders. Moreover, and following Hekkert et al.'s (2007) contribution to innovation systems research, our processual model can benefit from the identification of a set of functions that define innovation ecosystem dynamics, and which can be mapped onto the cast of roles.

In our work, innovation ecosystems are seen as emergent phenomena resulting from lower-level interactions of actors with specific roles. The wider (higher-level) context in which ecosystems emerge and how it stimulates emergence was discussed in several instances in our paper, but this may deserve additional attention in future work. The multi-level perspective on sociotechnical transition (e.g. Geels, 2005; Geels, 2020) provides a useful framework through which the grander context of innovation ecosystem emergence can be understood. For radically new innovations, such as Herceptin, we can expect the innovation ecosystem to emerge at the niche level, and in time move upwards into the regime level where it might co-exist with incumbent ecosystems or enter into competition with these. In the case of cancer treatment, for instance, we have historically witnessed the prescription of a combination or personalised mix of medicinal approaches, which indicates the co-existence of older and newer medicinal drugs and their ecosystems. The opportunity for the new, emerging ecosystem to enter the regime level would be motivated landscape-level changes, such as shifts in political, regulatory, or social systems. We believe that future work can continue the recent contributions of Walrave et al. (2018) and Lepoutre and Oguntoye, (2018) by assuming a multi-level perspective on the dynamics and pathways of innovation ecosystems emergence as shaped by activities across different levels of the sociotechnical system.

Finally, the use of historical data in our study may have introduced interpretation bias. We suggest that employing a prospective, qualitative approach can overcome this limitation in future extensions of our work (e.g. those examining more contemporary innovation ecosystems). To elaborate our finding that roles can be occupied by multiple actors, and conversely that actors can occupy multiple roles, we additionally encourage future research to clarify the actor-role constellations that would be most influential for ecosystem emergence. We propose that further integration of role theory can help uncover additional attributes of ecosystem emergence, such as the occurrence of role conflict, in other words, when a position requires an actor to assume a role that conflicts with the actor's value system (Galletta and Heckman, 1990). Our framework additionally identifies key interactions of actors through their connectivity, which point towards mechanisms driving the emergence process that future studies can examine. We believe that our understanding of the dynamic interactions and tensions between innovation ecosystem members can be enhanced by determining the types of governance mechanisms that address these relationships (e.g. Ring and Van de Ven, 1992; Wareham et al., 2014).

CRediT authorship contribution statement

Ozgur Dedehayir: Conceptualization, Data curation, Formal analysis, Methodology, Writing - original draft, Writing - review & editing.

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J. Roland Ortt: Conceptualization, Formal analysis, Methodology, Writing - original draft.

Appendix A. List of news agency sources and number of press releases used

Cited press releases	News (agency) source
26	Business Wire
21	Dow Jones News Service
12	Reuters News
12	The Wall Street Journal
10	M2 Presswire
10	PR Newswire
9	The Associated Press
7	The Washington Post
4	Biotechnology Newswatch
4	Gene Therapy Weekly
4	Investor's Business Daily
4	The New York Times
4	USA Today
3	Federal Filings Newswires
3	NBC News
3	The Philadelphia Inquirer
2	Cancer Weekly Plus
2	Chemical Market Reporter
2	Diagnostics Intelligence
2	Genentech (Annual Report)
2	San Francisco Business Times
2	San Jose Mercury News
1	Biopharm
1	Biotech Business
1	Chemical Business Newsbase
1	Clinica
1	Daily Telegraph
1	Factiva Press Release Service
1	Financial Times
1	Genesis Report
1	Hamilton Spectator
1	Informations Chimie Hebdo
1	Japan Chemical Week
1	New Jersey Business
1	Pharmaceutical Business News
1	Pittsburgh Post-Gazette
1	R & D Focus Drug News
1	Science
1	St. Louis Post-Dispatch
1	St. Petersburg Times (Florida)
1	The Daily Record
1	The Ottawa Citizen
1	The Press Democrat
1	The Toronto Star
1	World News

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