Policy-Driven Industrial Ecosystems

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1 Introduction

Technological progress is increasingly considered to be leading to a global tech race (Deutsche Gesellschaft für Auswärtige Politik, 2020). Nation states have begun to invest massively in emerging technology and create a state of competition, for example by establishing competing national artificial intelligence (AI) strategies, and industrial prosperity is a key political objective. An emerging strategic priority for policymakers has thereby become the pursuit of "technological sovereignty" in their area of responsibility (European Centre for International Political Economy, 2020). Practitioners consider this to be game-changing for geopolitics, with Eric Schmidt and Jared Cohen famously postulating a "new digital age" that could potentially be characterised by a digital world order (Schmidt & Cohen, 2013). EU Commissioner Thierry Breton (2020) expects this outlook to fuel a "real industrial revolution".

As a driver behind these developments, the role of network constructs on inter-firm level that are influenced by policies and government interventions has not been sufficiently researched. However, there are various industrial inter-firm network activities such as ecosystems, value chains and platforms that can be supported and fostered by policy initiatives in the domains of industrial, innovation and technology policy. This potentially increases the "technological sovereignty" of a polity and should ultimately provide greater prosperity. The European Commission, for instance, has made the growth of industrial ecosystems to achieve digital and green twin transitions a core of its Industrial Strategy, since they want to nurture ecosystems under the geoeconomic objective of sovereignty and open strategic autonomy (European Commission, 2020, 2021c). And the U.S. Innovation and Competition Act of 2021 calls for the development of local and regional capacity for innovation ecosystems (U.S. Government Publishing Office, 2021). Schwab (2017, p. 22) even asserts that the competitiveness of economies in the light of the fourth industrial revolution depends on an ability to build innovation ecosystems.

This contemporary development has been somewhat neglected by the academic literature so far and has mainly been taken up by think tanks and practice-oriented research institutions. Indeed, prior academic research considers theories on ecosystems mostly from a firm-level view of an orchestrating firm and collaborating partner organisations rather than a perspective, in which ecosystems are shaped or even driven by policy influences such as initiatives and instruments, and not merely by individual firm-level efforts. Notable exceptions are the research by Li and Garnsey (2014) and Rinkinen and Harmaakorpi (2018, 2019). The former has introduced a concept of "policy-driven ecosystems" for the health sector, as the authors find new vaccine development to follow clear public policy objectives. And the latter authors argue in favour of an "ecosystem-based innovation policy" to foster business ecosystems, which could complement policymaking approaches like clusters, innovation systems, and smart specialization. They also identify a taxonomy of policy instruments that are useful in fostering the evolution of such ecosystems.

Further related research develops an industrial ecosystem concept in the context of regional and changing industrial policies (Andreoni, 2018, 2020). The ecosystem definition provided by Andreoni (2018, p. 1620) is taken as basis for this paper:

> "Industrial ecosystems can be defined as multi-tiered production systems involving heterogeneous agents operating in sectoral value chains and contributing to the capability domains of the ecosystem (and its participants) with closely complementary but dissimilar sets of resources and capabilities. The industrial ecosystem is thus a structured production space centred mainly on its productive organisations, as well as other public actors, intermediaries and demand-side actors, purposefully involved in co-value creation processes along various types of diversification and innovative industrial renewal trajectories."

All mentioned studies call for a research agenda on the topic. They suggest that further empirical and conceptual research on ecosystems bridging the activities of the public and private sector is needed, and to examine policies that enable ecosystem evolution.

2 Properties of Ecosystems

The wider construct of inter-organisational relationships (IORs) constitutes a "general and all-encompassing term" as diagnosed by Agostini et al. (2019, p. 357). Their work, Provan et al. (2007), and Ozman (2009) notably provide systematic literature reviews for the concept of IOR mostly as network constructs, but do not address any interplay with policy and government interventions. A definition for IOR is provided by Parmigiani and Rivera-Santos (2011, p. 1109):

> "We define these relationships as being strategically important, cooperative relationships between a focal organization and one or more other organizations to share or exchange resources with the goal of improved performance."

A special manifestation of inter-organisational relationships with N>1 participating actors in a network is the ecosystem concept. Ecosystems are usually researched in three academic domains according to McIntyre and Srinivasan (2017, p. 142): industrial organisation economics, technology management and strategic management. The latter emphasises ecosystem-embeddedness for firms' competitive advantage and attributes value co-creation practices to unlocking unique value propositions. The term "ecosystem" in a business context aims to characterise novel value creation networks and stresses the role of focal firms in capturing value that was generated based on the interconnection with collaborating entities (actors) for complex innovation (Dougherty & Dunne, 2011). What makes ecosystems distinct from other forms of network collaborations or systems are their ecological characteristics, in an analogy of biological structures. This is important for policymakers to consider when thinking about potential policy and government interactions that might influence ecosystems.

Moore (1993, p. 75) attributes the anthropological idea of interdependent species' co-evolution as underlying characteristic of ecosystems, in which changes for one actor induce changes for another actor "in an endless reciprocal cycle". As Moore (1993, p. 76) further suggests, such an ecosystem, "like its biological counterpart, gradually moves from a random collection of elements to a more structured community". Any change and transformation of the ecosystem can thus be expected to follow co-evolutionary patterns, in which adjustments occur amongst all ecosystem participants (Riasanow et al., 2020). The community or network is orchestrated by the focal actors and connects related entities "who depend on each other for their mutual effectiveness and survival" (Iansiti & Levien, 2004, p. 8). This mandates businesses to combine both strategies for competition as well as cooperation into their conduct, and Moore (1993, pp. 77-85) identifies four phases of the evolutionary process for the case of business ecosystems:

(1) **Ecosystem Birth:** During this phase, the ecosystem value proposition is developed based on customer demand. It is decided how the value is best delivered and which methods support the implementation of the customer value. The initiation of cooperation amongst involved entities can be costly at first.

(2) **Ecosystem Expansion:** This phase describes the growth process of the ecosystems based on new actors and interactions that occur. Competition with rivalling ecosystems or single actors can increasingly determine the success and fate of the ecosystem. The value of the business concept and its scalability provide the competitive advantage. The maintenance of customer and supplier relationships is key for ecosystem orchestrators.

(3) **Ecosystem Leadership:** The pre-mature to mature phases typically see a contest for ecosystem leadership, control, and bargaining power once the value generating mechanisms, profitability and ecosystem relationships are stabilized. Actors might consider taking over additional steps of the value chain from others, and the dependency on the single-dominant "ecological contributor" decreases.

(4) **Ecosystem Self-Renewal:** In the mature phase of the ecosystem, although the alignment structure might be steady, the ecosystem could face various external threats to its stability and success. This could be caused by rivalling ecosystems and their innovations, or other environmental conditions such as regulations. The longer-term success will therefore depend on the ecosystems' innovative capability and ability to reinvent itself and its value proposition by taking up innovations or adapting to external circumstances, which was also coined as "self-renewal" capability.

If the self-renewal phase of the ecosystem is not successful, it faces the potential fifth phase of ecosystem death. This follows the Darwinian logic of "survival of the fittest", but has potentially massive repercussions for the economy, society, and stability of a polity. Dougherty and Dunne (2011) attest that the process of emergence is an inherent characteristic of complex ecological systems and occurs in a self-organizing manner that creates order. The innovative power, however, is then dependent on the ability of the system to move away from equilibrium structures, whose rigidity hampers value creation and avoids new knowledge to be absorbed and included in the system.

These ecological characteristics can be incorporated in an "ecosystem-as-affiliation", a term coined by Adner (2017, p. 41) to describe "networks of affiliated companies":

> "This perspective, which I call ecosystem-as-affiliation, places emphasis on the breakdown of traditional industry boundaries, the rise of interdependence, and the potential for symbiotic relationships in productive ecosystems. It focuses on questions of access and openness, highlighting measures such as number of partners, network density, and actors' centrality in larger networks."

The multitude of different ecosystem actors forming a network is already mentioned in this perspective, and their role depends on the ability as entity to contribute to the ecosystem's success. Moreover, the interrelationship between entities can serve different purposes and is often subject to varying degrees of coupling between actors (Hein et al., 2018). Ultimately, their interplay leads to a value co-creation process (Sarker et al., 2012).

The roles of the central ecosystem actors have been most prominently described by Iansiti and Levien (2004), who distinguish between keystone actors, physical and value dominators, as well as niche players. Keystone actors correspond to the ecological contributors mentioned by Moore (1993) – powerful ecosystem connectors and orchestrators, which play a systemtic role to stabilize the ecosystem health and make it more robust based on common provided assets, tools, technologies and innovations. Their task is to ensure that value is fairly created, shared and ultimately captured by the ecosystem actors. If they try to drain too much value out of the ecosystem for themselves, their role can however shift to that of a physical dominator, preventing other ecosystem actors from profiting of the value created and failing to incentivice for innovation in the ecosystem. Is the contribution of such actors to the ecosystem and control over it low at the same time, then Iansiti and Levien (2004) refers to them as value dominators. Both forms endanger the stability and survival of the ecosystem. Most remaining ecosystem actors are considered niche players, which manage to leverage capabilities and relations to other ecosystem actors for their own value creation of niche aspects with importance to the overall value proposition of the ecosystem, thus taking over a small share of the value chain but relying on the orchestration provided by keystone actors.

Further expanding the "ecosystem-as-affilitation" concept, Adner (2017) reiterates the importance of the ecosystem's value proposition for the health and success of the ecosystem. A central perspective is the alignment of interests by an incentivisation of ecosystem actors to participate – not only by monetary rewards and generated value, but also by ensuring an alignment of motivations. This is called "ecosystem-as-structure" and defines the ecosystem with its boundaries (Adner, 2017, p. 42):

> "The ecosystem is defined by the alignment structure of the multilateral set of partners that need to interact in order for a focal value proposition to materialize".

This idea of multilaterally interacting organisations that are bound together by modularity and intrinsically-motivated interdependence rather than hierarchical forms of governance and organisation has been championed by Jacobides et al. (2018) in their seminal paper. They nevertheless stress the relevance of contractual partnership management for the different types of complementarities, which could provide innovations, input products or services for the ecosystem. These typically provide some form of modular value-add and could be generic, unique and thus co-specialized, or even supermodular in its value-adding characteristics. Only the existence of non-generic complementarities properly defines the boundaries of ecosystems though. Dedicated ecosystem governance and regulation is likewise considered a prerequisite for a functioning ecosystem, typically conducted by central coordinating actors, keystones in the nomenclature by Iansiti and Levien (2004).

In order to maintain a functioning ecosystem and to unlock its competitive advantage, firms operating in an ecosystem should possess ecosystem-related capabilities and resources. This view is derived from the dynamic capabilities theory developed by Teece et al. (1997) based on the resource-based view of the firm (Barney, 1991), and describes the ability of ecosystem actors to adapt to the outside and oftentimes changing environment by leveraging network relations in the ecosystem. Lütjen et al. (2019) condense these capabilities to firms' sensing, seizing and reconfiguration capabilities – the exploration and finding of new cooperation partners, the operation of the ecosystem, and the upholding and adjustment of a supporting governance structure.

Importantly, Jacobides et al. (2018) begin to differentiate between business ecosystems, innovation ecosystems and platform ecosystems based on an analysis of the literature. However, they also referred to Teece (2014, p. 151, cited after Jacobides et al. 2018, p. 2256), who asserts that "the concept of ecosystem might now substitute for the industry for performing analysis" – an indication about the relevance of the industrial ecosystem concept propagated by Andreoni (2018). It must be mentioned that this idea of an industrial ecosystem is distinct to the definition of industrial ecosystems by industrial ecology research, which describes networks designed for sustainability to reduce waste and energy consumption (cf. exemplary Frosch & Gallopoulos, 1989; Korhonen, 2001). Other specialized forms of ecosystems found in the literature are entrepreneurial ecosystems (Spigel & Harrison, 2018), service ecosystems (Wieland et al., 2012), and knowledge ecosystems (Clarysse et al., 2014). The exact definitions tend to vary, and different ecosystem typologies continue to co-exist (cf. Pilinkienė & Mačiulis, 2014).

3 Interplay of Ecosystems and Policy

An ecosystem always implies that dyadic relations are only part of a "web of interactions", which comprises a multitude of different actors and is often described as "network-embeddedness". This allows ecosystem actors to partake in such strategic networks that facilitate a competitive and comparative advantage based on often non-linear relations with different nodes in the web, e.g. in the form of alliance portfolios (Gomes et al., 2016; Gulati et al., 2000; Wassmer, 2010). Jacobides et al. (2018, p. 2267) conclude that this leads to varying "collaboration and coordination behaviors" depending on the characteristic of the underlying relations. The collaboration networks can also have different degrees of formalization (Guercini & Tunisini, 2017).

Business ecosystems not only embed actors that focus on production, but also involve the customer in the network and its value co-creation processes; this is a notable difference to other networks described in the literature, such as clusters or production networks (Autio & Thomas, 2014, pp. 205-206). The management of ecosystems is typically executed by an "architect" – often the keystone – and requires a governance regime with targets for the ecosystem development, an allocation of individual actors' rights and duties, and mechanisms to facilitate the collaboration amongst ecosystem actors (Gulati et al., 2012). These usually have to contribute non-fungible investments to the ecosystem in order to incentivise greater engagement with the ecosystem (Jacobides et al., 2018, p. 2265). Political-will in the form of legislative support and the provision of resources has been found to facilitate the evolution of business ecosystems (Senyo et al., 2019). The simultaneous existence of both a business ecosystem and a knowledge ecosystem can be observed, but requires different policymaking approaches (Clarysse et al., 2014).

Innovation ecosystems are related to the concept of business ecosystems, but also entail and emphasise the elements of supply – both upstream and downstream – together with actors necessary for, involved in, and affected by innovative processes, like regulators and research institutions; ultimately creating a "system of innovations" (Edquist, 2005; Gu et al., 2021; Jacobides et al., 2018, p. 2257). This follows ecological and evolutionary principles, as well, and the important role of the government for the evolution of innovation ecosystems has been documented (Ma et al., 2019). Strategic innovation has also been linked to the emergence of innovation ecosystems and global value chains for the adaptation of national economies (Shelomentsev et al., 2021). Therefore, innovation ecosystems are considered an important foundation for the development of industry 4.0 capabilities and advanced manufacturing in a polity (Pasi et al., 2021; Reynolds & Uygun, 2018). A feedback mechanism often drives complementors to also innovate their input products based on the technologically intertwined properties with the focal firms' offerings, which constitutes a distinct feature and challenge of innovation ecosystems as compared to business ecosystems (Adner & Kapoor, 2010). If the system is in a nascent state and focuses on the creation of a favourable environment for new business formation, an entrepreneurial ecosystem is developed (Jolley & Pittaway, 2019). On the other end of the spectrum in terms of the network's control and ownership structure can public-private partnerships be located. If public funding matches private investments, such a public-private partnership is born, potentially consortium-backed (Leviäkangas et al., 2018; Sengoku, 2019). It constitutes a tightly coupled relationship that requires project management and governance mechanisms and can be seen as a multi-actor project ecosystem (Leviäkangas et al., 2018). Traditional innovation policy mechanisms have always been the support of firm-level research and development (R&D) with public funding, which could also be provided for networks and consortia (Mathews, 2002; Nishimura & Okamuro, 2016).

The idea of innovation and entrepreneurial ecosystems is connected to clusters and industrial districts (Belussi, 2015; Marshall, 1890; Porter, 1998); as well as regional and national innovation systems (Chung, 2002; Freeman, 1987; Lundvall et al., 2002; Nelson, 1993; Nelson & Nelson, 2002). These concepts take a stronger perspective on the institutional policy environment, put more emphasis on geographical aspects of innovation and are less centric to a dedicated value co-creation process on organisation-level. Ecosystems, however, define their boundaries less around geographical boundaries but rather around ideas of common value propositions, power, identity and efficiency (Santos & Eisenhardt, 2005; Tsujimoto et al., 2018). However, Harmaakorpi and Rinkinen (2020) question whether an "ecosystem-facilitating competitiveness policy at the regional level" could be beneficial for regional development and aim to introduce a geographical component to the ecosystem concept in the context of policymaking. The academic research on clusters, districts and innovation systems is closely related to policy literature on innovation and technology policy, such as research on the policy mix and helix model of government-industry-university relations (Carayannis & Campbell, 2009; Etzkowitz & Leydesdorff, 2000; Flanagan et al., 2011; Magro & Wilson, 2013).

The ecosystem can have a platform at its core, and innovations are related to this platform (Yoo et al., 2012, p. 1400). Such a platform ecosystem is dominated by the platform owner as central keystone, comprises complementors that contribute with add-on products and services to the platform and together with other actors in the ecosystem, value co-creation is achieved (Fuller et al., 2019, p. 2). Ultimately, however, the value appropriability and monetization will be an issue of strategic importance for ecosystem actors (Cusumano et al., 2020; Teece, 1986). Although platforms often profit form network effects, they therefore require dedicated platform strategies to attract platform participants and ensure growth (Hagiu & Rothman, 2016; Yoffie et al., 2019). Aside from platform ecosystems, other platform nomenclatures and types exist in the literature, like organisational platforms, internal platforms, supply-chain platforms, product family platforms, or marketplaces and intermediaries (Gawer, 2014; Thomas et al., 2014). Notably, an industry platform also comprises an ecosystem with the platform owner at the centre and contributing complementors, which provide products and services based on the technological and modular platform core with open interfaces and governance structures (Tiwana, 2014). Most of the academic literature still focuses on B2C platform ecosystems, whereas B2B settings have specific requirements in terms of market structure and customs (Aarikka-Stenroos & Ritala, 2017; Schermuly et al., 2019, p. 33). The platform can also build on digital technologies and resemble around a digital ecosystem (De Reuver et al., 2018, p. 162). Its technological foundation comprises an extensible codebase, add-on software subsystem, and IT infrastructure with a sociotechnical element (Tiwana et al., 2010, p. 676). An integration of platform ecosystem actors can be achieved with boundary resources (Ghazawneh & Henfridsson, 2013). The regulation of platforms and surrounding ecosystems has become an issue of concern for policymaking bodies around the world, especially motivated by competition policy and aiming towards scrutinizing the often quasi-monopolistic market power of the GAFA companies (Bossio et al., 2022).

Ecosystems often centre around the provision of services rather than emphasising an exchange of goods, and actors need to contribute their capabilities and resources for value co-creation. This ecosystem conceptualisation follows a service-dominant logic (S-D) and in extreme cases, if even tangible innovations are perceived as service innovations, service ecosystems are formed (Vargo & Lusch, 2008). The value of data and venues of service innovation has thus increased tremendously (Lusch & Nambisan, 2015, pp. 156-157). Research also finds that relations to "non-direct value-adding" stakeholders in a service ecosystem, such as local governments and legislators, plays a role for the ecosystem's success (Lu et al., 2014; Lütjen et al., 2019). This stakeholder-orientation has been found to be a helpful strategy when forming an ecosystem during foreign market entry (Rong et al., 2015). It demonstrates an affinity between ecosystem and stakeholder theories in strategic management research (Donaldson & Preston, 1995; Freeman, 1983; Stanczyk, 2017). Closely related is the concept of non-market strategy and corporate political activity of organisations (Doh et al., 2012; Lawton et al., 2013). An important element of the management of collaborations has become the area of resilience and crisis management with major policy implications, especially for supply chains (Natarajarathinam et al., 2009). Supply chain security has thus become a part of organisation-level strategy (Williams et al., 2008). Platforms and their ecosystems have shown a greater degree of resilience than non-platform-based firms (Floetgen et al., 2021). Moreover, government interventions have been found to affect both supply chains and supply networks, often with a dedicated political objective at heart (Hafezalkotob, 2018; Moradlou et al., 2021; Srai et al., 2021). Industrial policy can support the development of such supply networks (Srai & Gregory, 2008).

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Further related research develops an industrial ecosystem concept in the context of regional and changing industrial policies (Andreoni, 2018, 2020) following an ecosystem definition provided by Andreoni (2018, p. 1620):

> "Industrial ecosystems can be defined as multi-tiered production systems involving heterogeneous agents operating in sectoral value chains and contributing to the capability domains of the ecosystem (and its participants) with closely complementary but dissimilar sets of resources and capabilities. The industrial ecosystem is thus a structured production space centred mainly on its productive organisations, as well as other public actors, intermediaries and demand-side actors, purposefully involved in co-value creation processes along various types of diversification and innovative industrial renewal trajectories."

Finally, sectoral considerations often play an important role in the collaboration between organisations and for policymaking approaches alike (Liu et al., 2012). In ecosystem theory, the concept of industrial ecosystems emphasises this practical reality. As part of the sectoral value generation, value chains both domestically and on global scale, alongside value networks, are researched in the academic literature (Gereffi et al., 2005; Porter, 1985; Ricciotti, 2020). An industrial ecosystem can be embedded in such sectoral and global value chains utilizing technology platforms, which Andreoni (2017, p. 3) describes as the "combination of resources and capabilities" in the tradition of Teece (1996) and Teece et al. (1997).

Industrial ecosystems then also facilitate the uptake of industry 4.0 capabilities (Schmidt et al., 2021). A further important characteristic for such sectoral concepts is the existence of powerful lead firms (Sturgeon et al., 2008). An industrial ecosystem can also have a regional scope (Ashton, 2009), but ultimately, the development of a whole strategic industry is often the objective and can be a factor of strategic importance for an economy (Xiaohua & Feng, 2013). O'Sullivan et al. (2013, p. 458-459) indeed find that an industrial policy must depend on the national industrial context, for instance value chain configurations, the institutional context, such as industrial networks, and the national policy context. The support of manufacturing then requires policymakers to form a partnership with industry and the acknowledgment of manufacturing's "systems-nature", with industrial policies concentrating on key manufacturing sectors.

4 Conclusion

Figure 1 summarizes the key constructs found in the IOR and related policy literature. The schematic displays an onion structure that should be interpreted from the inner to the outer rings widening up the production system from an undirected network to a system with defined geographical boundaries. The inclusion of users as actors then adds the ecosystem characteristic for value co-creation purposes with different foci but typically non-geographical orientation, and the inclusion of a supply element facilitates the creation of an innovation ecosystem. All individual IOR concepts can then be embedded in a system of innovation with other stakeholders. As part of a sequence of value adding steps, the system could also constitute one value adding element in a value chain, or it could be a part of a value network. This is especially the case in an industrial ecosystem, which is embedded in a sectoral value chain.

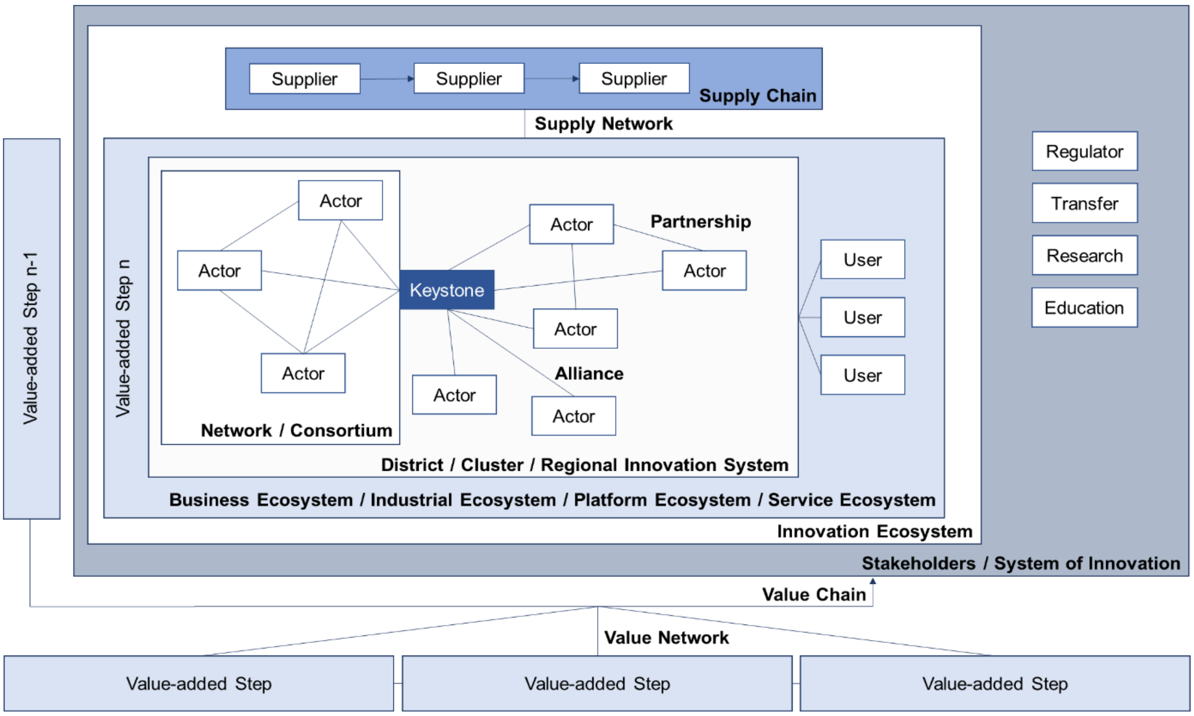

Figure 1 Summary Schematic of IORs
(Source: Own Analysis)

It is important to note that the public sector could in theory influence the ecosystem as endogenous or exogenous actor, or both at the same time. For instance endogenously, it could partake in a public-private partnership and thus be a value co-creating producer. Governments could also constitute users by facilitating public procurement or they could be involved as co-producers through public firms as ecosystem actors. Policymakers can exogenously influence the ecosystem as stakeholders, for instance as regulators, via legislative activities, by engaging with research programs or when providing public funding for R&D purposes.

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