An Agent-based Modeling Approach for Effective Innovation Ecosystem Orchestration

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Abstract

Innovation ecosystems are classified as one of the complex economic systems where many parties with different interests are involved. The holistic objective of such alignment of entities is to cooperate in the creation of innovative outputs. The innovation ecosystem provides the environment for large corporates, entrepreneurs, investors, and governmental institutions to accumulate their sole offering into value capturing via networking and exchanging knowledge and expertise. Thus, such kind of ecosystem exhibits multiple partnerships and interactions among actors to fulfill their own needs and contribute to the value co-creation process. This paper explores the nature of innovation ecosystem as a set of networks comprising a large spectrum of agents interacting with each other. Most of the previous work on ecosystems has pursued qualitative studies emphasizing on how to orchestrate an innovation ecosystem entirely. However, we addressed such a phenomenon by means of an agent-based modeling considering both the micro level of the system which consists of the individual agents and the macro level which is represented by the aggregating of individuals' behaviors. The model can be used as a decision-making tool to examine the validity of an orchestrating strategy by detecting its dual impact on individual agents and on the overall performance of the ecosystem.

Keywords

Innovation Ecosystem, Orchestration, Agent-based Modeling, Decision-analysis, Policymaking.

1. Introduction

For ages, economies around the world have been seeking to secure its economic stability through encouraging different national sectors to contribute into the rise of national economy. On this account, the initiation of innovation ecosystem was explained as the new direction that would lead nations to enrich their economic foundations with novel trends of economic activities other than relying solely on few industrial sectors. The diversity of contributions that is imposed by such collaborative settings ensures a yield that would outweigh offerings created individually by the actors. The innovation ecosystem is a grouping of entities that aims to create and capture value through joint innovation practices (Ritala et al. 2013). It consists of diverse entities that consider both external and internal innovation practices to enhance their profitability (Fosfuri and Rønde 2004). Such economic setting ensures high level of productivity and business diversity through merging different outputs from different participated organizations (Garibay et al. 2015). However, this kind of ecosystems is characterized by dynamic flows, non-linearity, and unpredicted pattern of interdependencies which are emerged from the engagement in open innovation activities. Added to that, members of an innovation ecosystem usually demonstrate an accelerated learning curve which is strongly emphasized by the interconnections among them (Ferasso et al. 2018). Similarly, innovation ecosystem is described as a network where flow of knowledge takes a place (Tejero and Leon 2016). This economic structure tends to expand its boundaries to enclose entities with diverse backgrounds and schemes to integrate their vital role in capturing and creating value

(Weil et al. 2014). Furthermore, innovation ecosystem's players potential contributions are affected by the surrounding economic conditions (Saguy and Sirotinskaya 2014). The versatility medium where entities interact with each other is subjected to political, technological, and economic circumstances (Engler and Kusiak 2011). Innovation ecosystem is a metaphor which holds many dimensions, this leads to a broad spectrum of definitions. However, all relevant research came to a census about the significance of establishing such a collaborative setting. They all emphasized on the holistic goal of the innovation ecosystem is construct a solution-oriented network where innovative outputs are induced by sharing knowledge, technologies, and expertise despite all the members' discriminants. Therefore, ensuring the harmonization of such systems would have outstanding consequences due to their potential contribution to the development of national economics. This paper is organized as follows. Firstly, the purpose of this paper is addressed and then, some literatures about the complexity of such system are revisited as well as some previous efforts in orchestrating and simulating Innovation ecosystem are highlighted. Afterwards, the followed methodology is explained along with the attempt of simulating an innovation ecosystem. Potential future work is mentioned in the last section.

1.1 Objective

The phrase "innovation ecosystem" refers to the networking of businesses despite differences in their nature, size, and specialty. They frequently combine their many offers to provide unique goods and/or services that cannot be produced separately. The establishment of an innovation ecosystem requires participating businesses to engage with one another and exchange a range of resources in order to ensure mutual advantages. In relation to that, the research primarily examines the presence of such economic alignments in the Sultanate of Oman and how they are successfully coordinated. Unfortunately, due to the presence of multiple forms of interactions and interdependence between the elements, such a system comes within the category of complex systems. As a result, it necessitates close attention, especially when hundreds of interactions occur, which must be dissolved into a clearer picture to ensure active management of their occurrences in real-life scenarios. In these conditions, Agent Based Modeling was adopted as a bottom-up technique to solve this complexity. It focuses on the micro level of the system, treating each individual entity as an agent who fulfills a certain function and displays a particular behavior within the ecosystem. The system's performance on a macro level is then created by the aggregate of the agents' interactions. To support the project's goal, a simulation model will be developed to investigate several aspects that may have a substantial influence on the stability and efficiency of these types of systems. The simulation model will be used to monitor and track the many interactions that occur between the various entities to determine the most appropriate orchestrating policies and mechanisms that will assure the success of such alignment.

2. Literature Review

The goal of the literature review section is to comprehend and learn more about the challenge of coordinating innovation ecosystems from many angles. Furthermore, the purpose of this part is to connect the numerous literature studies with one another and with the current topic, as well as to identify any gaps. This section will be structured in the following manner: The first section discusses the intricacy of the innovation ecosystem, the second section looks at how such a system is orchestrated, and the third portion highlights former attempts to simulate such kind of ecosystems.

2.1 The Complex Characteristic of Innovation Ecosystem

The innovation ecosystem is categorized as a complex system since it interacts with several entities that are unique in most of their characteristics. These discrepancies create benefits in the form of rich knowledge and a variety of resources that may be shared and traded between the parties, but they also act as obstacles that could make it difficult to harmonize individual interests and foster mutual gain. As a result, orchestrating such networks demands a lot of work from the focal entities which are in charge of overseeing and organizing the structure of a certain innovation ecosystem. The effectiveness of the innovation ecosystem depends on continuity of the flow of resources among its members, those flows involve interchange of both physical and intangible resources, in which they require excellent orchestrating techniques and procedures to maintain them. Additionally, this system's participants must effectively communicate with one another outside of their organizational boundaries. Therefore, the development of such interdependences is inherently associated with risks that need to be reduced in order to create a setting that makes networking procedures among parties smoother. According to Adner (2006), when resource allocation occurs to partners outside of the firm's premises, it dramatically raises a red flag when evaluating the linked risk. In addition, regrettably, some organizations tend to ignore the shared objectives that should be reached collectively and act selfishly in the name of their own self-worth rather than completing the tasks that have been delegated to them. Despite the fact that the business market's dynamism may cause unexpected

changes, which in turn have an influence on flow, the innovation ecosystem is nevertheless subject to these alterations. Especially in cases where small and medium enterprises (SMEs) are engaged in the innovation ecosystem. According to Gawer (2014), a SME's participation in an innovation ecosystem is only partially advantageous because of the limitations associated with their early development stage maturity in the market. In other instances, large firms tend to refuse to work with SMEs because they view them as inexperienced parties. This type of collaborative setting has some ambiguity when it comes to the strategic positioning of each entity; certain members have indirect contributions to the innovation ecosystem that cannot be explicitly classified. The strategic positioning of entities within an ecosystem tends to be more emergent than predetermined, as mentioned in (Mintzberg and Waters 1985). The innovation ecosystem presents a challenge in maintaining harmony, therefore getting all the players to cooperate for the greater benefit is not a simple task.

The process of controlling such structure is known as orchestrating. And instead of being a precise and rigid approach, the term refers to resilient management practices in this context. As previously indicated, coping with a changing economic environment necessitates a hybrid blend of informal and formal management systems. Due to the dynamic nature of the market's constant evolution, this poses difficulties for those in charge of orchestrating innovation ecosystems. They must choose the best mix of management mechanisms based on a variety of economic factors. With the unstable state of the market which is brought by the quick adoption of new technology and variable economic needs, the business market's inherent stochasticity creates obstacles that prevent the free exchange of ideas and interactions among participants in innovation ecosystems and encourages their opportunistic behavior.

2.2 Orchestrating Innovation Ecosystem

To coordinate interactions within innovation ecosystems, numerous strategies were developed. According to some authors, formal controls over the interactions and linkages between entities are necessary for such economic alignments. In contrast, several academic works advise handling the alliance between innovation ecosystems with caution. Hybrid combinations of formal and informal regulating mechanisms have been proposed in certain publications. Cobben and Roijakkers (2019) asserted that an evaluation of the degree of partnership alignment would be a necessary step in determining the correct orchestration methods by the hub organization. To preserve discipline within the innovation ecosystem, for instance, the focal entity would be compelled to take strict measures in situations where entities disobey orders and tend to resist harmonization. Through the employment of explicit rules and regulations, control-based methods are utilized to bring entities into alignment. whereas in certain circumstances, the focal entity might have a tendency to loosen the regulating mechanisms toward the participants in the innovation ecosystem. In this case, building trust became the hub firm's primary concern.

Dhanarai and Parkhe (2006) identified three orchestration aspects that a focal entity might use to direct the innovation ecosystem. These factors primarily focus on controlling innovation appropriability, promoting network stability, and facilitating knowledge mobility. The hub business makes sure that all entities are demonstrating a high degree of information absorption, application, and rationing throughout the initial step. The allocation of value among the stakeholders is of interest to the focal entity. Likewise, In the context of innovation ecosystem, the focal entity is in charge of bringing the participants to a consensus on how to jointly capture value. The authors also place a strong emphasis on the hub firm's capacity to mobilize and maintain participant commitment in order to foster value generation and accelerate ecosystem growth. However, Adner (2012) proposed five potential ways to reconfigure the innovation ecosystem: relocation, separation, combination, addition, and subtraction.

The author suggests that the members' roles can be divided and assigned to them separately, or they can merge their work. Additionally, he noted, current players may be removed if they are no longer contributing value to the ecosystem and new actors can be considered anytime new specialized activities are involved in the innovation ecosystem. Iansiti and Levien (2004) mentioned three sorts of network strategies—keystone, dominator, or niche—that an entity may employ in an innovation ecosystem depend on its strategic position within the ecosystem and the need for a specific authority structure that establishes the functional hierarchy in such ecosystems. In a similar manner, Muegge (2011) identified four distinct roles that are particularly prevalent in innovation ecosystems where intensive technology business enterprises are active participants. They are described by the author as promoters, guardians, adopters, and users of open platforms.

2.3 Simulation of Innovation Ecosystem

There has been a growing interest in studying complex systems by means of many approaches to simplify the associated complexity. For instance, Bandini et al. (2001) and Chopard et al. (2002) attempted to model complex systems resembling a cellular automaton where cells' behavior is influenced by the surroundings. They further illustrated an empirical and more comprehensive agent-based modeling. Likewise, Koritarov (2004) used an agent-based modeling to simulate the electricity market possible scenarios. whereas Tesfatsion (2003) developed an agent-based model simulating complex economic conditions. Albino et al. (2006) addressed the interdependencies between industrial innovators as a complex system using an agent-based model. Similarly, Ma and Nakamori (2005) proposed an agent-based simulation model of evolutionary approaches related to innovation framework. Hirata and Ulanowicz (1984) and Hannon (1973) introduced an agent-based approach to model the economy structure as an ecosystem where agents are addressed as elements of an ecological network. Luke et al. (2005) constructed an agent-based model of innovation ecosystems using MASON to explore the effect of microeconomic behaviors on the macroeconomic phenomenon. The agents are interacting in a spatial environment, where they are driven by economic behaviors.

3. Method

Through the use of interviews and the analysis of information supplied by key parties. A conceptual model of an innovation ecosystem was created, which assisted in defining all of the primary characters who engage in such a system, as well as the interactions that occur between those actors. Following that, a Netlogo simulation tool was used to transform the obtained conceptual model into an agent-based model. The simulation model is employed as a what-if analysis tool in which several scenarios with various policies may be addressed in order to ascertain how the innovation ecosystem is anticipated to function and how players within the ecosystem would theoretically respond under multiple different conditions, taking into consideration the influence of innovation policy intervention in managing the national innovation ecosystem. The following section is dedicated to illustrating the generated data.

4. Data Collection

Since innovation ecosystems are treated as complex systems, developing a simulation model is one of the adaptive approaches to address them. The goal of modeling such a system is to alleviate its uncertainties and reduce its complexity. In the case of agent-based modeling, for instance, agents like major companies, SME firms, governmental organizations, and academic institutions are modeled in accordance with their sets of simple rules and interactions in the simulation environment, which in this case would represent the ecosystem of interacting contributors and the venue where value creation takes place. After conducting research and studying relevant literatures, a conceptual model of an innovation ecosystem is created to point out the different interconnections among the agents. As shown in figure.1, actors attempt to initiate multiple links with other actors and especially with well-established ones. These interdependencies involve the exchange of both cognitive and physical resources between parties. Furthermore, the conceptual model emphasizes the significance of the focal agents (orchestrators, incubators, and accelerators). Those agents assure the integrity of the innovation ecosystem as they form links with most players.

It can be clearly observed that focal entities launchers of networking practices withing the ecosystem. However, the conceptual model reveals the complexity associated with this network. The nature of partnerships established amongst entities may vary as they have different strategic positions.

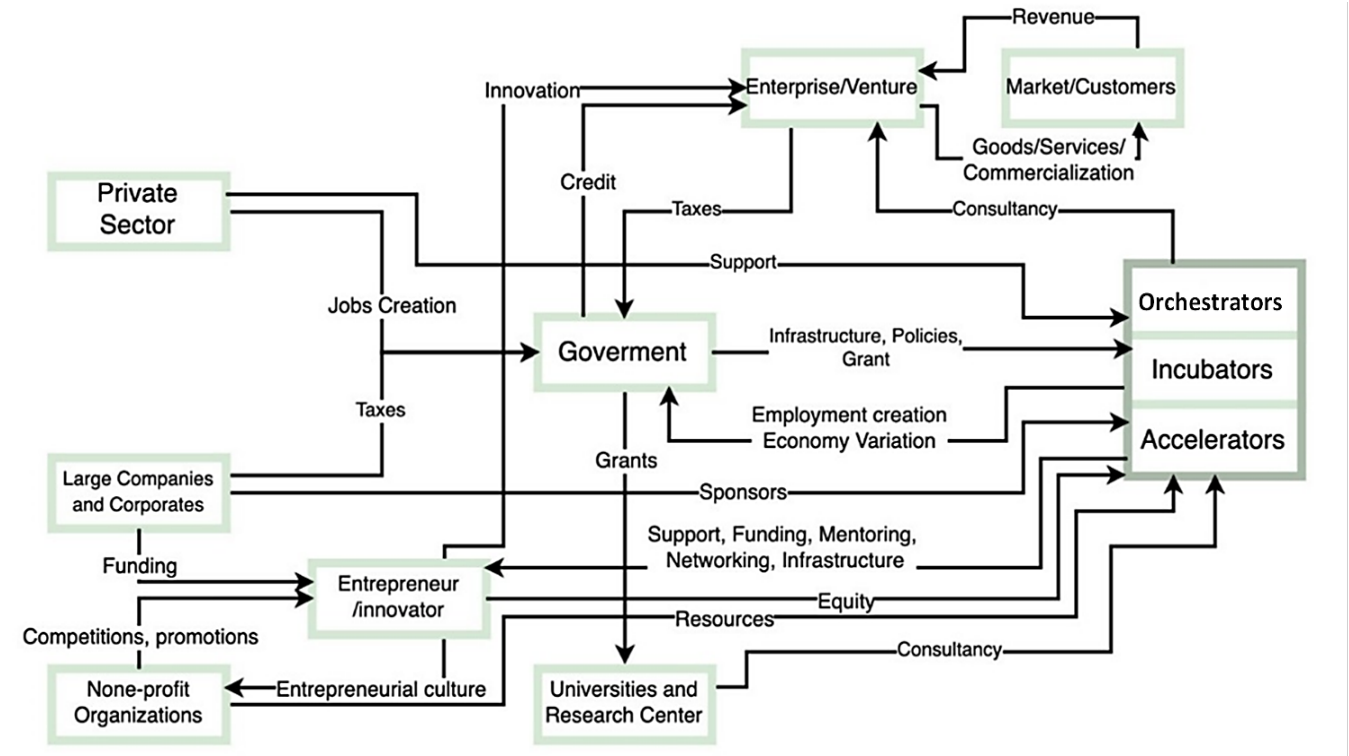

Figure 1. Conceptual Model of Innovation Ecosystem.

Thus, the nature of links may fluctuate between control-based relationships and trust-based relationships with which may result in opportunistic behavior of actors and stimulating complications in the innovations ecosystems. The simulation model is designed to address a complicated system with numerous agents and interactions. As a result, various factors are examined and given as input variables, as tabulated and discussed in the table.1.

Table 1. simulation model's input parameters.

Factors/input parameters	indication
Number of orchestration entities	Indicates how many orchestrators are there in IE
Number of incubation entities	Indicates how many incubators are there in IE
Number of acceleration entities	Indicates how many accelerators are there in IE
Number of intermediaries	Indicates how many intermediate entities are there in IE
Number of large enterprises	Indicates how many large enterprises are there in IE
Number of governmental entities	Indicates how many governmental entities are there in IE
Number of banks	Indicates how many banks are there in IE
Number of academic entities	Indicates how many higher education entities are there in IE
Number of research centers	Indicates how many research centers are there in IE
Number of oil and gas entities	Indicates how many entities are specialized in oil and gas sector
Number of companies	Indicates how many companies are there in Oman IE
Number of telecommunication entities	Indicates How many entities in telecommunication sector in Oman IE

Number of agricultural entities	Indicates How many entities in agricultural sector in Oman IE
Number of logistical entities	Indicates How many entities that deal with logistics in Oman IE
Number of private equity firms	Indicates How many private equity firms are in Oman IE
Number of entities in Oman's technology park	Indicates how many entities in Oman technology park
agents' arrival to orchestration	Mean value of agents' arrival distribution to orchestration
agents' arrival to incubation	Mean value of agents' arrival distribution to incubation
agents' arrival to acceleration	Mean value of agents' arrival distribution to acceleration
Orchestration process time	Time needed to accomplish orchestration service
Incubation process time	Time needed to accomplish incubation service
Acceleration process time	Time needed to accomplish acceleration service
Stable innovation score	Threshold weighted score indicates the fulfillment of orchestration process
Stable incubation score	Threshold weighted score indicates the fulfillment of incubation process
Stable acceleration score	Threshold weighted score indicates the fulfillment of acceleration process
Connection capacity	Maximum number of links an agent may have
Partnering likelihood	The probability of initiating a partnership
Threshold value	Weighted score that agents have to fulfill it to initiate partnerships
radius	The distance between two agents
Birth of SME	The probability of establishing new SMEs
SME IRR	The average value of SMEs IRR
W1	Amount of importance of IRR
W2	Amount of importance of age
W3	Amount of importance of Market share

5. The New Concept of Consortium Orchestrator

The most challenging part of innovation ecosystem is sustaining its performance throughout the contributing partners. By means of effective orchestrating strategies, the health of the innovation ecosystem is maintained. Besides orchestrating strategies, and despite the fact that innovation ecosystem encounters uncertainties that result in a co-evolving environment for entities; this indicates that the strategic positions of firms are evolving as well. therefore, a firm networking strategy is intended to be compatible and adaptable with its surroundings for the sake of the overall performance of the innovation ecosystem and its survival. Hence, those strategics must be flexible and agile to endure any abrupt changes that are induced by the dynamics of the market. Many writings have been highlighting the significance of the focal entity which dedicates its efforts to sustain the harmonization of the innovation ecosystem. However, they have not mentioned nothing about the composition of this kind of organizing structure that its main contributions to the ecosystem are basically regulations and instructions that are used to manage interactions among the partners. This leaves unexplained challenges of handling opportunistic behaviors of members and thus, relevant deviations from the overall objective of the innovation ecosystem are to be expected to occur. In this section, we attempt to fill some of this gap by suggesting a new concept and in order to emphasize the importance of effective orchestration of innovation ecosystem in facing potential deviation and opportunistic behavior of the members, we adopt the term "Consortium Orchestrator". As it was mentioned before, that one of the concerning characteristics that

distinguishes innovation ecosystem from other economic alignments is the "co-evolving "of strategic positions of the partners. Owing to the dynamic nature of the innovation ecosystem; where entities may switch their roles or positions depending on the variable requirements of the economic alignment that they participate in. As a result, our suggestion is absolutely based on the fact that innovation ecosystems postulate their complexity due to their diversity among their actors. The presence of dissimilarities in business strategies, sizes, market positions, fields, offerings of the players make it harder for the hub firm to align them properly in intention to fill the innovation ecosystem's needs. In the light of that, establishing a focal entity which includes representatives from each firm that participates in the innovation ecosystem. each firm must elect members who are responsible for representing their entity in during policies making process which takes a place in the hub firm. Whether the innovation ecosystem is specialized in one certain industry of not, the hub firms should be including elected representatives in order to assure a high level of consensus regarding establishing any policy or making any decision. In such way, the probability of having any type of opportunistic behavior would be lessen comparing to cases where the focal entity has an independent structure.

Moreover, if the hub firm is responsible for offering platforms of connections, with the presence of those representatives would ease the dynamic of interconnecting and would clarifies all the interdependencies among the innovation ecosystem' members. Engaging agents in the central activities of the focal entity would be effective in providing both zoom in and zoom out view of the innovation ecosystem. Hence, providing wide and narrowed lenses to coordinate the whole system would probably stand as a strong advantage for the sake of the system's health and sustaining its performance as well. As shown in figure.1; what is suggested is looks like establishing a centralized innovation ecosystem inside the hub itself, but the innovative part would be relevant to inventing new and agile managerial actions and tools instead of making commercial innovations as the other part of the system is responsible for.

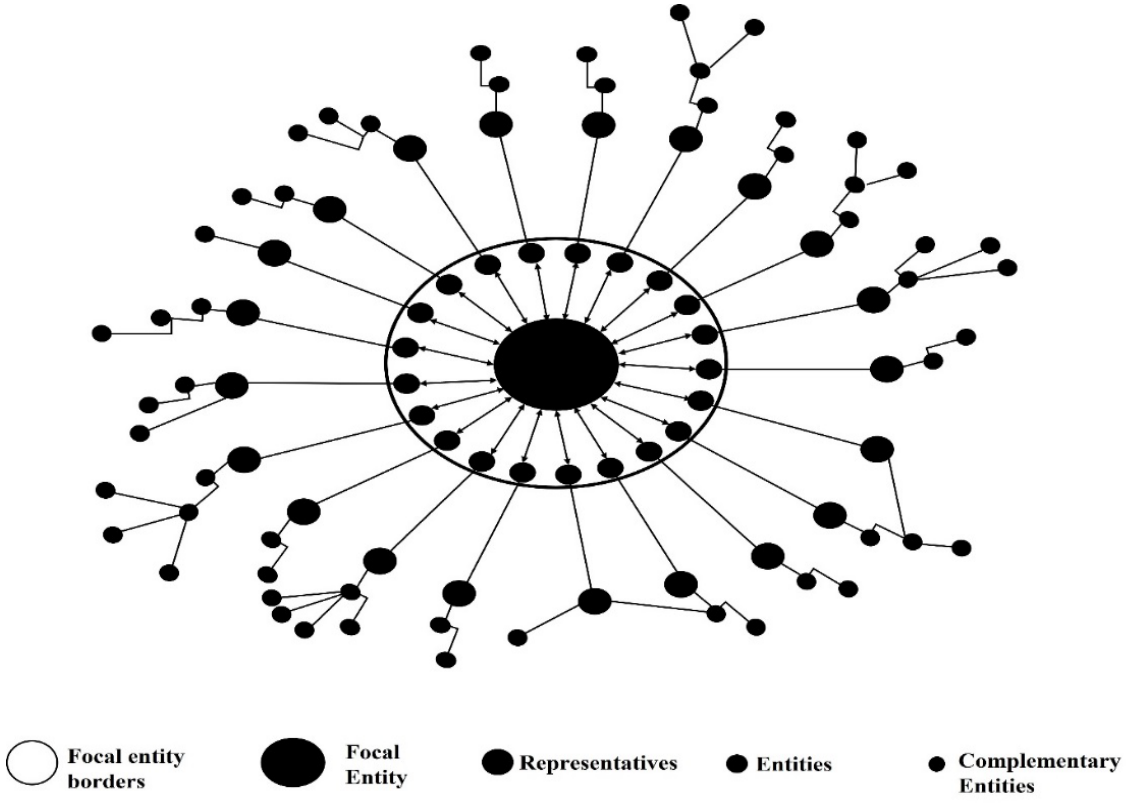

Figure 2. The Structure of Consortium Orchestration in The Innovation Ecosystem

5.1 Simulating the Innovation Ecosystem with a Consortium Orchestrator

The simulation model's interface window as shown in figure.2, is used in this part to display several graphs and indicators that will be used to analyze the complicated system. The influence of having varying values of input parameters is retrieved from key performance indicators (KPIs) values. These metrics quantify the IE's overall

performance by aggregating individual behaviors and averaging the resulting collection of individual values. This clarifies the agent-based modeling's bottom-up methodology.

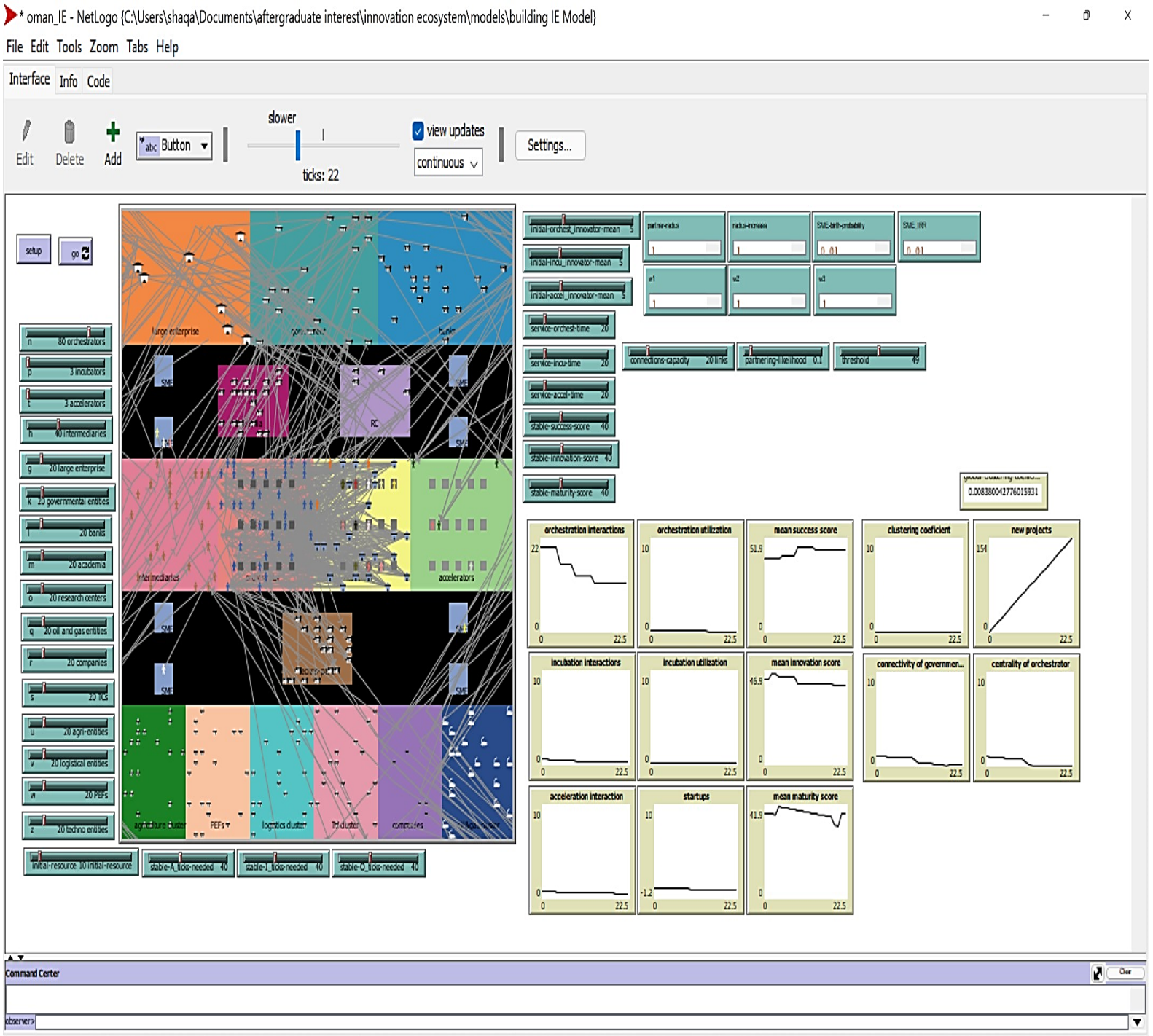

Fig 3. Simulation Model of Innovation Ecosystem with a consortium orchestrator Using Netlogo.

6. Discussion of Results

The created model aims to identify the elements that affect the harmony of an innovation ecosystem and explore various orchestrating policies that may be used to maintain the proper alignment of agents. As was already discussed,

the dynamic environment is made up of innovation agents, each of whom gives resources and expertise that are at any given moment pertinent to the value proposition. Each agent interacts with other agents to trade any necessary information or resources in response to demand. As a result, various alliances develop amongst agents. Additionally, each agent has a unique set of characteristics that characterize it and set it apart from other agents. Market share, the degree of interaction with other agents, type of resources, etc. are examples of these factors. A minimum market share value must be introduced to symbolize the beginning of a potential interaction, for example, the value of an agent's market share may decide whether or not an interaction might occur. However, it is not mandatory to rely solely on market share values; other financial measures, such as revenues, may also be taken into account.

Because not every actor would be biased toward just one financial metric, we often adopt a weighted score of financial metrics when developing our model in order to account for all the selection criteria that could have been used in a real, dynamic market context. The model is focused on providing KPIs of the innovation ecosystem with which a policy makers may analyze their recommended policies and strategic settings by analyzing the impact of the alteration. These KPIs are produced from the aggregation of the factors that characterize the system's agents. For instance, the innovation ecosystem growth rate, the number of new startups, etc. It should be mentioned that because some of those KPIs cannot be directly correlated to the performance of the orchestrators, the policy designers must carefully choose them. The attempt of simulation a hypothetical innovation ecosystem using Netlogo software is shown in figure.2. The three primary components of the simulation model are displayed in the Netlogo software's interface window. These are the input parameters, the interaction environment (IE), which includes agents interacting in the IE, and the output monitors.

Plots and monitors show how each and every simulation model's unique set of contributing elements affects the results. For instance, the sliding buttons on the left-hand side of the window are designated to show the various input parameter values. A variety of input values are available for the user to choose from, allowing for the creation of different scenarios and the analysis of possible outcomes and their effects. For instance, the user will initially press the setup button, alter the input values collectively or individually in accordance with his or her viewpoints, and press the go button to see how the agents behave and determine the appropriate consequence through the indicated plots and monitors. In the addressed scenario, the number of orchestrators is kept high and the number of incubators and accelerators in the simulation model are reduced.

Therefore, both average innovation score (46.9) and maturity score (41.9) are lower than their corresponding stable values of (50). Less interactions are detected between the agents and incubators and accelerators, which represent only 0.2% of the total interactions occurred within the IE. However, the availability of orchestrators compensates the shortages of incubators and accelerators as in a decentralized approach where most agents tend to maintain connections with the focal entities. Due to the lack of incubators and accelerators, no relevant clustering activities were detected, where in this case agents are not matured enough in terms of the level of innovation and networking capabilities. Consequently, the establishment of new matured startups is relatively low; as almost no startup was established due to the scarcity of mentoring and financial support which are mainly provided by incubators and accelerators. On the other side, the level of governmental interactions is at an acceptable level, which indicted their tendency of forming links as with orchestrators and other matured and well-established entities such as large enterprises. The overall global clustering coefficient indicator shows a low value of 0.008. This implies the effect of not having sufficient incubators and accelerators.

7. Conclusion

This paper aimed to explain the phenomenon of establishing innovation ecosystem and proposed a new approach to tackle the complexity associated with orchestrating such systems. The nature of innovation ecosystem was addressed by developing An Agent-based modeling simulation. The calibrated simulation model can serve as a what-if analysis tool that policymakers may use to evaluate and confirm their strategic recommendations without having to carry out a real experiment. Therefore, our future work will mainly concentrate on adopting real data in the model for the purposes of calibrating the model and ensuring its functionality.

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Biography

Emad Summad is an Assistant Professor at the Department of Mechanical and Industrial Engineering, Sultan Qaboos University, Muscat, Oman. Emad Summad has a BSc, MSc, and Ph.D. in Industrial Engineering. He specializes in policy issues for innovation and entrepreneurship in the knowledge-based economy. Dr. Summad's research interest includes innovation ecosystem orchestration mechanisms & partner selection for open innovation. He promotes technology-based lean startups.

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Alzahra Al Kindi is a fresh minded thinker with a finance and economics BSc from Sultan Qaboos University. She started her career years before graduation and continued on the marketing field due to its spontaneity, energy and innovation. Partnering with the CEO of Gate10, they founded the now 6-figure business in the hopes of bringing innovative marketing solutions to Oman and helping to raise brands up to the international standard.