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Comprehensive Framework of Influential Factors on Innovation Ecosystem Resilience: Using Meta-Synthesis and Structural Equation Modelling

S. Abdi[a], M. Yazdani*[b], E. Najafi[a]

[a] *Department of Industrial Engineering, Science and Research branch, Islamic Azad University, Tehran, Iran*
[b] *Department of Industrial Engineering, Qazvin Branch, Islamic Azad University, Qazvin, Iran*

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ABSTRACT

Resilience of the innovation ecosystem as a driving force of knowledge-based economies, provides relative stability against environmental disruptions. Currently, finding a comprehensive framework of factors influencing innovation ecosystem resilience is a major concern of policymakers to effectively select policies of resilience improvement. This research analyzes and presents a comprehensive framework of factors influencing innovation ecosystem resilience by using meta-synthesis approach, confirmatory factor analysis and structural equation modelling. These factors include Adaptability, Innovation Management, Recovery Capability, Culture, Resource, Robustness, Strategic Planning, and Vulnerability. In this paper, Iranian Power Innovation Ecosystem is considered as a case study. The computational results indicate that vulnerability and adaptability are the most influential factors on innovation ecosystem resilience, while recovery capacity and resiliency culture are less impactful factors. The innovative aspects of this study include the use of meta-Synthesis method for systematic review, content analysis, and categorization of influential factors, as well as the presentation of a comprehensive framework based on factor analysis and structural modelling. The findings of this research assist innovation ecosystem policymakers in evaluating various factors and planning accordingly to achieve their desired goals based on the aforementioned framework.

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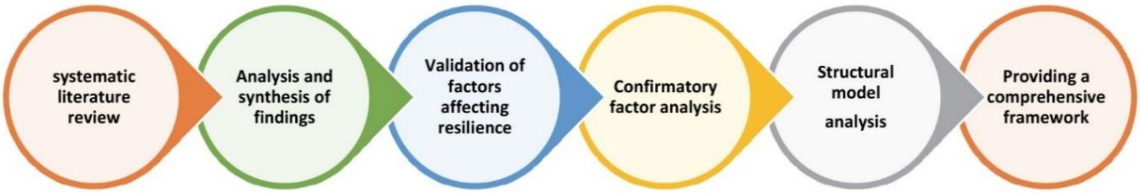
Graphical Abstract



1. INTRODUCTION

Today, it is increasingly important for organizations to adjust their innovation strategy from organization-based to ecosystem-based (1). Due to dynamics social complexity of innovation and concept of complex adaptive systems; policymakers change their mind from an innovation system to an innovation ecosystem (2). Innovation ecosystem is a set of innovation entities which interact in a dynamic environment (3) that enables collective work to empower knowledge flow, supporting technology development, and creating innovation (4). Due to significant role of innovation as a source of competitive advantage, policymakers are seeking solutions to improve the performance of the innovation ecosystem.

The resilience of an innovation ecosystem refers to its capacity to absorb disturbances, and reorganize throughout undergoing changes, to maintain the core functions. This resilience significantly influences the ecosystem's overall performance (5). Unsuitable resilience assessment can lead to weak strategies to

*Corresponding Author's Email: Mehdi_yazdani2007@yahoo.com (M. Yazdani)

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reduce the severity effects of possible disruption and inappropriate adaptation to environmental conditions (5) Resilient systems are characterized by system characteristics that affect different components of resilience, such as robustness, redundancy, reliability, readiness, vulnerability, sustainability, and adaptive capacity (5). Bai and Li (6) emphasized that the stability and development of the innovation ecosystem, are enhanced by improving internal structure, better adapting to external environment changes, and having the ability to restore after damage.

As stated, the main reason for this article's focus on research about the resilience of the innovation ecosystem is to help preserve and improve its performance in different situations by making it resilient against various crises. This makes the knowledge-based economy in the countries to enjoy stability and prosperity and improve the level of well-being of human societies.

Resilience evaluation methods vary depending on evaluation objectives and the characteristics of the study system. Hosseini et al. (7) categorized them into two quantitative and qualitative methods. The concept of resilience requires a comprehensive framework of factors that influence on resilience, as well as an integrated assessment for a better understanding, which we have not noticed in previous provided researches (8). So, we seek to develop a comprehensive framework of factors affecting the resilience of the innovation ecosystem by using meta-synthesis and structural equation modeling technique in our study. Hosseini et al. (7) identified economical, engineering, social and organizational as four main area of resilience. Meanwhile other researchers such as Nylund et al. (9) define innovation ecosystems as a loose network of organizations and individuals collaborate and evolve together to create value through innovation. Also, according to Xiao and Cao (10) the resilience of a whole system is achieved through its components resiliency. Therefore, it is essential for all actors of the ecosystem including different organizations, to be resilient to achieve the overall resilience of the ecosystem. with this in mind, our literature review focus on the system resilience and organization resilience. Then we analyzed and presented a comprehensive framework of factors influencing innovation ecosystem resilience by using meta-synthesis approach, confirmatory factor analysis (CFA) and structural equation modelling (SEM). Our statistical population consisted of actors of the *Iranian Power Innovation Ecosystem.*

In general, the contribution of this paper includes the presentation of a comprehensive framework of influential factors on innovation ecosystem resilience by using meta-synthesis and structural equation modelling.

The rest of the paper is structured as follows: Section 2 presents a research background, it covers past studies in the field of innovation ecosystem resilience, different systems and organizations, and related factors. Section 3 introduces problem definition and research method. Section 4 contains research findings include primary framework, CFA, SEM analysis and comprehensive framework of the factors affecting the resilience of the innovation ecosystem. Finally, conclusion and some suggestions for further research are presented in section 5.

2. RESEARCH BACKGROUND

Walker et al. (11) stated that resilience has four components: elasticity (the maximum amount a system can change before losing its ability for recovery), resistance, instability and panarchy. Herrera and Kopainsky (12) combined system dynamics (SD) and participatory approaches to assess resilience.

Egli et al. (13) investigated resilience and agent-based models (ABMs) in ecological and social-ecological systems by reviewing the literature. Bruneau et al. (14) presented a conceptual framework for defining the resilience of communities after an earthquake and quantitative measures of resilience. Sauser et al. (15) investigated the resilience of SMEs after a disaster event. In their study, resilience is defined as an adaptive capacity of SMEs to meet and achieve priorities and objectives in order to absorb and limit disruptions while maintaining service continuity. Henry and Ramirez-Marquez (16) proposed general criteria and a quantitative method to evaluate the resilience of systems. Sweetapple et al. (17) presented a framework to plan a reliable and resilient system through the integration of multi-objective optimization and reliability, robustness, and resilience assessment. Ahmadi et al. (18) proposed characteristics of prediction, absorption, adaptation and recovery for energy system resilience modelling. Tran et al. (19) provided a flexible conceptual framework that can be applied to a variety of systems. Biddle et al. (20) believed that most of the literature on the previous topic only deals with certain aspects such as absorptive and adaptive capacities in relation to the resilience of systems; while the rightfulness of institutions and transformative capacity have rarely been considered. Zhu et al. (21) studied the assessment of the infrastructure systems resilience using eight factors including: vulnerability, predictability, redundancy, adaptive capacity, speed, resourcefulness, interactions, and learning culture. Yu et al. (22) introduced Community Resilience Cost Index (CRCI) as a method for resilience assessment.

Burnard and Bhamra (23) reviewed the challenges of organizational resilience and declare that in order for an organization to be considered resilient, both active resilience (active participation and adjustment of a system in relation to change) and passive resilience (the ability to resist or absorbing disorders) are required.

Hillmann and Guenther (24) identified concepts such as awareness, sustainability, change, growth and performance for organizational resilience. Ma et al. (25) proposed an organizational resilience integrated model including three dimensions of cognitive, behavioural and contextual resilience. On the other hand, Hamel and Valikangas (26) determined organizational resilience challenges into four categories: cognitive, strategic, political and ideological. Chen et al. (27) used grounded theory to extract the main characteristics of organizational resilience. They indicated that organizational resilience includes five dimensions: financial, cultural, strategic, communication and learning resilience. But in other research, Annarelli et al. (28) considered adaptability, reliability, agility, effectiveness, flexibility, recovery level and recovery time. Lee et al. (29) provided a tool includes two main factors of adaptability and planning capacity and consists of thirteen indicators to measure and compare the resilience of organizations. McManus et al. (30) proposed a model called the "Relative Overall Resilience" (ROR), in which relative overall resilience consists of three factors: awareness of the situation, management of key vulnerabilities, and adaptive capacity. Rahi (31) also states the two dimensions of awareness and adaptability that are related to organizational resilience. Xiao and Cao (10) presented a theoretical model of organizational resilience. In their model an organization must become resilient at the individual, group and organizational levels; and the factors for each one is different. Sanchis and Poler (32) presented a quantitative approach to increase the resilience of the organization with a dynamic planning approach. Aleksić et al. (33) evaluated the potential of organizational resilience in SMEs in process industries using fuzzy mathematical modelling. Tong et al. (34) identified five key factors empower the resilience of the innovation ecosystem of high-tech companies, including resilience thinking, environmental uncertainties, tolerance threshold, evolutionary capacity and hidden resources. Roundy et al. (35) have shown that the interaction between ecosystem diversity and cohesion would result in ecosystem resilience.

Based on the literature review, the subject of measuring the resilience of the innovation ecosystem has received less attention, additionally a comprehensive framework of factors affecting the resilience of the innovation ecosystem based on a comprehensive qualitative research method has not been presented yet. Thus, the main objective of our research is to present a comprehensive framework of factors influencing innovation ecosystem resilience by using a systematic literature review, meta-synthesis approach and structural equation modelling. on the other hand, Innovation ecosystems not only vary in their architecture and internal collaboration models (36), but they also differ significantly in terms of actors, governance, investments, and business models. Therefore, the tailoring and adaptation of the resilience factors framework for the innovation ecosystem as a case study for Iran's Power industry highlights the novelty of this research.

3. PROBLEM DEFINITION AND RESEARCH METHOD

This research, through a systematic literature review and a holistic view, seeks to resolve the research gap stated in the background section of the research and answer the following question:

• What factors affect the resilience of the innovation ecosystem and how are they connected to resilience?

To answer the above question and present the results, it is necessary to follow steps shown in Figure 1.

The first and second steps are related to the systematic literature review, information extraction and analysis, combining the findings and extracting the primary factors affecting the resilience of the innovation ecosystem. In the third step, the validation of the extracted factors is done to present the primary framework. The concepts are categorized according to a scientific method and the overall outline of the primary framework is formed. For this purpose, the meta-synthesis method, which provides a systematic approach for researchers by combining past research, discovers new theme; is used. It should be

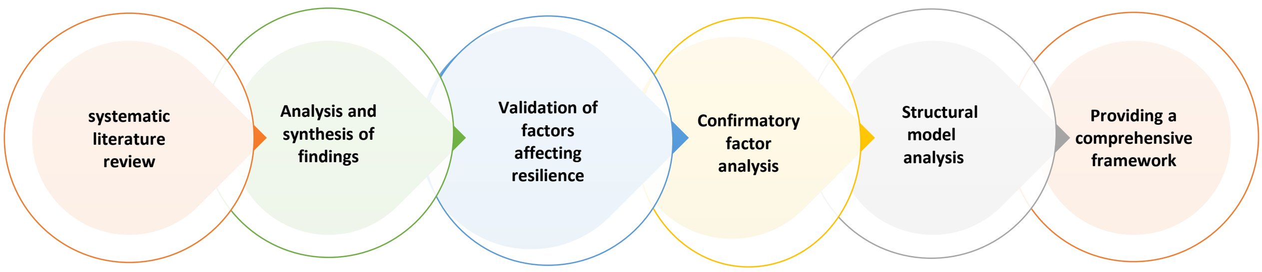

Figure 1. The steps of providing a comprehensive framework

noted that so far, based on our literature review, meta-synthesis approach has not been used in innovation ecosystem resilience studies. Sandelowski and Barroso (37) have presented a seven-step method in connection with the use of meta-synthesis method, which is more general. These steps consist of formulating the review questions; Systematic review of the literature; Selecting appropriate research articles; Extracting the results; Analyzing and synthesizing qualitative findings; validating and presenting findings (primary framework) that will be used in this research as well. It should be noted that after providing the primary framework, using confirmatory factor analysis and then structural model analysis, a comprehensive framework of factors affecting the resilience of the innovation ecosystem is finally presented.

4. FUNDING AND RESULTS

In this section, the findings of research are presented separately in related subsections. First, the primary factors affecting the innovation ecosystem resilience, which is the result of articles content analysis, and also how to validate these findings are presented. Then, in the continuation, the method of using confirmatory factor analysis and structural equation analysis to finalize the observed and latent variables as well as the test of various Hypothesized path is presented. Finally, based on the results, the comprehensive framework of factors affecting the resilience of the innovation ecosystem and additional explanations are presented.

4. 1. Systematic Literature Review In this research, we have taken a comprehensive approach to gather relevant information. The study includes articles from peer reviewed journals and prestigious conferences between 2002 and the first half of 2022 in Scopus and Web of Science. Also, to ensure an inclusive search, we have utilized Google Scholar. According to literature review, the keywords of "*system resilience*", "*ecosystem resilience*", "*organizational resilience*", and "*resilience assessment*" were used to search articles more comprehensively. Vast number of articles (217) were found in the initial research based on keywords. After reviewing the abstract and content of the articles and removing the articles with incomplete information or unrelated to the specified topic, finally we select 33 articles for full review and content analysis.

4. 2. Analysis and Synthesis of Findings Factors affecting the resilience of the innovation ecosystem recognized based on the content analysis of reviewed articles. Each concept identified in the articles was considered as a code, and then codes with similar meanings were grouped into categories. Ultimately, 60 concepts were extracted, leading to the identification of 8 categories including: culture, strategic planning, resources, innovation management, vulnerability, robustness, adaptability and recovery capability as shown in Table 1. Among these factors, adaptability was the most frequently mentioned, while innovation management was the least frequently referred to as shown in Figure 2.

TABLE 1. Extracted concepts and their categorizations

No.	Reference	Concept	Category
1	(13, 26, 29, 38-40)	Culture	Culture
2	(25, 41)	Risk Management Culture	
3	(26)	Relationship Resilience	
4	(13, 26, 41)	Interaction	
5	(38, 39)	Resilience Thinking	
6	(5, 7, 8, 24, 30, 42, 43)	Awareness- Sense Making	
7	(8, 9, 13, 20, 26, 42, 43)	Learning Culture	
8	(44 ,27 ,26)	Strategic Resilience	Strategic Planning
9	(2, 12, 16, 42, 45, 46)	Planning	
10	(38)	Flexibility in Organizational Strategy	
11	(9, 13, 45, 47, 48)	Resourcefulness	
12	(13, 16, 42, 49, 50)	Anticipation	
13	(16, 51)	Efficiency/Effectiveness	

No.	Reference	Concept	Category
14	(52 ,51 ,33 ,29 ,28 ,25)	Information Systems	Resources
15	[(34)	Financial Resources, Intangible Resources	
16	(53 ,46 ,21 ,14 ,7)	Cash Flow	
17	(54 ,28 ,25 ,21 ,18)	Social Capital	
18	(49 ,28)	Talent Diversity ‹Personal Skills	
19	(55 ,6)	Enterprise Diversity	Innovation Management
20	(56 ,55 ,45 ,41 ,34 ,33 ,27 ,15 ,6)	Internal Structural Complexity	
21	(6)	Robust Organizational Structure	
22	(56 ,53 ,34 ,10)	Entrepreneurial Talents	
23	(34 ,6)	Diversity of Innovation Subjects	
24	(6)	Innovation Capital Investment	
25	(6)	Innovation Output	
26	(34)	Technology Stream	
27	(56 ,34)	Redundancy	Vulnerability
28	(55 ,48 ,6)	Vulnerability	
29	(6)	Vulnerability Management	
30	[(6)	Business Environments	
31	(6)	Governance Condition	
32	(58 ,57 ,53 ,49 ,46 ,45 ,43 ,28 ,21 ,14 ,7)	Environmental Uncertainty	Robustness
33	(60 ,59 ,51 ,42 ,28 ,21)	Sustainability	
34	(61 ,30)	Resistance	
35	(56 ,39)	Overall Resilience Strategy	
36	(51)	Robustness	
37	(34)	Tolerance	
38	(62 ,28 ,24 ,11 ,6)	Absorption Capacity	Adaptability
39	(63 ,51 ,23 ,11)	Business Continuity	
40	(16)	Adaptive Capacity, Adaptability	
41	(53 ,46 ,45 ,38 ,17 ,14)	Evolutionary Ability	
42	(34 ,15)	Transformative Capacity	
43	(51 ,20-18 ,7)	Self-Organization	
44	(51)	Readiness	
45	(64 ,61 ,58 ,54 ,51 ,48 ,31-28 ,24 ,21-18 ,15 ,10 ,7)	The Appropriate Response of Organization	Recovery Capability
46	(34)	Coping Capacity	
47	(64 ,20)	Improvisation	
48	(58 ,57)	Latitude	
49	(66 ,65 ,60 ,59 ,57 ,51 ,42 ,28 ,23)	Flexibility	
50	(23)	Self-Adjustment	
51	(64 ,24)	Self-Adaptation	
52	(10)	Recovery	
53	(11)	Recovery Time and Speed	
54	(57 ,49 ,45 ,34 ,28)	Agility	
55	(6)	Recovery Costs	

No.	Reference	Concept	Category
56	(6)	Recovery Level	
57	(67 ,55 ,51 ,50 ,19 ,18 ,16 ,7)	Growth	
58	(70-68 ,60 ,59 ,51 ,49 ,46 ,42 ,28 ,21 ,14)	Performance Level	
59	(49 ,28)	Ability to Reconfigure	
60	(22 ,18)	Availability	

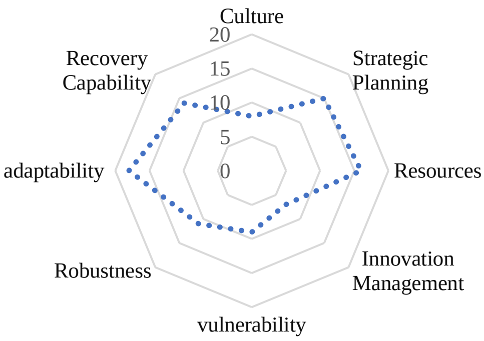

Figure 2. Frequency of extracted factors from articles

4. 3. Validation of Factors Affecting the Resilience of the Innovation Ecosystem In this step of the research, for validation concepts and their related categories, we used experts' opinion. in a purposeful way nine experts selected from university and industry who were familiar with the power innovation ecosystem. Academic experts must have participated in at least one of the innovative technological projects in power innovation ecosystem, or have published research papers or books in the field of innovation. In connection with industrial experts, having a managerial position in one of the players of the innovation ecosystem, as well as a history of performing activities related to the performance indicators of power innovation ecosystem, have been considered. To assess the importance of each concept, we employed Lawshe's content analysis method (71). Each expert was asked to evaluate the importance of each concept using a triple spectrum consisting of three categories: "*essential*", "*useful but not necessary*" and "*not necessary*".

The Content Validity Ratio (CVR) and the Numerical Average of Judgments (NAJ) for each concept were computed That $CVR = (ne - \frac{N}{2})/\frac{N}{2}$, where " ne " represents the number of experts indicating "essential" and "N" represents the total number of experts. Additionally, we computed the Content Validity Index (CVI) for each category. That $CVI = \sum CVR/Retained\ Numbers,\ and\ "Retained\ Numbers"$ present the number of approved concepts. the attribute which has values greater than 0.78 have been accepted and shown in Table 2.

TABLE 2. CVR, CVI for concepts and their related categories

No.	Concept	Category	CVR	NAJ	CVI
1	Culture		1.00	2.00	
2	Risk Management Culture		0.78	1.89	
3	Relationship Resilience		1.00	2.00	
4	Interaction	Culture	1.00	2.00	94%
5	Resilience Thinking		1.00	2.00	
6	Awareness- Sense Making		1.00	2.00	
7	Learning Culture		0.78	1.89	
8	Strategic Resilience		0.78	1.89	
9	Planning		0.78	1.89	
10	Flexibility in Organizational Strategy		1.00	2.00	
11	Resourcefulness	Strategic Planning	0.78	1.89	87%
12	Anticipation		1.00	2.00	
13	Efficiency		0.78	1.89	
14	Effectiveness		1.00	2.00	

No.	Concept	Category	CVR	NAJ	CVI
15	Information Systems	Resources	1.00	2.00	93%
16	Financial Resources		1.00	2.00	
17	Intangible Resources		0.78	1.89	
18	Cash Flow		0.78	1.89	
19	Social Capital		1.00	2.00	
20	Personal Skills		0.78	1.89	
21	Enterprise Diversity		1.00	2.00	
22	Internal Structural Complexity		1.00	2.00	
23	Robust Organizational Structure		1.00	2.00	
24	Entrepreneurial Talents	Innovation Management	1.00	2.00	91%
25	Diversity of Innovation Subjects		0.78	1.89	
26	Innovation Capital Investment		0.78	1.89	
27	Innovation Output		1.00	2.00	
28	Technology Stream		1.00	2.00	
29	Redundancy	Vulnerability	1.00	2.00	89%
30	Vulnerability		1.00	2.00	
31	Vulnerability Management		1.00	2.00	
32	Business Environments		0.78	1.89	
33	Governance Condition		0.78	1.89	
34	Environmental Uncertainty		0.78	1.89	
35	Sustainability	Robustness	1.00	2.00	94%
36	Resistance		1.00	2.00	
37	Overall Resilience Strategy		1.00	2.00	
38	Robustness		1.00	2.00	
39	Tolerance		0.78	1.89	
40	Absorption Capacity		0.78	1.89	
41	Business Continuity		1.00	2.00	
42	Adaptive Capacity	Adaptability	1.00	2.00	87%
43	Evolutionary Ability		1.00	2.00	
44	Transformative Capacity		0.78	1.89	
45	Self-Organization		1.00	2.00	
46	Readiness		1.00	2.00	
47	The Appropriate Response of Organization		1.00	2.00	
48	Coping Capacity		0.78	2.00	
49	Improvisation		0.78	2.00	
50	Latitude		0.78	2.00	
51	Flexibility		0.78	2.00	
52	Self-Adjustment		0.78	2.00	
53	Self-Adaptation		0.78	2.00	
54	Recovery	Recovery Capability	1.00	2.00	93%
55	Recovery Speed		0.78	1.89	
56	Agility		1.00	2.00	
57	Recovery Costs		0.78	1.89	
58	Recovery Level		1.00	2.00	
59	Growth		0.78	1.89	
60	Performance Level		1.00	2.00	
61	Ability to Reconfigure		1.00	2.00	
62	Availability		1.00	2.00	

According to the results obtained from the meta-synthesis and validation method, eight factors affecting the resilience of the innovation ecosystem include culture, strategic planning, resources, innovation management, vulnerability, robustness, adaptability and recovery capability are discovered that formed the base of primary framework.

4. 4. Confirmatory Factor Analysis As presented in previous section, the primary framework includes eight factors. In this step, based on confirmatory factor analysis, all factors were considered as latent variables. Then, in order to measure and analyze them, a number of observed variables that will form the questionnaire were identified. These observed variables were formulated based on the analysis and Synthesis of findings from the literature review (Section 4.2). Therefore, for each latent variable, a number of observed variables have been recognised; and questionnaire with 39 observed variable (questions) was prepared. Therefore, this researcher-made questionnaire was used to survey a statistical population consisting of all actors of Power Innovation Ecosystem that includes the Deputy of Research of Ministry of Energy, Power Generation, Transmission & Distribution Company, Universities, Power Research Institute, Venture Capitalists, Incubators, and Knowledge-based companies. In this questionnaire 5-point Likert scale (Strongly Disagree=1, Disagree=2, Neutral=3, Agree=4, Strongly Agree=5) used for each question. It is important to note that the questionnaires were collected in both paper and electronic forms.

The process of collecting and analysing data by research made questionnaire was done in two stages:

- First stage: selecting 30 experts familiar with the subject, conducting factor analysis and finalizing the questionnaire
- The second stage: sending the final questionnaire to a larger number of experts, collecting the completed ones and analyze through the structural modelling equations.

In the first stage, 30 experts familiar with the Iranian power innovation ecosystem were selected using the snowball method in a purposeful manner, Subsequently, we distributed the initial questionnaire consisting of 39 observed variables related to 9 latent variables, to these experts. All the questionnaires were collected and utilized in confirmatory factor analysis. In factor analysis, it is determined, which observed variables are suitable to descript a latent variable and which are not. after removing unsuitable observed variables, the model is run again until finally all the remaining observed variables are recognized as appropriate. This research used Partial Least Squares (PLS) method that is a non-parametric multivariate statistical technique that allows comparison between multiple observed variables and multiple latent variables. PLS is one of a covariance-based statistical methods which are often referred to as structural equation modeling that designed to cope with problems in data specifically, small datasets, missing values and multicollinearity.

The data of the collected questionnaires were entered into the *SmartPLS* software. The standard deviation associated with all observed variables was examined if it is equal to zero, that variable was removed, and values less than 0.3 were also re-examined and corrected as suggested by Lowry and Gaskin (40), the software was configured for confirmatory factor analysis with the following setting:

- PLS Algorithm
- Weighting Scheme: Factor
- Maximum Iteration:1000
- Stop Criterion:7

After running the software with the aforementioned settings, the results of the confirmatory factor analysis were examined using *factor loading* which is visualized in the software as *Outer Loading* (Figure 3). when the factor loading of an observed variable exceeds 0.6, it is accepted, otherwise there is no significant relationship between this variable and the associated latent variable (44).

As shown in Figure 3 and According to Hair et al. (44), there is no significant relationship between the observed variables *Specialized Networks* and *Organizational Structure* with the "*Resources*" latent variable, having factor loadings of 0.492 and 0.391 (they are less than 0.6). Therefore, these two variables are removed from the model. But since the factor loadings of other relationships is greater than 0.6, it can be concluded that there is a significant relationship between the related observed and latent variables. for example, factor loading index between the observed variables *Readiness*, *Self-Organization* and *Flexibility* with the "*Adaptability*" latent variable, are 0.826, 0.892 and 0.804, respectively; Therefore, these variables are maintained in the model. This fact is also true in relation to other variables in the model.

The software is run again with the previous settings. Figure 4 shows the obtained results that is based on the updated factor load values. There is a significant relationship between all the observed and latent variables in the modified model. As shown in Figure 4, there is no factor loading less than 0.6. for example, factor loading index between the observed variables *Redundancy*, *Business Environments*, *Vulnerability Management* and *Governance Conditions* with the "*Vulnerability*" latent variable, are 0.643, 0.750, 0.892 and 0.843, respectively; Therefore, there is a significant relationship between all the mentioned observed and latent variables in this modified model.

After ensuring the establishment of a meaningful relationship between the observed variables and latent variables; it is essential to analyse their validity and

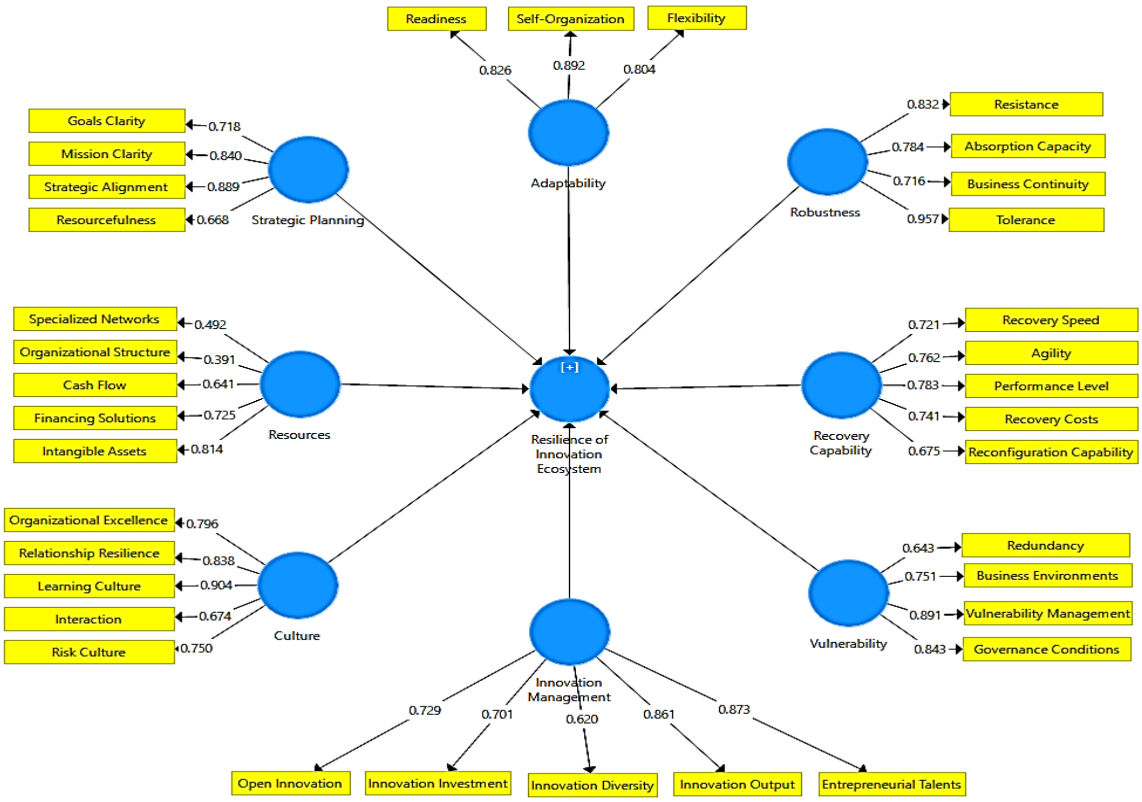

Figure 3. Factor loading values of observed variables and related latent variables in the primary model

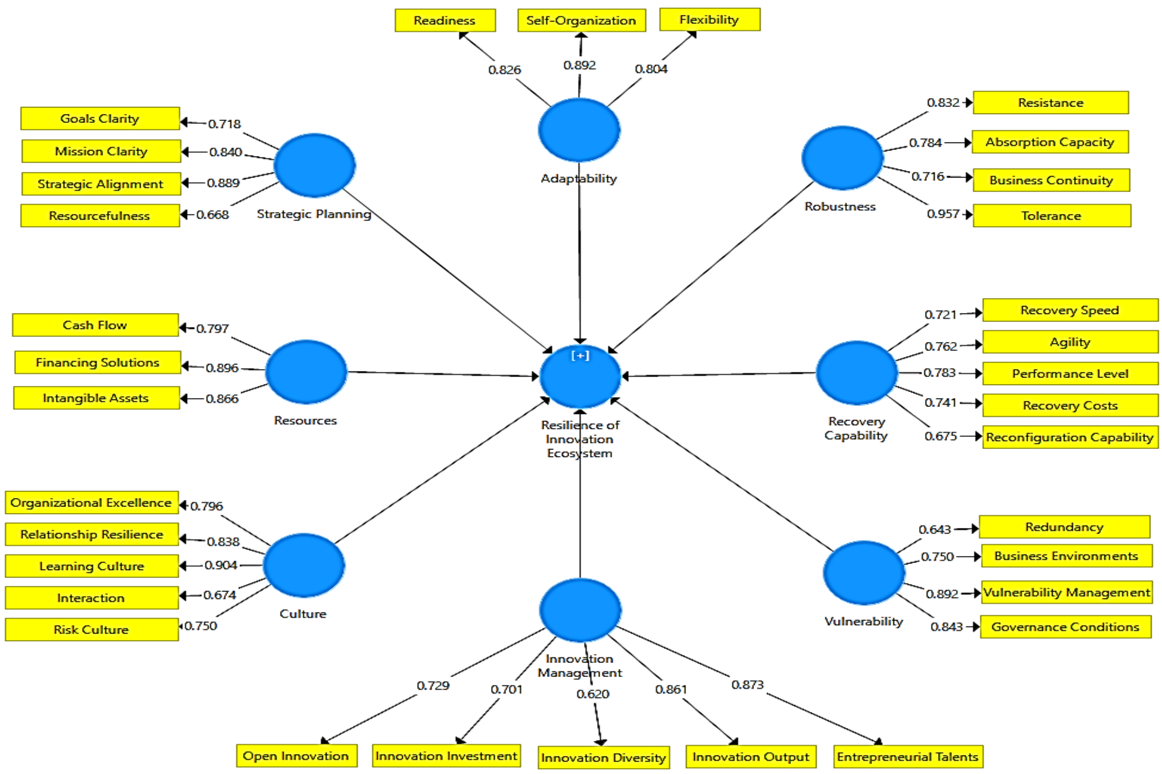

Figure 4. Factor loading values of observed variables and related latent variables in the modified model

reliability. To achieve this, several measures were calculated and analyzed, including *Cronbach's alpha*, *Composite Reliability (CR)*, *Factor loading*, and *Average Variance Extracted (AVE)*. Reliability analysis is conducted for the scales using Cronbach's alpha. Normally reliability coefficient of Cronbach's alpha ranges between 0 and 1. Greater or equal to 0.80 for a good scale, 0.70 for an acceptable scale and 0.60 for a scale for exploratory purposes (72). Composite reliability (CR) is a preferred alternative to Cronbach's alpha as a test of convergent validity in a reflective model. Composite reliability varies from 0 to 1, with 1 being perfect estimated reliability. Average variance extracted (AVE) may be used as a test of both convergent and divergent validity. AVE reflects the average communality for each latent factor in a reflective model. In general, According to previous researches, to create a model with appropriate validity and reliability, Cronbach's alpha value should be greater than 0.6 (73), and the value of the CR index should also be greater than 0.6 (47), in addition to the mentioned indicators, the AVE should also be greater than 0.5 (74) correspondingly the value of rho_A should be greater than 0.7 (75). As mentioned before, factor loading value should be more than 0.6. The aforementioned indicators are shown in Table 3; which shows that the framework of the factors affecting the resilience of the innovation ecosystem along with the relevant questions have appropriate validity and reliability.

TABLE 3. Validity and reliability indices associated with the modified framework after CFA

Construct	Item	Factor Loading	Cronbach's Alpha	Rho_A	Composite Reliability (Cr)	Average Variance Extracted (Ave)
	Readiness	0.826				
Adaptability	Self-Organization	0.892	0.796	0.835	0.879	0.708
	Flexibility	0.804				
	Open Innovation	0.729				
	Innovation Investment	0.701				
Innovation Management	Innovation Diversity	0.620	0.824	0.878	0.873	0.582
	Innovation Output	0.861				
	Entrepreneurial Talents	0.873				
	Recovery Speed	0.721				
	Agility	0.762				
Recovery Capability	Performance Level	0.783	0.796	0.811	0.856	0.544
	Recovery Costs	0.741				
	Reconfiguration Capability	0.675				
	Organizational Excellence	0.796				
	Relationship Resilience	0.838				
Culture	Learning Culture	0.904	0.854	0.876	0.896	0.634
	Interaction	0.674				
	Risk Culture	0.750				
	Cash Flow	0.797				
Resource	Financing Solutions	0.896	0.823	0.888	0.89	0.73
	Intangible Assets	0.866				
	Resistance	0.832				
	Absorption Capacity	0.784				
Robustness	Business Continuity	0.716	0.841	0.862	0.895	0.684
	Tolerance	0.957				
	Goals Clarity	0.718				
	Mission Clarity	0.840				
Strategic Planning	Strategic Alignment	0.889	0.784	0.798	0.863	0.615
	Resourcefulness	0.668				

Vulnerability	Redundancy	0.643	0.804	0.868	0.866	0.621
	Business Environments	0.750				
	Vulnerability Management	0.892				
	Governance Conditions	0.843				

4. 5. Structural Model Analysis After the confirmatory factor analysis, we investigated the causal relationship between the independent and dependent variables, as well as investigating the Hypothesis raised in the context of the relationship between the independent variables and the dependent variable of innovation ecosystem resilience in the primary framework. Then, based on confirmed and meaningful Hypothesized path, a comprehensive framework of factors affecting the resilience of the innovation ecosystem was formed. The Hypothesis:

- H1: The resilience of innovation ecosystem is influenced by the adaptability factor (AD ⇨ RE)
- H2: The resilience of innovation ecosystem is influenced by innovation management factor (IM⇨RE)
- H3: The resilience of innovation ecosystem is influenced by the recovery capability factor (RY⇨RE)
- H4: The resilience of innovation ecosystem is influenced by the culture factor (RC ⇨ RE)
- H5: The resilience of innovation ecosystem is influenced by the resources factor (RS ⇨ RE)
- H6: The resilience of innovation ecosystem is influenced by the robustness factor (RO ⇨ RE)
- H7: The resilience of innovation ecosystem is influenced by the strategic planning factor (SP ⇨ RE)
- H8: The resilience of innovation ecosystem is influenced by the vulnerability factor (VU ⇨ RE)

As stated, at this stage of structural model analysis, we ensured the significance of the relationships between the observed variables related to each latent variable. Additionally, we verified the validity and reliability of the entire model. Subsequently the questionnaire was sent to a large number of experts from the target community. A total of 185 correct questionnaires were collected from different actors within the innovation ecosystem, and the structural model analysis process was performed in *SmartPLS* software.

The respondents must be familiar with the power innovation ecosystem. They should participate in at least one of the innovative technological projects in power innovation ecosystem, or having an organization position in one of the players of the innovation ecosystem, as well as a history of performing activities related to the performance indicators of the power innovation ecosystem. The personal information of the respondents is in Table 4. The majority of respondents had a master's degree. The gender of most of them was male and they were between 35 and 50 years old.

TABLE 4. Descriptive statistics of personal information

No.	Category	Item	Frequency
1	Gender	Male	160
		Female	25
2	Age	Under 35	37
		35–50	106
		Over 50	42
3	Education level	BS	11
		MS	123
		PHD	51

The settings applied in software to analyse the structural model are as follows:

- Bootstrapping (complete)
- Subsample: 5000
- Weighting Scheme: path
- Maximum Iteration:1000
- Stop Criterion:7

Bootstrapping option has been used to determine the statistical significance of the path coefficient and to calculate the t-values in this study. In Table 5, for each Hypothesized path, the indicators of *path coefficient*, *standard deviation*, *t-statistic*, *p-value* and Final Result are presented. According to the values in Table 5, it can be concluded that all the Hypothesized path with the t-values above 1.96 (α =0.05; two-sided test) and p-value less than 0.05 are significant with a probability of about 95% and the Hypothesized path with the t-values above 2.58 (α =0.01; two-sided test) and p-value less than 0.01 are significant with a probability of about 99% (74, 75).

According to the stated conditions, the t-values of the hypothesized path of AD and RE is 3.964, which is above 1.96 (α =0.05; two-sided test) and p-value is 0. So, the hypotheses path of AD and RE of the inner model is statistically significant with a probability of about 95%. It means that resilience of innovation ecosystem is influenced by adaptability factor.

The t-values of the hypothesized path of IM and RE is 1.981, which is above 1.96 (α =0.05; two-sided test) and p-value is 0.033. So, the hypotheses path of IM and RE of the inner model is statistically significant. It means that resilience of innovation ecosystem is influenced by Innovation Management factor.

Another t-values of the hypothesized path of RY and RE is 2.062, which is above 1.96 (α =0.05; two-sided test) and p-value is 0.039. So, the hypotheses path of RY and RE of the inner model is statistically significant. It means that resilience of innovation ecosystem is influenced by Recovery Capability factor.

Another t-values of the hypothesized path of RC and RE is 2.101, which is above 1.96 (α =0.05; two-sided test) and p-value is 0.036. So, the hypotheses path of RC and RE of the inner model is statistically significant. It means that resilience of innovation ecosystem is influenced by Culture factor.

The t-values of the hypothesized path of RS and RE is 2.403, which is above 1.96 (α =0.05; two-sided test) and p-value is 0.016. So, the hypotheses path of RS and RE of the inner model is statistically significant. It means that resilience of innovation ecosystem is influenced by Resources factor.

Another t-values of the hypothesized path of RO and RE is 2.777, which is above 1.96 (α =0.05; two-sided test) and p-value is 0.005. So, the hypotheses path of RO and RE of the inner model is statistically significant. It means that resilience of innovation ecosystem is influenced by Robustness factor.

The t-values of the hypothesized path of SP and RE is 3.307, which is above 1.96 (α =0.05; two-sided test) and p-value is 0.001. So, the hypotheses path of SP and RE of the inner model is statistically significant. It means that resilience of innovation ecosystem is influenced by Strategic Planning factor.

The t-values of the hypothesized path of VU and RE is 9.518, which is above 1.96 (α =0.05; two-sided test) and p-value is 0. So, the hypotheses path of VU and RE of the inner model is statistically significant. It means that resilience of innovation ecosystem is influenced by vulnerability factor.

4. 6. Providing a Comprehensive Framework and Discussion

According to the results (α=0.05) of Table 5 and the confirmed Hypothesis, the comprehensive framework of factors affecting the resilience of the innovation ecosystem is shown in Figure 5.

TABLE 5. Analysis of the structural model and Result of Hypothesis

Hypothesized Path (Inner Model)	Coefficient Sample Mean	Standard Deviation	T-Statistics (O/STDEV)	P-Values	Results (α=0.01)	Results (α=0.05)
H1: (AD ⇨ RE)	0.258	0.068	3.964	0	supported	supported
H2: (IM ⇨ RE)	0.094	0.041	1.981	0.033	Not supported	supported
H3: (RY ⇨ RE)	0.165	0.073	2.062	0.039	Not supported	supported
H4: (RC ⇨ RE)	0.102	0.048	2.101	0.036	Not supported	supported
H5: (RS ⇨ RE)	0.125	0.052	2.403	0.016	Not supported	supported
H6: (RO ⇨ RE)	0.161	0.058	2.777	0.005	supported	supported
H7: (SP ⇨ RE)	0.262	0.083	3.307	0.001	supported	supported
H8: (VU ⇨ RE)	0.498	0.052	9.518	0	supported	supported

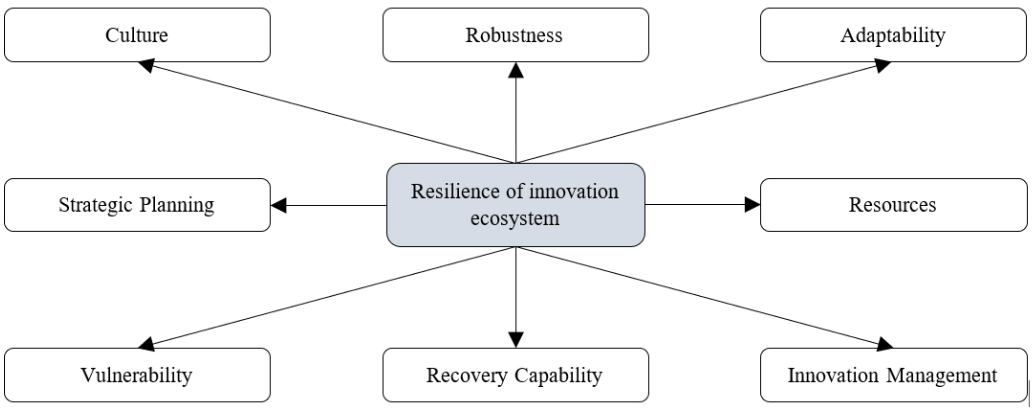

Figure 5. The comprehensive framework of factors affecting the resilience of the innovation ecosystem

Each factor of aforementioned framework is described as follows:

4. 2. 1. Culture as an Influent Factor on Innovation Ecosystem Resilience The culture factor in a resilient innovative ecosystem refers to concepts such as Resilience thinking culture, Organizational Excellence, Relationship Resilience, Interaction, Risk Culture and Learning Culture. Resilience thinking culture among the actors of the innovation ecosystem has an important effect on the formation of the resilient innovation ecosystem. This culture includes resilience thinking at the individual level and at the organizational level in the entire ecosystem. Resilience thinking at the individual level refers to the spirit of solidarity and cooperation among employees, and the stronger this thinking is with the formation of resilient relationships and networks between stakeholders; The greater the flexibility of the organization and subsequently the entire ecosystem has increased so that the innovation ecosystem can unite in the face of crisis and create good strategic guidelines to deal with such situations (34). Resilience thinking along with raising awareness enables organizations to anticipate potential crises in the ecosystem to reduce the costs of crises when they occur (34). The culture of an organization shapes the interactive spirit of employees and their commitment to the organization. It encourages them to have a long-term commitment to the organization and they took appropriate steps towards organizational excellence. Risk management culture can be defined as the process of identifying, analyzing, monitoring and developing plan to response the risks to an acceptable level at an acceptable cost in different organization. In fact, risk management involves understanding the threats that can potentially affect performance and resilience. Organizational learning is one of the most important cultural components of a resilient organization, which helps the organization in gaining lessons learned from the failures of similar organizations, raises awareness in the direction of resilience and aids in planning for its improvement. Furthermore gives meaning to the cooperation of all employees of an organization, in this direction communication resilience helps organizations to create mutually beneficial relationships between different stakeholders enabling them to effectively address crises (27).

4. 2. 2. Strategic Planning as an Influent Factor on Innovation Ecosystem Resilience Strategic resilience in an organization means achieving a balance between strategic stability (27) and flexibility in the organization's strategic plans to deal with various types of disruption, which requires that destructive events be predicted in the first step and its adverse consequences be limited (76). Clarity in Goals and Mission, Strategic Alignment and Resourcefulness are elements of Strategic resilience. That means Mission, vision and long-term, mid-term and short-term objectives should clearly define at different levels of organizations in innovation ecosystem. Strategic Alignment in ecosystem means that Strategic goals aligned with operational plans of different organization levels. Resourcefulness can be further considered as the ability to use resources (such as financial, physical, technological and informational) and human resources to meet set priorities and achieve goals. Anticipation of destructive events is one of the most important characteristics of resilience. This feature can be used to increase the adaptability and resistance of ecosystems by predicting and responding appropriately to malicious events. Anticipation is defined as the ability to learn, adapt, take preventive action, resist and recover from catastrophic events (18). After forecasting, the next crucial step is to prepare plans before the occurrence of destructive events in order to reduce vulnerability, prevent secondary disasters following the initial event, and establish short-term and long-term priorities after the disaster (21). To implement the prepared plans, it is essential to engage in effective planning, which involves setting priorities and mobilizing resources.

4. 2. 3. Resources as an Influent Factor on Innovation Ecosystem Resilience Resources are key factors in creating innovation ecosystem resilience and determine the ability of ecosystem actors to improve resilience (34). Resources include wide range of elements such as human resources, financial resources, social capital, diversity of talent and personal skills, organizational structure, information systems, and intangible assets. The proper management of resources improves the supportive infrastructure and provides the necessary implementation of the strategic plans of an organization. Generally, in a resilient innovation ecosystem, organizations have a suitable cash flow and several financing solutions.

One of the most important resources in recent years is information and communication technology, this kind of resource has increased the awareness by creating a flow of valuable information from within and outside the ecosystem. As a result, it plays an effective role in identifying, monitoring and controlling risks and ultimately helps to improve the resilience of the organization. Organizational structure is also considered as another important resource. The more complex the internal structure of the innovation ecosystem and the greater its diversity, the stronger its internal support capacity and higher its external resistance ability; and this is due to increase in the proportion of innovation-related sectors as well as multiple aligned activities (6). In general, a strong and flexible organizational structure enables organizations to grow by opportunities and improve their overall resistance to risk (34).

4. 2. 4. Innovation Management as an Influent Factor on Innovation Ecosystem Resilience Concepts such as Implementing Open Innovation, diversity of innovators and innovative subjects, Innovation Output and Appropriate Investments in innovative subjects refers to Innovation Management factor. Regarding to Open innovation concept organization in ecosystem does not just rely on their own internal knowledge and resources for innovation but also uses multiple external sources to drive innovation.

In natural ecosystems, biodiversity is a key factor that affects the resilience of the ecosystem. Similarly, in the innovation ecosystem, the diversity of innovators and innovative subjects is an important basis for establishing stable connections between various topics especially when faced with external shocks (6). In order to examine the diversity, flow and output of innovation in an innovation ecosystem, several indicators may be used. These may include: the number of registered patents, scientific publications including scientific articles and books, the proportion of researchers, the proportion of companies with dedicated research and development units, the number of research and development institutions, the number of products commercialized, the number of technology contracts in the technology market, etc. In an innovation ecosystem, greater diversity and innovation flow lead to enhanced adaptability to disturbances and by implementing proper planning, the resilience of the ecosystem against risks and disturbances can also be boosted.

4. 2. 5. Vulnerability as an Influent Factor on Innovation Ecosystem Resilience Vulnerability is the measure of an ecosystem's susceptibility to damage caused by a disruption. It is an undesirable concept, as it highlights the potential weaknesses in an ecosystem.

Redundancy, as one of the elements of evaluating vulnerability, refers to the degree to which player, or other units of an innovation ecosystem are replaceable and can meet functional needs in the event of destruction. Also, the stability of the business environment (economic, political and social conditions) and governance conditions are other elements that affect vulnerability. Vulnerability assessment has been developed in two areas of natural hazards and social science communities (5). In the field of natural hazards, vulnerability is defined as a combination of risk factors and the likelihood of ecosystem losses. In the field of social science societies, vulnerability focuses on inequality of sensitivity and exposure to threat (social equity). Vulnerability assessment is often used as a preventive planning tool or post-event analysis. Therefore, to enhance the innovation ecosystem's resilience, we must first identify and monitor vulnerable points. Then, we need to create and implement a timely plan to address any disruptions. One of the most influential factors influencing the vulnerability of actors in the innovation ecosystem is the governance, social, economic and political conditions, that govern the business environment. For example, the fluctuations of the economic cycle affect the political environment and the market environment. Therefore, it will have a direct impact on the business of innovation ecosystem actors (34).

4. 2. 6. Robustness as an Influent Factor on Innovation Ecosystem Robustness is defined as the ability of ecosystems' elements to withstand a certain level of disturbance without experiencing major change in their performance (14). A resilient innovation ecosystem must be resistant to uncertainties and disruptions and increase its tolerance level. Tolerance represents the persistence of the innovation ecosystem in uncertain situations. Ecosystem with a high level of tolerance have a positive attitude towards challenges and see them as an opportunity for ideation and innovative behaviour. Therefore, different players within the innovation ecosystem should improve absorption capacity of their organization which is defined as a measure of an ecosystem's ability to resist turbulent conditions and reduce consequences; make appropriate strategic planning for its improvement. We can outline the capacity to absorb and the level of tolerance and resistance of an organization expressed in robustness.

4. 2. 7. Adaptability as an Influent Factor on Innovation Ecosystem Resilience In general, Adaptability includes concepts such as Readiness, Flexibility and Self-Organization. Readiness means the innovation ecosystem can well prepared to respond to changes and disruptions. Flexibility in an innovation ecosystem causes to its players and their operational processes to have appropriate flexibility when it faces disruption and change. Self-Organization refers to ability of innovation ecosystem and its players to adapt and organize itself after disruptions. In this regard, adaptive capacity is very important. Adaptive capacity is defined as the extent to which an ecosystem can organize itself and overcome a disruptive event to restore ecosystem performance and overcome the disturbance without requiring any recovery activities. The knowledge learned through disruptive event, system reconfiguration, and trained personnel are the most adaptive activities that contribute to resilience (18). Actually, The concept of adaptive capacity is known as the ability for responding to disruption (5). Organizations in an innovation ecosystem need to focus on improving transformative capacity and evolutionary capacity in addition to adaptive capacity. Evolutionary capacity refers to the ability of an innovation ecosystem to gradually evolve and develop over time. Evolutionary capacity is built on adaptability and its purpose is to change or restore the environment in which the innovation ecosystem is set, so that the organization can develop in a better direction. Only by continuously evolving in a complex environment, the innovation ecosystem can resist environmental uncertainties and move towards sustainable development. A stronger evolutionary capacity results in a greater resilience value for the innovation ecosystem, allowing organizations to thrive and survive. On the contrary, if we face weaker evolutionary capacity, the adaptation capacity of the innovation ecosystem decreases; and a lower resilience value leads to weaker the organization's competitiveness and it encounter the risk of being vanished from the market (34).

4. 2. 8. Recovery Capability as an Influent Factor on Innovation Ecosystem Resilience The characteristic of a resilient ecosystem is its recovery and restoration ability after a destructive event. Concepts such as Recovery Speed, Agility, Performance Level, Recovery Costs and Reconfiguration Capability constitute the Recovery Capability factor in an innovation ecosystem. Different players of innovation ecosystem must have appropriate agility in order to deal with ecosystem change. It is necessary to focus on quickly recover and return to desired performance level in case of ecosystem disruption. In this regard, recovery speed and recovery cost are imperative components.

5. CONCLUSION AND FUTURE RESEARCH

Due to environmental uncertainties as well as the high speed of changes, organizations face various and intermittent threats. Therefore, the innovation ecosystem as a network of interconnected organizations such as universities, knowledge-based companies, etc. always faces destructive events such as international commercial limitations, competitive pressures, loss of experts, technology changes, financial crises, etc. Improving the resilience of this kind of ecosystems means enhancing the ability of its various actors to absorb, adapt and recover from these crises as well as increasing the assurance of maintaining its performance at the desired level; In return, these efforts could result in the sustainable development of countries. As stated before, we find that a holistic view of innovation ecosystem resilience has received less attention and so far, we do not explore any comprehensive framework of factors affecting resilience. Therefore, in this article, in response to the research question, we investigate what factors affect the resilience of the innovation ecosystem in a holistic perspective, and what are the connections between them and resilience.

First, based on the meta-Synthesis method, we systematically reviewed past related research, extracted the concept and analysed them. After validation of findings (based on content analysis method) we presented a primary framework of factors affecting the innovation ecosystem resilience. Then, in order to develop a comprehensive framework of affecting factors on resilience of the innovation ecosystem, Confirmatory factor analysis and structural equation modelling (SEM) were used. In the process of CFA, we identified 39 observed variables and used them to create a questionnaire then analysed information gathered from the target population. After removing any unrelated variables, in the second step, the structural model analysis was done and eight main hypothesized paths were tested to investigate the causal relationships between the identified factors (independent variables) and the dependent variable under the title of "resilience of the innovation ecosystem". Subsequently the comprehensive framework of affecting factors on resilience of the innovation ecosystem was presented. The results indicate that the factors of vulnerability and adaptability are the most important influencing ones on the resilience of the innovation ecosystem, and the recovery capacity and culture of resilience factors are less influential than other independent variables. In addition to the innovation of using the meta-synthesis qualitative method in order to provide the initial framework, finalizing the effective factors using the structural equation method, and providing a comprehensive framework of the effective factors on resilience of the innovation ecosystem, are also other novelties of this article. On the other hand, due to the diversity of players, the architecture and internal cooperation model modification of different innovation ecosystems, we benefited the experts' opinions of the power innovation ecosystem affiliated to Iranian power industry (as a case study), besides we tailored and coordinated the resilience assessment framework for the Iranian power innovation ecosystem, which are another witness for the uniqueness of this research.

According to the presented framework, the leaders and coordinators of the innovation ecosystem should emphasize several concepts, including the promotion of resilience thinking throughout the entire ecosystem. This includes resilience thinking at the individual level and the organizational level throughout innovation ecosystem; and it can shape the foundation of appropriate relationships and networking between stakeholders, improv the interactive spirit, increase commitment to the goals of the entire ecosystem, and finally making effective alliance against disruptions. Identifying vulnerable points and predicting destructive events are also among the most important features of resilience that should be considered by managers. This feature can be used to increase adaptability and robustness by appropriate anticipating and responding to disruptive events. In addition, forecasting, formulating and implementing strategic plans are also useful means to deal with all kinds of disturbances. Obviously, the proper management of resources (including human resources, financial resources, social capital, diversity of talent and personal skills, organizational structure, information systems, and etc.) improves the supportive infrastructures along with implementation of an organization's strategic plan. In addition, the more innovation policymakers support open innovation events, diversity of the innovation flow in an innovation ecosystem would become stronger and more stable; so, the ecosystem can easily adapt to disruptions. In order to create a resilient innovation ecosystem, different actors of the ecosystem also need to focus on the adaptive capacity and improve the transformative and evolutionary capacity.

The results of this research help the policy makers of technology development and innovation to evaluate the resilience of their governed innovation ecosystems based on the mentioned framework, and with the aim of achieving intended objectives, they would make appropriate strategies considering effective factors by identifying the strengths and weaknesses; and improve the ecosystem resilience. Considering the importance of innovation in improving the national economy, the realization of sustainable development of societies seems to be more accessible in practice by being more resilient in innovation ecosystem.

Due to variety of conditions governing the internal and external environment of innovation ecosystems, it is suggested that future research explores and analyzes the proposed framework in this article across various statistical communities, industries, and countries.

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Persian Abstract

چکیده

امروزه اکوسیستم نوآوری به عنوان موتور محرک اقتصاد دانش بنیان کشورها درنظر گرفته می شود و تاب آوری آن در برابر اختلالات و حفظ عملکرد آن، از دغدغه بسیاری از سیاست‌گذاران می باشد. بنابراین یافتن چارچوب جامعی از فاکتورهای موثر بر تاب‌آوری اکوسیستم نوآوری می‌تواند در این راستا راهگشا باشد که این پژوهش به دنبال ارائه چنین چارچوب جامعی با استفاده از رویکرد فراترکیب، تحلیل عاملی تأییدی و مدل‌سازی معادلات ساختاری است و اکوسیستم نوآوری وزارت نیروی ایران نیز به عنوان مطالعه موردی در نظر گرفته شده است. فاکتورهای چارچوب فوق الذکر عبارتند از انطباق پذیری، مدیریت نوآوری، توانمندی بازیابی، فرهنگ، منابع، استحکام و پایداری، برنامه‌ریزی راهبردی و آسیب‌پذیری. نتایج نشان می‌دهد که فاکتورهای آسیب‌پذیری و انطباق پذیری مهم‌ترین فاکتورهای تاثیرگذار بر تاب‌آوری اکوسیستم نوآوری و فاکتورهای ظرفیت بازیابی و فرهنگ تاب‌آوری کمترین تاثیر را در این ارتباط دارند. استفاده از روش فراترکیب برای مرور نظام‌مند ادبیات، تحلیل محتوا و دسته‌بندی فاکتورهای موثر و همچنین ارائه یک چارچوب جامع از آنها مبتنی بر تحلیل عاملی و مدل‌سازی معادلات ساختاری از نوآوری‌های این پژوهش است. نتایج این پژوهش به سیاستگذاران اکوسیستم نوآوری کمک می‌نماید تا مبتنی بر چارچوب مذکور، به ارزیابی فاکتورهای مختلف پرداخته و سپس جهت تحقق اهداف مدنظر، برنامه‌ریزی راهبردی و عملیاتی نمایند.