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Decoding university–industry collaboration: A SEM-ANN quadruple helix approach

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Abstract
University–industry collaboration (UIC) has received special emphasis from academicians and policymakers due to its potential for innovation diffusion and knowledge dissemination, leading to innovation ecosystem development and socio-economic advancement. Though extant literature has explored mechanisms to enhance university–industry collaboration, it has not investigated the quadruple helix model by integrating the role of academia, business firms, government, and civil society in fostering UIC. Grounded in the quadruple helix model, the objective of this research is to unveil the determinants of university–industry collaboration through developing an integrated framework. Data were gathered through a cross-sectional survey with 253 faculty members involved with the academia–industry collaboration research projects in Bangladeshi universities. To detect nonlinear relationships among variables, data were analyzed using a novel dual-staged structural equation modeling-artificial neural network (SEM-ANN) approach. The university's innovation climate, mismatch of orientation in the academia–industry, and motivation-related constraints were found to have significant influence on university–industry collaboration (UIC). Besides, government support and input from civil society moderate the relationships between the predictors and UIC. However, the alignment of mutual goals does not have significant impact on harnessing UIC. Based on the normalized importance imputed from the ANN algorithm, the university's innovation climate was proved to be the strongest predictor, followed by motivation-related constraint and mismatch of orientation between the university and industry. In light of the results, several insightful theoretical and practical implications are discussed for enhancing university–industry collaboration.

Keywords University–industry collaboration, Quadruple helix model, Innovation, Artificial neural network, Structural equation modeling, Socio-economic development

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Introduction

Researchers have been increasingly interested in university–industry collaboration (UIC) in recent decades, particularly in the elements of its success and barriers [1, 2]. Collaborations between universities and businesses, frequently aided by government action, are essential to enhancing local and countrywide innovation practices [3, 4] and promoting financial growth [5]. Universities are increasingly working with outside networks of industry players and other universities [6]. In addition to promoting economic expansion, universities and businesses profit financially from these partnerships [5, 7]. UIC, or university–industry collaboration, encompasses several activities, from patent licensing and formalized technology transfer agreements to joint research projects to boost both parties' technical quality and financial returns. UIC refers to the mechanisms through which research conducted at academic institutions is translated into practical insights for commercial enterprises. Due to this, nations work to foster an atmosphere conducive to innovation [8], with the active participation of universities, research institutions, and the key players in their country's innovation structures [9, 10].

Researchers have looked at UIC through various lenses, including the incentives of researchers to connect with businesses (e.g., Perkmann, Tartari [11]); kinds and effects of government actions (e.g., Park and Leydesdorff [12]); the significance of contracts and funds in; boundary organizations' role in easing open access [13]; problems impeding the development of spin-offs in the academic community [14]; the quality and usefulness of the knowledge produced by UIC in diverse regional situations [7]; the function of communities in enabling the transfer exchange of technology between universities and industries [15]; and the contribution that different facilitators make in accelerating technology transfer from academic institutions to commercial enterprises [16]. Although academics have discussed the disparities between industry and academic motivations, rewards, and organizational cultures [5, 17], our knowledge of the fundamental processes involved in U-I collaboration remains incomplete [16, 18, 19].

There has been a growing scholarly and policy focus on the triple helix (TH) paradigm in recent times [20, 21]. Etzkowitz and Leydesdorff initially suggested the triple helix model in 1995 to describe the interconnected connections among academics, business, and government in promoting economic development, creativity, and entrepreneurship in a knowledge-driven economy [22]. Nonetheless, this model's efficiency has been scrutinized recently, given that certain regions have yet to attain anticipated UIC levels concerning employment, GDP, and innovation [23]. As a result, a new model has emerged named "quadruple helix model"—QHM [24], which expands the conventional triple helix of stakeholders (university, government, and industry) to incorporate the end users in local innovation networks. The quadruple helix concept incorporated a 4th helix—end users—into the innovation system [25]. In essence, a country's economic structure revolves around four interconnected components: the university, government, industry, and end users. These components work in tandem to foster ongoing innovation, which serves as the driving force behind economic advancement [26]. As this emerging idea gains momentum, more study is required to fully comprehend the reasons for the success and problems of its implementation among the model's various actors [27, 28]. Moreover, there is a dearth of empirical quantitative examination of factors influencing UIC in the previous research [29]. Research conducted by Arshed, Ahmad [29] and Bryson, Crosby [30] highlights the necessity of quantitative analyses in addressing obstacles associated with UIC. There is also a call for exploring the potential for developing a complete and holistic framework that efficiently manages multiple facets of UIC, leading to improved efficacy and successful outcomes. Hence, our research question is as follows:

RQ: What are the enablers and barriers toward the attainment of university–industry collaboration from a quadruple helix context?

This study attempts to quantitatively analyze the enablers and barriers associated with UIC among the stakeholders who comprise the quadruple helix setting. A considerable body of research has investigated various forms of university–industry collaboration in established economies, focusing on Western nations. However, there is scant research regarding the analysis of collaboration models in Asian countries or emerging nations [31–33]. Being an emerging economy, Bangladesh is no exception in this regard. University–industry collaboration is still a nascent concept in Bangladesh. In terms of global innovation, Bangladesh ranked 116th in 2021 and 102nd in 2022 among 132 countries [34]. Bangladesh is one of the countries yet to catch up in formulating a knowledge-based, creative society. The absence of a cultural framework that promotes and sustains innovation, insufficient facilitation of organizational cooperation and collaboration among academic institutions, industries, government, and civil society, and the absence of a structured and systematic approach to generating novel ideas and improved problem-solving methods are among the primary factors contributing to the existence of innovation gaps in Bangladesh [33]. From this standpoint, it becomes imperative to inquire about the applicability of the quadruple helix model for promoting academia–industry collaboration in the specific context of Bangladesh. Due to the lack of prior research in this arena, current research intends to explore the components that promote and hinder university–industry cooperation toward developing a workable framework of quadruple helix partnerships for knowledge-driven innovation in Bangladesh.

The outcomes of this paper have several implications for both theory and practice. First, this study incorporates the quadruple helix model, which results in enrichment of the UIC. Our study paves the way for the potential for co-creation within the UIC environment by considering the perspectives of the users and the stakeholders. Secondly, this study contributes to the extant theoretical framework of the quadruple helix by examining its relevance in the context of academia–industry cooperation. The UIC approach presented in this study can potentially provide advantages for cooperation partners and industry stakeholders by including the perspectives and involvement of users, who play a pivotal role in driving university-led innovation. While the present model of academia–industry cooperation is considered bi-directional between academia and industry, our study offers a holistic, collaborative model that includes government and civil society as innovation users who may determine the success of UIC.

This paper's remaining sections are arranged as follows. First, we present an analysis of literature regarding the role of the four actors of the quadruple helix model for successful UIC and hypotheses. Second, we provide our analyses of the data using co-variance-based structural equation modeling (SEM), complemented by the artificial neural network (ANN) technique. We wrap up with an explanation of our results, several theoretical and policy options for accelerating UIC, and possible future research directions.

Review of the literature

Conceptualizing university–industry collaboration

University–industry collaboration (UIC) is a two-way connection between university and industry developed to promote the exchange of talent, skills, and ideas with the long-term goal of generating value for both parties. "University–industry innovation collaboration processes are based on interactions between university and industry scientists working to transform academic science with commercial potential toward market applications" [35, 36]. Research and development (R&D) functions such as consulting work, collaborative R&D research projects and programs, spin-off creation, and patenting [37, 38], or the purchase of prototypes developed at universities, as well as the sharing of equipment and infrastructure between industries and universities are the focus of university–industry collaboration [39, 40]. University–industry collaboration channels are typically grouped into formal and informal genres [41, 42]. Link, Siegel [43] regard joint research and consulting as informal, whereas Perkmann, Tartari [11] treat them as formal. UIC has significance in promoting innovation and regional development. For instance, collaboration between academia and industry is crucial for fostering economic growth and raising the degree of innovation in universities and businesses [29, 44].

On the other hand, researchers have utilized several frameworks, such as the triple helix model (THM), through which universities, industry, and government interact toward UIC and greater innovation, resulting in local and region-based socio-economic development [45]. However, considering the limitation of THM in explaining the detailed intricacies of UIC and regional development, the current study explores the potential of the quadruple helix model, whereby one additional helix, i.e., civil society, has been included [24, 46]. The subsequent segments reflect the micro-foundations and the relevance of the quadruple helix model in facilitating university–industry collaboration performance.

Structure of quadruple helix model (QHM)

The quadruple helix concept was created in 2009 by Elias G. Carayannis and David F.J. Campbell to uphold innovation and entrepreneurship and better comprehend the dynamics of links between universities, businesses, governments, and civil society. Some authors (e.g., Van Horne and Dutot [26]) claim that the quadruple helix model results from the long-term evolution of innovation and the significance of incorporating the citizens' standpoints. The economy's structure is made up of 4 helixes: academia, business, government, and civil society that interact with one another to foster economic growth and innovation and collaboration between stakeholders and the public in a quadruple helix [24, 47]. In this research paper, 4 parties of the quadruple helix model involve the university, industry, government, and civil society that is shown in Fig. 1. The interaction among these 4 parties is expected to influence university–industry collaboration.

University There is strong evidence that university research not only fosters company innovation but also creates local knowledge spillover that can aid in forming innovation systems [49, 50]. Moreover, patenting, licensing, intellectual property, spin-out companies from university incubators, and other technology intermediaries are examples of resultant entities [47]. These entities facilitate the codification and commercialization of ideas for commercialization purposes in the university environments [51].

Industry The ongoing argument that the industry lacks innovation and does not fully capitalize on its scientific successes is at the heart of the arguments surrounding university–industry partnerships today [4, 52]. As industrial strategy relied more on information transfer as a mechanism for growing knowledge-enriched economies and greater competitiveness, fascination for university–industry collaborations rapidly grew during the 1990s.

Government In recent decades, governments have refocused their research policies on encouraging innovation by encouraging collaboration and formulating regulatory assistance [19]. The government can aid in luring foreign investment, entrepreneurship, and innovation. According to Rybnicek and Königsgruber [19], the support offered by government institutions

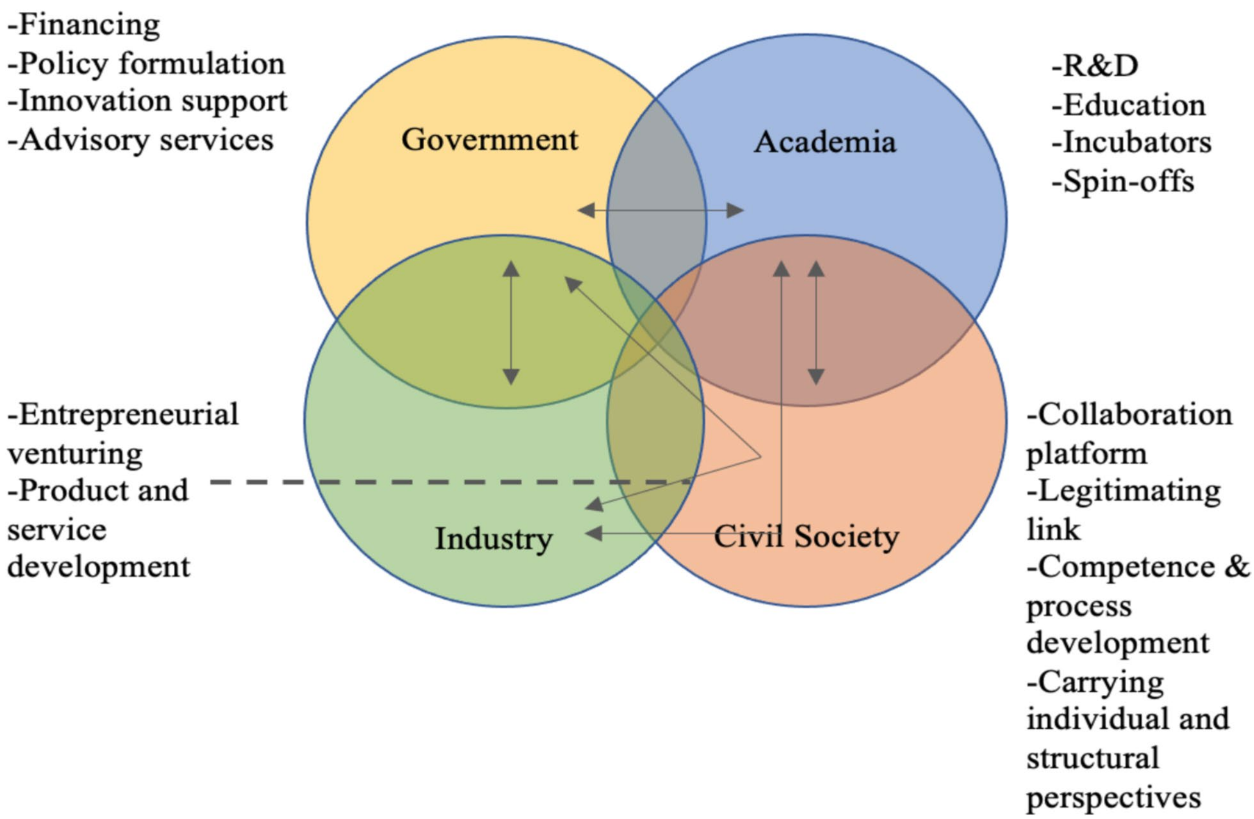

Fig. 1 Developed motion of a quadruple helix innovation system. Source: Adapted from Lindberg, Lindgren [48]

contributes to creating an atmosphere that fosters collaborative innovation partnerships.

Civil Society The 4th helix has been demarcated in several ways, comprising consumers, users of innovation, the public as represented by culture and media, the crowd as users in innovation systems, and civil society [53]. This new type of civil society was termed by Carayannis and Campbell [24] as the culture- and media-based public. By, the society and public, we have indicated the inputs from media-based, and culture-based, and society, as mentioned in the study of Carayannis and Campbell (2010). The media-based public includes the general consumers, electronic, print, and social media public who can influence the trajectory of innovation. The culture-based public entails citizens, local communities, and users who can provide feedback on the products and services, and innovation generated by the academia–industry. The term "media-based public" denotes the general public that the media affects and engages with to generate public discourses around learning and innovation [24]. On the other hand, the culture-based public develops social capital through interactions with people who have various values, customs, and worldviews [54]. Civil society participation helps legitimize and justify innovations as well as create social innovations [27, 55].

Applicability of quadruple helix model for promoting university–industry collaboration

According to the quadruple helix model (QHM), innovation is co-created through the interdisciplinary transfer of knowledge among academia, industry, civil society, and government [56]. The 4 institutional actors in innovation systems establish resilient and reactive institutional arrangements while being largely independent and frequently holding competing beliefs. Carayannis and Rakhmatullin [27] argue that the quadruple helix model represents a shift toward a more open-minded, complex view of innovation that involves influencing stakeholders in co-creation [57]. The incorporation of the 4th helix, which represents users of societally based innovation [54], and the consequent appearance of quadruple helix structures present a review by Bozeman, Rimes [58] that shows the growing significance of societally led or public valued university–industry collaboration. Realizing the importance of this strategy, governments and policy think tanks have attempted to adopt regulations that would enhance their innovation systems and assign resources to encourage interactions among quadruple helix members [59]. According to Mavroeidis and Tarnawska [60], the quadruple helix idea advocates taking into account democratic and social viewpoints to stimulate knowledge generation (research) and application of knowledge (in innovation). The quadruple helix model is an innovation-push model through which technology development is assisted by state funding and industry investment. The concepts of incorporating university-industrial partnership and a wide spectrum of university-public knowledge interchange are discussed by Hughes and Kitson [61] and Carayannis and Campbell [24].

The quadruple helix idea is used to analyze the multifaceted interactions among universities, corporations, and governments that support economic advancement and innovation [62]. Cross-sectoral collaborations are crucial for fruitful innovation because they encourage knowledge distribution and exchange, expand opportunities (such as for projects and products), lessen knowledge redundancy [63], enhance innovative and economic performance, and enable an improved understanding of different viewpoints. The quadruple helix concept aims to comprehend better the complex interactions between diverse academic, industrial, and governmental bodies that may foster innovation and entrepreneurship.

Quadruple helix model has previously been used in different research contexts. For instance, [64] applied quadruple helix model (QHM) by introducing non-profit organizations (NPOs) as the 4th helix to explore how they contribute to the development of national innovation ecosystem. NPOs operate in a wide range of fields such as science, environment, education, and housing. By exploring the interaction among NPOs and other helices, [64] delineated NPOs' role in promoting innovation in delivering social services. Further, [65] developed a quadruple helix analytical framework to explore the influence of different stakeholders' motivations on technology transfer in the European context. They incorporated the citizens' needs and demands as the 4th helix. The study of [65] finds that the user-oriented innovation models helped universities to interact with industry and government to generate knowledge in the implementation of smart specialization strategy and boost R&D (research and development) commercialization's conditions. On the other hand, [66] included local community as the fourth helix, which can serve the purpose of local economic development is association with industry, government, and academia. By incorporating the local community needs, the higher education sector can bring desired changes in the existing teaching and learning practices that can bring societal innovation and development. By using quadruple helix framework, the Finnish Research Impact Foundation facilitated social networks among the QHM actors in creating and maintaining ties with others, while getting access to social resources, e.g., information and trust. Such QHM approach led to the flourishing of knowledge society and knowledge democracy. Next [67] incorporated civil society as the 4th helix to enable Finland's regional authorities to encourage participation of civil society in participatory policy-making functions. [68] developed a participative quadruple helix model which connects domestic firms, government, industry, and users to boost blue economy (BE) potential in the Shandong Province in China. [69] measured the performance of quadruple helix approach in Finnish research sector by examining the research outputs by focusing on Altmetrics.

Therefore, we find several instances of evidence regarding how quadruple helix model has been leveraged in various contexts such as local economic development, promoting collaboration among helices for innovative education, facilitating blue economy, and commercialization of R&D. It is evident that QHM has primarily been used in advanced economies such as Finland, Europe, and China. However, we have little empirical research involving emerging economies. Therefore, our research extends these prevailing research streams by applying QHM in the Bangladesh context, a representative of an emerging economy. Besides, while previous research focuses on the interaction among helices, the current research adds to the growing QHM literature by revealing how the motivations of different helix partners accelerate or hinder the collaboration process. While most of the QHM studies are qualitative and interview-based, our research stands out by adopting quantitative approach, while establishing cause–effect relationships among the constructs of QHM framework. Besides, while previous QHM research streams did not explicitly address the enablers and barriers of collaboration, our research has explicated the perceived barriers and facilitating factors required for fruitful interaction among helices. The current research thus complements and extends the extant research on QHM by empirically testing the relationships among the success factors and barriers behind the university–industry collaboration. Consequently, apart from adding to the theoretical underpinning of the quadruple helix model, the current research also diverges from the QHM research streams and potentially stimulates more quantitative research in this field to solidify the quantification of the QHM constructs.

Hypotheses development

Universities have a role in nurturing an innovation climate within the campus so that industries and stakeholders can participate, and more research is carried out. The innovation climate in universities can be fostered in many ways. Entrepreneurship programs, courses, and workshops may encourage industry cooperation. Organizations can effectively absorb new technologies and information through university–industry collaboration (UIC), boosting their innovation performance. A focus on innovation diffusion within the university has a bearing on universities' transformation of knowledge and achievement [49]. The university authorities are placing more focus on inventions and patents. Innovation atmosphere and industry-university collaboration performance are closely related [70]. According to Kenney and Richard Goe [71], higher levels of innovation are positively connected with university cultures that place a strong focus on learning and participation in decision-making by aligning all the stakeholders, including industry and government. So, the hypothesis below can be averred:

Hypotheses 1 The University's innovation climate has a positive relationship with university–industry collaboration (UIC).

The alignment of mutual organizational goals between the university and industry is important for enhancing UIC performance [72, 73]. Collaboration between the university and industry would proceed more quickly if there were an understanding regarding patent and intellectual property exchange between the university and industrial partners. Collaboration is encouraged by homogeneity in the attitudes and orientations of academic and industry officials [74, 75]. Providing the right incentives for the university and industry participants by their respective organizations would align the interests of the university–industry together [76]. Such a phenomenon would create greater collaboration [77]. Therefore, we develop the hypothesis below:

Hypotheses 2 Alignment of mutual organizational goals (AMOG) has positive relationship with UIC.

In many cases, the barrier to successful collaboration between university and business may emerge because universities and businesses don't fully comprehend the demands and expectations of each other [18, 78]. The orientations of university and business are sometimes different. It might seem obvious to the industry that university research tends to be more theoretical than applied or practical [79]. The likelihood of developing cooperative relationships may be lowered by ignorance of the advantages produced by a cooperative partnership. In many countries, particularly in developing economies, universities and industry sometimes do not trust each other enough to work together on initiatives. There is a lack of corporate interest in university research due to the perceived absence of industry relevance in university education and research [80, 81]. Considering these views, the following hypothesis is developed:

Hypotheses 3 Mismatch of orientation between industry and university (MOIU) has a negative relationship with university–industry collaboration

The collaborative research and innovation efforts might be hampered due to the absence of appropriate incentives for the parties [82]. For instance, in terms of advancing their careers, academics often don't perceive researching with industry as advantageous. Collaborations with businesses are in tension due to the faculty members' significant academic and research obligations [78, 83]. Universities fall short in offering faculty members both financial and non-financial incentives for conducting cooperative research with universities. Due to the lack of tangible advantages, businesses are less motivated to collaborate with academic institutions on research. One of the main drivers of multisector collaborations is infrastructure related to education and research [49]. However, the industry might also not perceive immediate success and quick product and process innovations from the collaborative relationships with universities. Therefore, we can assume the following**:**

Hypotheses 4 Motivation-related constraints (MRB) have a negative relationship with university–industry collaboration

Our previously hypothesized impact of university's innovation climate on collaboration performance may be impacted by the government interventions [84]. For example, the government's efforts to raise funds for businesses can improve business-academia cooperation. The government's establishment of technology transfer offices (TTO) and science parks is expected to hasten academic-industry cooperation [85]. Collaboration between academics and industry typically needs government backing [19, 86]. Therefore, government intervention is an integral helix of the quadruple helix model and may be a catalyst for successful academia–industry collaboration. The innovation climate in the university can lead to more collaborative performance in the presence of favorable government support. Considering these viewpoints, our research considers government support as a potential moderator and hypothesizes the following:

Hypotheses 5 Government support (GVS) moderates the relationship between the university's innovation climate and academia–industry collaboration.

Previously, we posited a positive association between mutual alignment of organizational goals and collaboration performance. However, amid this linear relationship, government support can play an intervening variable. Researchers have looked at how government funding affects university–industry partnerships, e.g., subsidies that support financially weakened innovative firms [87]. According to Liu and Li [88], a government subsidy is an exogenous variable and a parameter that mediates the functioning of the university–industry collaboration. Through its research laboratories, the government also encourages the equitable distribution of the outcomes of collaborative R&D initiatives [89]. Thus, government intervention can not only help align the mutual interests of industry but also dictate how their collaborative innovation outputs are enhanced. So, the following hypothesis is formulated:

Hypotheses 6 Government support (GVS) moderates the relationship between alignment of organizational goals and university–industry collaboration

Previously, we assumed the association between the university's innovation climate and collaboration performance. Such an association can be better explained through the 4th helix of QHM, i.e., the involvement of society and the public. Universities can engage in better product and innovation research with the industry through co-creation with the greater society and taking feedback from civil society groups who are the ultimate beneficiaries of innovation. Customers' needs can be better understood by conducting surveys regarding potential products [90, 91]. The university's end-user testing of goods and software would aid in the commercialization of research. Crowdsourcing and other online platforms can allow citizens and civil society to co-create product ideas and marketplaces [92, 93]. Successful academia–industry research partnership would result from including end users and allowing them to share their ideas and demands [94, 95]. Thus, considering the significant role of involving citizen action public in the university–industry collaboration, we hypothesize the following proposition:

Hypotheses 7 Input from society and the public (ISP) moderates the relationship between the university's innovation climate and collaboration performance.

Previously, we hypothesized that an alignment between the university's and industry's mutual goals would result in more positive collaboration. Such relationships can be influenced by the involvement of society and the public, the 4th helix. The owners and drivers of innovation processes are users or citizens [27]. The demand function of civil society, which has a significant impact on the creation of information and technology, is typically the end-user of innovation [95]. Due to its demand and user function, society, which is typically the last consumer of innovation, has a significant effect on the creation of knowledge and technology [96]. Thus, when universities and industries integrate civil society's participation, they can yield more collaborative performance. Thus, the following hypothesis is developed:

Hypotheses 8 Input from society and the public moderates the relationship between the alignment of mutual goals and collaborative performance

The factor "government support" has been found to be more of an intervening factor in the relationship between predictor variables and the U-I collaboration performance. In the study of [85], it is posited that government support is a catalyst that can help the efforts made by university's innovation development office in accelerating more collaborative research with industry partners. Moreover, [97] offered similar proposition that government backing is a significant intervention that can link the influencing factors with the collaboration performance. On the other hand, while explicating the role of "Input from society and public," [98] said that the feedback loops provided by the public have significant bearing on how the mutuality of goals between university and industry would lead them toward better collaborative results. Citizens and local communities can participate in the co-creating process of innovative products/services through sharing user ideas on commercialization feasibility, therefore facilitating the alignment between academia and industry. [99] also vouched for the incorporation of public knowledge as a mechanism to expedite the collaborative efforts. [100] explored the application of stakeholder theory in explaining the role of government as an important stakeholder in managing the overall quadruple helix stakeholders. The intervention of government can affect the university technology commercialization activities in association with industry stakeholders. Government can promote useful dialogue and engagement between university and private sector in aligning the processes of technology commercialization with relevant helices in the quadruple helix framework [100]. Considering such theoretical and conceptual underpinning, the constructs "government support" and "input from society and public" have been hypothesized as moderators or intervening factors.

Based on incorporating the above hypotheses, a conceptual model is developed in Fig. 2 as a framework for

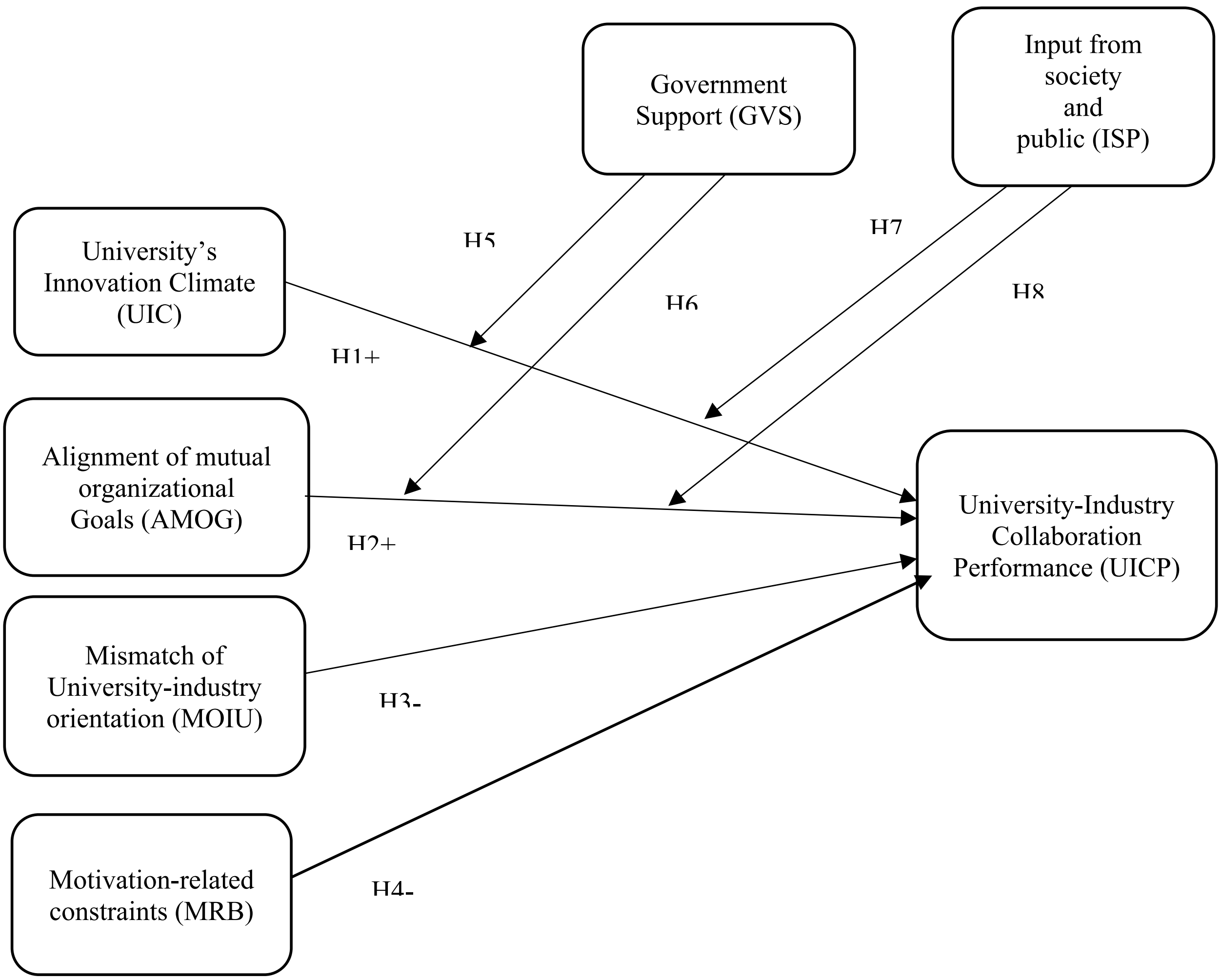

Fig. 2 Graphical representation of the research model. Source: Author's own

successful UIC and for further statistical measurement and validation.

The constructs have been chosen upon aligning them with the respective helices of the quadruple helix model (QHM). For example, the construct "AMOG" (alignment of mutual organizational goals) has been chosen based on the proposition of [101] and [73], who posited that the goals of the universities and businesses need to converge. There ought to be a mutuality of the priority on societal outcomes. The universities and academic institutions need to perceive the overall societal outcomes as important as their individual organizational goals. Secondly, we have derived the concept "MOIU" (mismatch of university–industry orientation) has been aligned based on the finding of [73], who averred that there appear tensions when the requirement for research funding surpasses the need for academic freedom. Consequently, the conflict between university–industry emerges and there is reportedly a researcher bias toward those collaborative projects that are beneficial for the overall industry rather than for individual firms. Therefore, the emerging mismatch of the orientation between university–industry tends to hinder collaborative research efforts. Thirdly, the construct "university's innovation climate" (UIC) as an enabler, has been generated from the U-I collaboration principles, specifically as part of "innovation ecosystem." The university's innovation climate creates congenial atmosphere for encouraging academicians to improve the teaching practices by aligning with the cutting-edge innovation offered by industry. According to [102], an innovation climate will foster positive interactions among project partners to enable the sharing of technological wisdom in university–industry collaboration projects. Universities that have an innovative climate have made a strong effort to offer programs, courses, or workshops in the entrepreneurship area or sponsor venture competitions not only as a way of demonstrating their technological capabilities, but also to get even more individuals involved in university–industry collaboration activities [85]. According to [103], building a support system based on a set of joint collaboration forums, entrepreneurial competitions, and innovation-related courses are strongly related to the innovation climates in universities. University–industry actors share ideas and influence the development of norms, understandings, and identities that reduce the ambiguity of technological innovation [104].

Fourthly, the construct "motivation-related barriers" has been adopted from the analysis of the challenges involved in the motivations of four helix partners. Specifically, the study of [81] demonstrated barriers such as "lack of perceived benefits by academicians in terms of career advancement," "insufficient academic rewards for collaboration with industry," "the presence of conflict with teaching/research duties," while conducting collaborative projects. Next, the construct "government support" has been developed by linking them with the literature related to the QHM literature such as [105] and [73], who posited the role of government support in promoting academia–industry collaboration. QHM actors acknowledge the active participation of governments to promote the efficiency of U-I innovation and increase wealth production. This support may be through the government stimulating research and development (R&D) through financial interventions such as grants and tax credits and developing a favorable legal framework on R&D [106]. Governments can ease the funding pressures by providing public funds, e.g., state, or regional governments or raised funds from licensing and patenting revenues associated with technology transfer activities. Finally, the variable "input from society and public" has been aligned with the definition of public provided by [105]. The media-based public includes the general consumers, public from electronic, print, and social media, who can influence the trajectory of innovation. The culture-based public entails citizens, local communities, and users who can provide feedback on the products and services, and innovation generated by the academia–industry.

Methodology of the research

Selecting samples and collecting data

The study administered a structured questionnaire to the public university teachers in Bangladesh who have experience in university–industry joint research collaboration. Only faculty members with a minimum rank of assistant professor or above were selected. The questionnaire was sent to seven public university faculty members in Bangladesh: Dhaka University, Khulna University, Khulna University of Engineering and Technology, Jashore University of Science and Technology, Bangladesh University of Engineering and Technology (BUET), Barisal University, and Islamic University Kushtia. Of the 450 faculty members approached/sent, the study received full questionnaire responses from 253 respondents, leading to a response rate of 66.92%. Both in-person and Google survey forms were used for the study. The research used a non-probability, non-random sampling-based sampling technique where each university's faculty website was visited to know the profiles of the faculty members to include them having the criteria for being minimum an assistant professor and having research and industry project collaboration.

Before sending the questionnaire or in-person visit, the faculty members' suitability to participate in the survey was discerned by confirming whether they had research collaboration with industry. To select the ideal sample size, the study followed several existing manuals. For example, Kline [107] averred that the sample size should be a minimum of 200 or 5 to 10 samples for each variable. As our research has 07 variables, a sample of 70 size would be appropriate. However, as our research is based on co-variance-based structural equation modeling, academicians suggest a large sample size of at least 200 to 300. However, we have included 253 samples in our study. Apart from the CB-SEM guideline, our study has used the G-power 3.1.9.7 application to select the right sample size as per the guidelines from Faul, Erdfelder [108] and Misbauddin, Alam [109]. Considering 6 predictors responsible for the dependent variable, we have developed a priori analysis in Table 1.

G*Power analysis from Table 1 demonstrates that with six predictors, a power of 0.95, and an effect size of 0.15, the sample size should be 146. Considering this, our size of 253 meets the minimum sample requirement. Moreover, this sample size also exceeds the 50 times rule for the analysis of artificial neural network (ANN), which asserts

Table 1 A priori analysis. Source: Authors' own

F tests—linear multiple regression: fixed model, R^2 deviation from zero			
Analysis:	**A priori: compute the required sample size**		
Input:	Effect size f^2	=	0.15
	α err prob	=	0.05
	Power (1-β err prob)	=	0.95
	Number of predictors	=	6
Output:	Noncentrality parameter λ	=	21.9000000
	Critical F	=	2.1644088
	Numerator df	=	6
	Denominator df	=	139
	Total sample size	=	146
	Actual power	=	0.9507965

that the samples need to beat minimum of 50 times the count of modifiable parameters [110, 111]. Due to 4 parameters in the ANN, the required minimum sample size is 200. Therefore, the sample count of 253 is deemed to be sufficient for the ANN analysis.

Measurement items' selection

The research identifies the factors driving the university–industry collaboration performance (UIC). To determine the measurement items, a rigorous literature review provided us with several independent variables as well as moderator variables that affect the UIC, the dependent variable. To meet the condition of content validity, the independent and dependent constructs and their respective indicators have been adopted from a comprehensive literature review. The construct "university's innovation climate" has been measured by 05 items adapted from Tseng, Huang [17]. The 05 measurement items of "alignment of mutual organizational goal" have been taken from the research of Khadhraoui, Plaisent [112], Muscio and Vallanti [72], Ankrah, Burgess [73], and Englund and Felice [75]. Besides, the work of Nsanzumuhire and Groot [81] provided indicators for measuring the "mismatch of orientation between university and industry" and "motivation-related barriers." Moreover, the indicators of the moderating variable "government support" were obtained from Bruneel, d'Este [85], Yun and Liu [113], and Ma, Liu [114].

"Input from society and public" was assessed with 04 items taken from [105], Schütz, Heidingsfelder [91], Morawska-Jancelewicz [47], and González-Martinez, García-Pérez-De-Lema [94]. Finally, the dependent variable "university–industry collaboration" was measured by taking 06 items from the study of Nsanzumuhire and Groot [81] and Kunttu [115]. We adopted a Likert scale of 5-point, where scale of 1 indicates the "strongly disagree" and 1 represents "strongly agree" with the respective statements by the respondents.

Pilot testing

Before going for a full-fledged field survey, we accomplished pilot tests. In line with the studies of Karmaker, Aziz [116], during the pilot test phase, the measurement items' face validity and content validity were determined through interviews with five professors and five C-Suite level industry professionals who are well acquainted and have experience in collaborative research between business and university. We discerned the redundancies and ambiguity in the questionnaire's wording and performed corrections to the indicator items. Following Srinivasan and Lohith [117], we administered a pilot test, where 45 (forty-five) respondents were provided with the modified questionnaire. The Cronbach's alpha values were found satisfactory, surpassing 0.70, suggesting acceptable construct reliability. Moreover, the preliminary data analysis showed the measurement model's goodness of fit based on CB-SEM quality criteria. Following such validation from the pilot test, we moved into the formal, complete field survey. The measurement instruments and their corresponding sources are summarized in ***Appendix***.

Data analysis techniques

For data analysis, the current study has applied structural equation modeling (SEM) to conceptualize and assess the hypothesized relationships among the multiple constructs. Out of two approaches of SEM (PLS-SEM vs. CB-SEM), the current study has used CB-SEM (Co-variance based structural equation modeling) because our sample size was large, and we had to test the complex relationships among the variables. Considering these issues, CB-SEM was more appropriate for the data analysis [118]. The study used SPSS AMOS application v.26 to conduct the CFA (confirmatory factor analysis) to determine the model fit [119]. The assessment of the measurement model was also done by quantifying the multi-item constructs' reliability and validity. Then, the structural model was evaluated to assess the acceptance or rejection of the hypothesized relationships among the endogenous and exogenous constructs.

To portray the nonlinear relationships between the endogenous and exogenous variables, we administered a two-staged SEM-ANN approach using artificial neural networks (ANN) to rank the normalized importance of significant predictors generated from the SEM analysis. SEM and ANN approaches are complementary because SEM is appropriate for testing hypotheses regarding linear relationships but doesn't show the nonlinear relationships [111]. On the other hand, the ANN can capture nonlinear relationships, but it is unfit for testing hypotheses due to the "black box" operation [120]. Therefore, further analysis was conducted to assess the nonlinear relationships between the dependent and independent variables by taking the significant predictors from CB-SEM analysis and assigning them as neurons for artificial neural network (ANN) analysis. Such ANN analysis helped the researchers calculate the ranking of the normalized importance of the significant independent variables generated from SEM results.

We have used the ANN approach considering the predominant focus on the conceptual/theoretical underpinning of the quadruple helix model. QHM is a nonlinear innovation model (Carayannas & Campbell, 2009). That means the factors influencing the academia–industry collaboration do not act in a linear way. In a linear innovation model, there is a sequential model. For example, first, university develops research and patents, and ultimately, they are commercialized by the industries. In this way, innovation happens. According to Carayannas and Campbell (2009), the linear model asserts that initially there is basic research which is conducted within the university environment. This fundamental research is translated afterward to applied research and later channeled to the university-related fields. Finally, experimental development is implemented into practice that is realized by business firms through applied research. The outcome is a first-then relationship, and it is the role of the universities and/or basic research to churn out the new waves of knowledge creation which are, at a later stage, picked up by business and finally the commercialization and marketing of R&D falls on the shoulders of business, in a national (multi-level) innovation system (Carayannas & Campbell, 2009). However, such a linear model would have been at a disadvantage because the time span of an entire R&D cycle, to reach the markets at all, could have been very long. Moreover, the linear model of innovation is found to have significant failure in terms of transferring the preferences of the users at the market end to the production of basic research. Considering such limitations, Carayannas and Campbell (2009) incorporated public and society in the form of quadruple helix model, which is a nonlinear innovation model where the addition of fourth helix, i.e., society and public, affects the relationship in a nonlinear way. The feedback and input generated by the public tend to interact with the innovation creation cycle developed by university, industry, and government, and therefore, the innovation might be re-developed and re-framed. Thus, quadruple helix is a nonlinear innovation hypothesized by Carayannis et al. (2022) and Carayannis and Campbell (2009). Considering this nonlinear nature, we have adopted artificial neural network (ANN) model, which primarily shows non-relationships among the independent and dependent variables (references). Thus, the addition of ANN adds value to our research considering the fact that QHM is a nonlinear innovation model. ANN in our research has been able to capture the nonlinear relationships among constructs and have elaborated the relationship in a nonlinear way. Besides, we need to prioritize the relative importance of the independent variables which SEM alone cannot do it. As a result, ANN enabled the researchers to find the strongest and least dominant factors affecting U-I collaboration.

Results

Demographics

The demographic particulars of the faculty respondents are portrayed in Table 2, which shows the gender, age, education, years of experience, and designation of the participants.

Table 2 Respondent's Information. Source: Authors' own compilation

Measure		Frequency	Percent (%)
Gender	Male	147	58.1
	Female	106	41.9
Designation	Assistant professor	75	29.6
	Associate professor	85	33.6
	Professor	93	36.8
Education	Masters	82	32.4
	PhD	171	67.6
Age	26–30	35	13.8
	31–45	75	29.6
	36–40	45	17.8
	41–45	41	16.2
	Above 45	57	22.6
Years of experience	Less than 3 years	25	9.9
	3–6 years	66	26.1
	7–10 years	57	22.5
	11–14 years	17	6.7
	More than 14 years	88	34.8

Checking common method bias

The self-reported measures could artificially increase the covariation, resulting in biased estimates. So, we opted to control for and detect the prevalence of common method bias. Harman's one-factor test in CFA was utilized to investigate common method variance. The six-factor CFA model's fit indices were compared with the model fit of the one-factor CFA model. The one-factor CFA model's fit indices were found unacceptable, resulting in the CMB threat not being present in our study [121]. Our six-factor model fit had a Chi-square (CMIN) of 837.134 and degrees of freedom (DF) of 315, leading to an acceptable CMIN/DF of 2.658. On the other hand, the one-factor model had a Chi-square of 560.12 with 120 degrees of freedom, indicating that CMB was not a threat in our measurement model [122].

Evaluation of the measurement model

The CFA results show an excellent fit for the research model. The tables below demonstrate the values of CR, AVE, and discriminant validity values through Fronell–Larcker and HTMT criteria. The CR (composite reliability) values for all the variables are well above 0.70, along with the AVE (average variance extracted) values greater than 0.5, demonstrating the reliability of our results [123] (Table 3). Besides, for testing discriminant validity, the Fornell–Larcker table (Table 4) portrays that diagonal values are higher than the off-diagonal values in the columns and rows. Also, in Table 5, none of the HTMT

Table 3 Reliability analysis

	CR	AVE
University_innovation_climate (UIC)	0.918	0.701
Aligning_mutual_goals (AMOG)	0.944	0.771
Mismatch_of_mutual_orientation (MOIU)	0.879	0.707
Motivation_constraints (MRB)	0.856	0.750
Government_support (GVS)	0.906	0.764
Input_of_Society_and_Public (ISP)	0.839	0.567
University_industry_collaboration (UICP)	0.937	0.712

CR 0.70 < *, AVE 0.50 < *

values exceed 0.85, resulting in the achievement of discriminant validity for our measurement model [124]. Thus, both Fornell–Larcker and HTMT values support discriminant validity for our model. In our CFA model, all items have a minimum factor loading value of 0.70, demonstrating that every calculation accounts for an appropriate level of variance of each latent variable (Table 6). In our CFA results, approximately every goodness of fit metric meets the recommended thresholds [125] (Table 7).

In Table 7, the summarized fit metrics are listed with their threshold values suggested by Hu and Bentler [126], according to which the interpretation and comparison of our results were made. In our model, the values of AGFI (adjusted goodness of fit) and GFI (goodness of fit) are AGFI = 0.921 and GFI = 0.912, resulting in the meeting of minimum cutoff values of 0.90 [127]. Besides, the value of CFI needs to be larger than 0.9. Our CFI value is 0.951, which is appropriate. RMSEA (root mean square error of approximation) value needs to be below 0.08. In our CFA model, RMSEA = 0.071 demonstrates a good fit. The value of Chi-square/degrees of freedom (CMIN/DF) is 2.658, which is also an acceptable fit. Figure 3 portrays the CFA path diagram.

Structural model results

The structural model shows the results of hypothesized relationships and their corresponding path coefficients.

From the results, the effect of the university's innovation climate on university–industry collaboration (UICP) has been found significant (b = 0.418, $p < 0.05$) (two-tailed test). Thus, the alternative hypothesis (H1) is accepted. On the other hand, the impact of alignment of mutual organizational goals on UICP is statistically insignificant ((b = -0.074, p = 0.501). Therefore, the null hypothesis is not rejected, resulting in the rejection of the alternate hypothesis (H2). The effect of the mismatch of mutual orientation (MOIU) on UICP is also significant (b = -0.35, $p < 0.05$), leading to acceptance of the alternative hypothesis (H3). The impact of motivation constraints on UICP has been proved statistically significant (b = -0.361, $p < 0.05$), resulting in the rejection of the null hypothesis and acceptance of H4. Therefore, from the 04

Table 4 Validity through Fornell–Larcker criteria

	UIC	AMOG	MOIU	MRB	GVS	ISP	UICP
UIC	0.832						
AMOG	0.821	0.878					
MOIU	−0.461	−0.461	0.841				
MRB	0.419	0.356	−0.100	0.866			
GVS	0.284	0.294	−0.160	0.358	0.874		
ISP	0.324	0.411	−0.094	−0.028	0.204	0.753	
UICP	0.606	0.526	−0.485	0.497	0.184	0.062	0.844

Table 5 Validity through HTMT ratio (heterotrait–monotrait ratio)

	UIC	AMOG	MOIU	MRB	GVS	ISP	UICP
UIC							
AMOG	0.882						
MOIU	0.461	0.470					
MRB	0.424	0.363	0.107				
GVS	0.264	0.277	0.174	0.293			
ISP	0.321	0.430	0.105	0.076	0.183		
UICP	0.634	0.537	0.492	0.546	0.204	0.052	

Table 6 Item-wise factor loadings

Items	Loadings
UIC_1	0.812
UIC_2	0.826
UIC_4	0.848
UIC_5	0.834
UIC_8	0.840
AMOG_1	0.895
AMOG_2	0.877
AMOG_3	0.896
AMOG_4	0.886
AMOG_5	0.836
MOIU_2	0.866
MOIU_4	0.806
MOIU_5	0.850
MRB_4	0.921
MRB_5	0.806
GVS_2	0.823
GVS_4	0.826
GVS_5	0.965
ISP_1	0.699
ISP_2	0.747
ISP_3	0.745
ISP_4	0.816
UICP_1	0.837
UICP_2	0.834
UICP_4	0.743
UICP_5	0.892
UICP_6	0.925
UICP_7	0.822

Table 7 Summary of model fit indices

Measure	Estimate	Threshold	Interpretation
Chi-square (CMIN)	837.134		
Degrees of freedom (DF)	315		
CMIN/DF	2.658	1–3	Excellent
Comparative fit index (CFI)	0.951	> 0.9	Excellent
Root mean square error of approximation (RMSEA)	0.071	< 0.08	Acceptable

The thresholds were proposed by Hu and Bentler [126]

independent variables, three significantly impact the university–industry collaboration. The standard error for all the hypothesized paths is also low. In the next segment, we elaborate on the hypothesis results of moderation tests.

From Table 8, it is evident that government support (GVS) and input from society and the public (ISP) have moderating effects on the university–industry collaboration performance. The H5: moderating effect on the relationship between university's innovation climate and university–industry collaboration performance is statistically significant ($b = 0.290$, $p < 0.05$). However, the effect of GVS on the relationship between UIC and UICP is insignificant ($p = 0.877$), resulting in the rejection of the alternative hypothesis (H6). On the other hand, the moderating effect of ISP on the relationships between UIC and UICP (H7) and between AMOG and UICP is both statistically significant (H7: $CR > 1.96$, $p < 0.05$; H8: $CR > 1{,}96$, $P < 0.05$). Nevertheless, the moderating effects of ISP are weak (H7: $b = 0.004$; H8: $b = 0.078$). Thus, from four moderating paths, three are accepted, and one is rejected. Figure 4 presents the structural model results.

ANN Analysis

In accordance with Leong, Hew [111] and Liébana-Cabanillas, Ramos De Luna [128], we adopted the significant variables of the CB-SEM path as the input neurons for the ANN (Artificial Neural Network) analysis (Fig. 5). The justification for using ANN is to detect the prevalence of nonlinear relationships between the endogenous and exogenous variables. ANN can manage non-compensatory models where a reduction in one factor does not require to be compensated by an enlargement in another factor. In our study, the ANN algorithm was operationalized using IBM SPSS 26 version's neural network interface. The ANN algorithm is able to learn through several phases of training and learning processes to predict the outcome variable using a feed-forward–backward propagation (FFBP) algorithm [111, 129]. For the hidden and input layers, we applied multilayer perceptrons and sigmoid activation functions.

We distributed 90% of the total samples to the training mechanism, and the rest 10% was allocated to the testing procedure. Besides, to avert the chance of overfitting, a tenfold cross-validating mechanism was operationalized, resulting in RMSE (root mean square of error) values as shown in Fig. 6. As seen in RMSE Table 9, the RSME values in the testing and training modules are relatively lower. The average RMSE value for the training procedure is 0.118, and for the testing procedure, the mean RMSE value is 0.127. Thus, it confirms a satisfactory ANN model fit (Ooi & Tan, 2016). The RMSE values and corresponding tables and figures are stated below:

Next, in line with the study of Hew and Kadir (2016), R^2 of the ANN model was computed. With an R^2 of 71.3%, the results unveil that the ANN model is capable of predicting university–industry collaboration with an accuracy of 71.3%.

Next, we performed a sensitivity analysis to ascertain the input neurons' predictive power as shown in Table 10. We imputed the normalized importance of each input

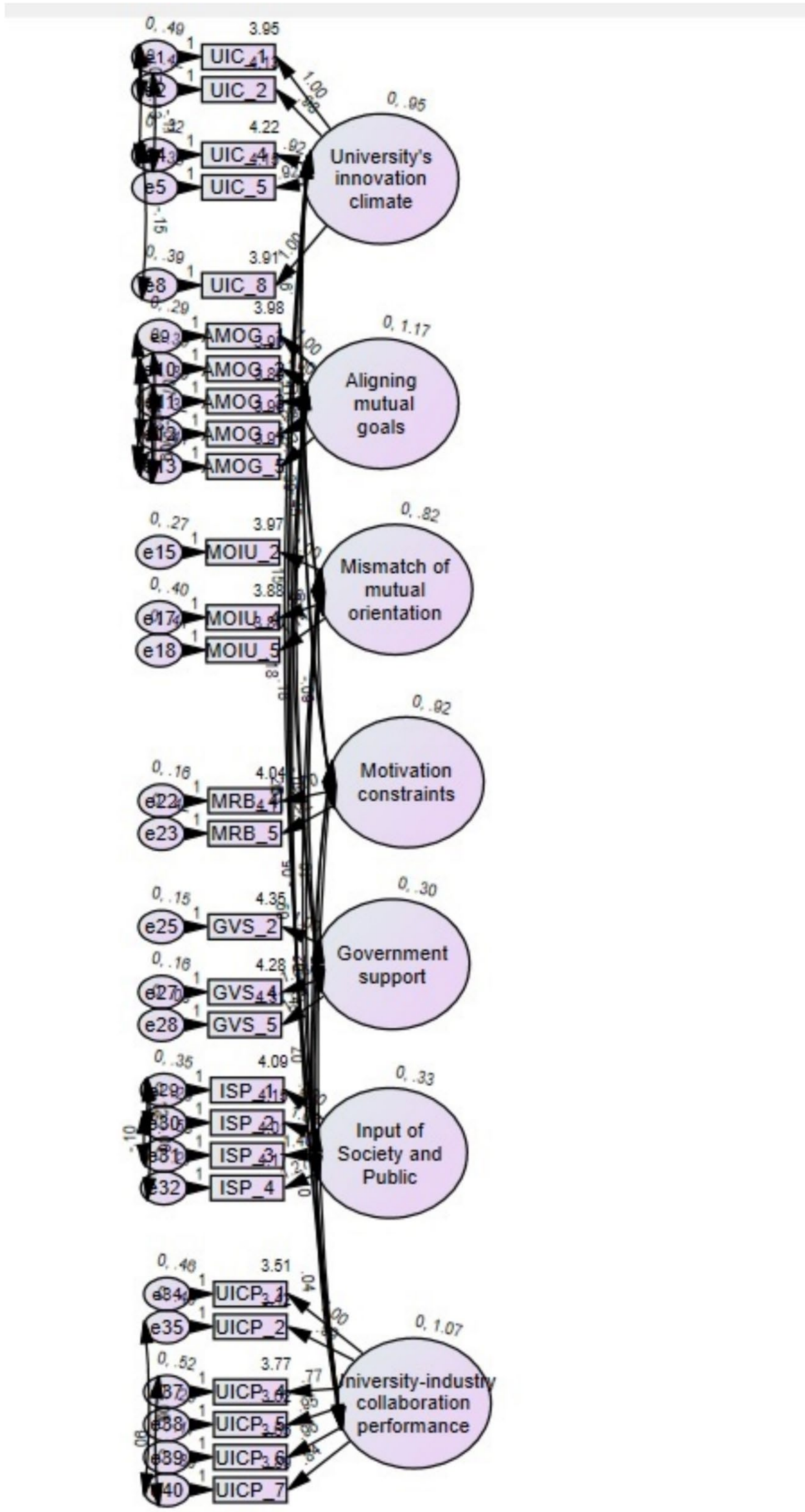

Fig. 3 CFA model in AMOS

Table 8 Hypothesis testing results

Hypothesis	Original sample	Standard deviation	*p*-Values	Decision
H_1: UIC → UICP	0.418	0.129	0.001	Accepted
H_2: AMOG → UICP	−0.074	0.110	0.501	Rejected
H_3: MOIU → UICP	−0.350	0.071	0.000	Accepted
H_4: MRB → UICP	−0.361	0.069	0.000	Accepted
H_5: UIC*GVS → UICP	0.290	0.041	0.034	Accepted
H_6: AMOG*GVS → UICP	−0.007	0.046	0.877	Rejected
H_7: UIC*ISP → UICP	0.004	0.044	0.001	Accepted
H_8: AMOG*ISP → UICP	0.078	0.035	0.026	Accepted

UIC = university's innovation climate, UICP = university–industry collaboration performance, AMOG = alignment of mutual organizational goals, MOIU = mismatch of mutual orientation, MRB = motivation-related constraints, GVS = government support

neuron (independent variables) [130]. The sensitivity analysis demonstrates that the university's innovation climate is the most significant predictor, followed by motivation-related barrier that has a normalized importance of 77.4%. This predictor is followed by the mismatch of orientation between university and industry (63.92%).

Discussion

Our study has explored the enablers and barriers predicting university–industry collaboration using the quadruple helix model, whereby civil society and government roles have been used as moderating variables. Leveraging a hybrid SEM-ANN approach, our research proffers a novel methodological perspective in predicting the factors influencing university–industry collaboration. Therefore, our research provides an innovative methodological paradigm in academia–industry and quadruple helix literature.

Innovation has gained significant attention from academics, businesses, and governments due to the fast advancement of technology and increased global competition, driving them to collaborate. Universities investigate, generate, and disseminate ideas and innovations, while industries subsequently employ these results from academia in real-world applications. However, it is still challenging for industries and universities to determine what procedures work best when forming and maintaining collaborations. As a result, there is a growing demand for codifying practices and principles to steer conception, execution, and completion of collaborative efforts. Correspondingly, this study attempts to delineate the inhibitors and success factors of university–industry collaboration in the milieu of Bangladesh, an emerging economy. Establishing an innovation climate is advocated to foster constructive interactions among collaborators to promote the exchange and dissemination of technological knowledge within UIC projects [85]. Universities with a culture of innovation have fervently launched entrepreneurial programs, seminars, or sessions and sponsored the start-up contests to demonstrate their technical prowess and promote more engagement in UIC initiatives [17]. Furthermore, Shirahada and Hamazaki [131] stated that universities' innovative atmosphere in Research and development (R&D) domains enhances creative behaviors and inventive performance. This study's findings also corroborate the hypothesis (H1) that the universities' innovation climate is an impetus for encouraging innovation outside universities since it provides a forum for exchanging diverse perspectives on specific subjects and highlights the commonalities across the organizations that comprise the UIC.

Collaborations between universities and businesses are significantly influenced by the nature of shared knowledge. A successful relationship depends on the parties' mutual trust, awareness of industry requirements and aspirations, and alignment of mutual goals and research objectives [132]. To our surprise, this study reveals that the alignment of mutual organizational goals between university and industry has no significant impact on UICP (H2). This may be because university researchers are motivated by their innate curiosity and the pursuit of academic recognition. In contrast, industry professionals are primarily motivated by profit-oriented problem-solving and achieving tangible outcomes. Several studies also pointed out that academics are perceived as not particularly pragmatic, while the business's emphasis is more pragmatic and on urgent concerns [73]. According to [133], Bangladeshi universities have a weak R&D orientation because they place more emphasis on teaching and exams than on research and innovation. Instead of seeing universities as co-creators of innovation, industries tend to see them as talent pipelines. Bangladesh lacks the overlapping institutional spheres necessary for effective UICs. university–industry collaboration is further constrained by structural and policy limitations. There is little incentive for industries to invest in collaborative research, and government funding for academic research is scarce and dispersed across ministries [134]. Aligning organizational goals is aspirational rather than practical in the absence of a robust policy framework to encourage co-investment.

This study finds that the mismatch of orientation between industry and university has a negative relationship with UICP (H3). A university's devotion to "open science" may be weakened if it embraces a more business-linked culture to strengthen ties with industry [73]. Openness is related to the objective search for the

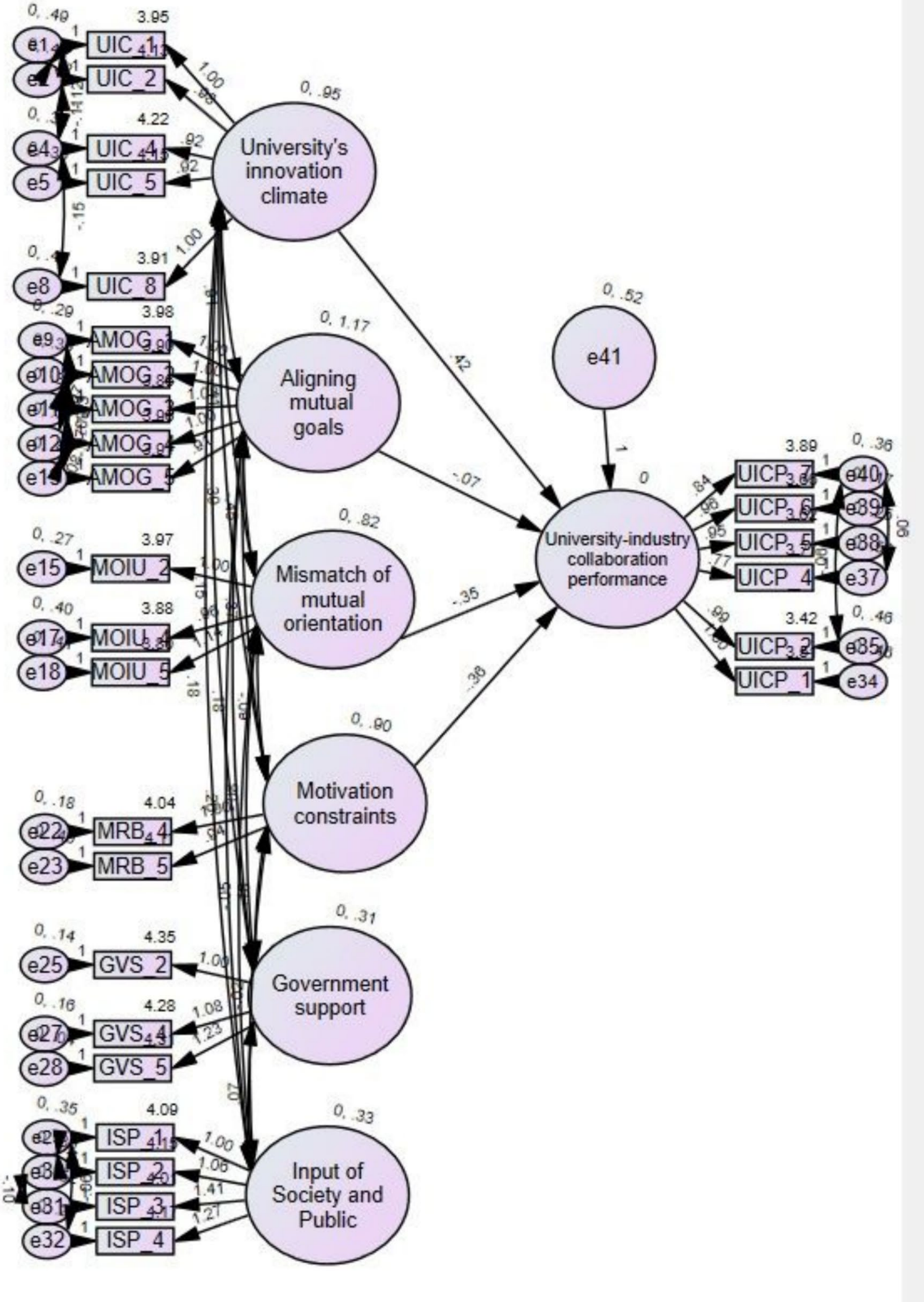

Fig. 4 Structural model in AMOS

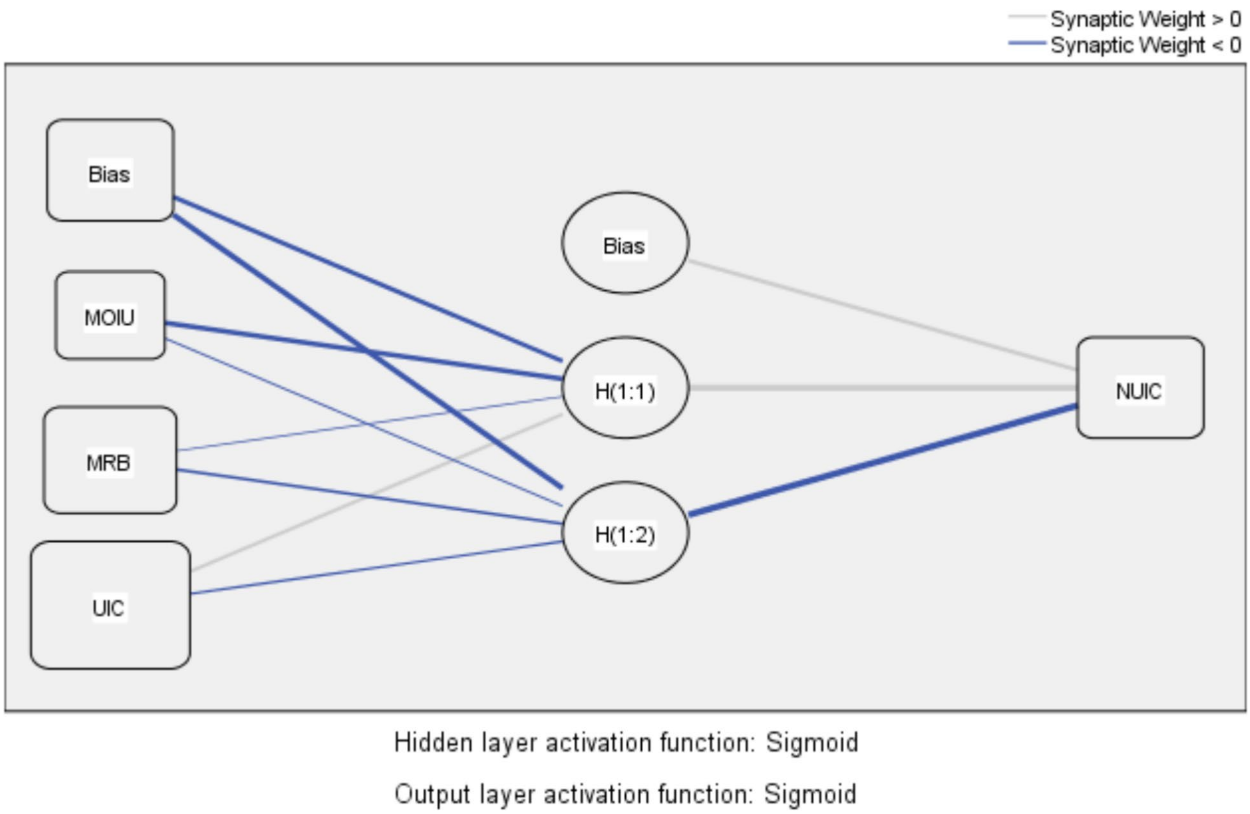

Fig. 5 Artificial neural network diagram

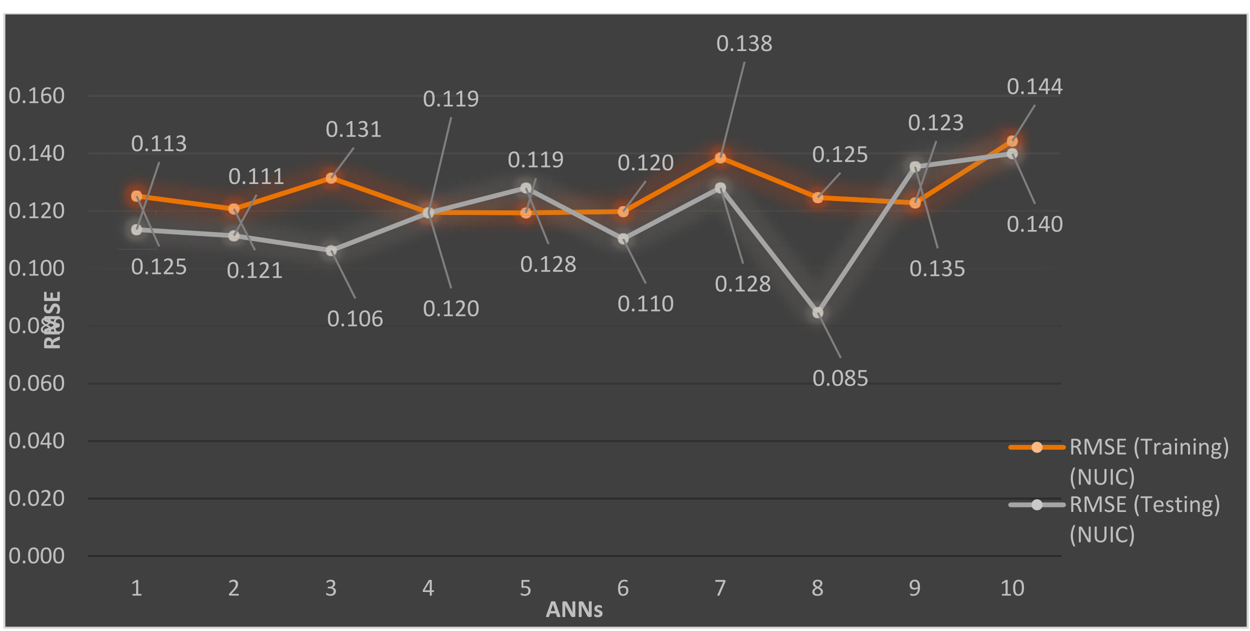

Fig. 6 RMSE values

Table 9 RMSE values in ANN

Training			Testing			
N	SSE	RMSE	N	SSE	RMSE	Total samples
228	3.573	0.125	25	0.322	0.113	253
231	3.366	0.121	22	0.273	0.111	253
229	3.955	0.131	24	0.271	0.106	253
224	3.199	0.120	29	0.413	0.119	253
222	3.161	0.119	31	0.508	0.128	253
228	3.271	0.120	25	0.304	0.110	253
225	4.316	0.138	28	0.459	0.128	253
229	3.558	0.125	24	0.172	0.085	253
225	3.394	0.123	28	0.513	0.135	253
227	4.727	0.144	26	0.509	0.140	253
Mean	3.652	0.127	Mean	0.374	0.118	253
Standard deviation	0.521	0.009	Sd	0.122	0.016	253

SSE = sum square of errors, RMSE = root mean square of errors, N = sample size

Table 10 Sensitivity analysis in ANN

Neural network (NN)	MOIU	MRB	UIC
NN (i)	0.132	0.325	0.543
NN (ii)	0.228	0.305	0.467
NN (iii)	0.248	0.398	0.354
NN (iv)	0.262	0.313	0.425
NN (v)	0.258	0.315	0.427
NN (vi)	0.292	0.275	0.433
NN (vii)	0.317	0.311	0.372
NN (viii)	0.262	0.317	0.422
NN (ix)	0.344	0.306	0.350
NN (x)	0.306	0.344	0.351
Average importance	0.265	0.321	0.414
Normalized importance (%)	63.92%	77.44%	100.00%

truth, academic freedom, and the greatest possible diffusion of information and knowledge. On the contrary, industry depends on commercial secrecy, which is usually linked with a more limited scope of inquiry, a focus on bottom-line results, and less openness to sharing information [135]. In its fundamental nature, the alignment between an industry and a university may present inherent incompatibilities regarding the strategic interests of the former [81]. Furthermore, universities and industries do not trust each other to work together on initiatives [18], and there is a lack of corporate interest in university research due to the absence of industry relevance in university education and research [81]. Notwithstanding the structural and institutional limitations observed in Bangladesh, global trends indicate an increasing trust and collaboration between universities and industries. Recently, universities have increasingly adopted a trend of engaging with industry in a more open and collaborative manner, allowing their intellectual property to be evaluated and developed by industry. Several institutions in the UK have participated in the Easy Access IP project, which facilitates rapid access to university technology, hence optimizing knowledge transfer for public benefit [79]. These patterns highlight the significant impact that established trust can have—an aspect that institutions in Bangladesh might aim to incorporate through organized efforts and supportive policies.

In addition, this study finds that motivation-related constraints have a negative relationship with UICP (H4). This result confirms the findings of earlier studies. Regarding career advancement, academics often do not perceive collaborating with businesses as beneficial. There is also a lack of both monetary and non-monetary incentives offered by universities to academic members who engage in collaborative research with industry partners [72, 83]. In addition, faculty members observed that engagements with industry partners posed a challenge to their responsibilities in teaching and academic research. Companies lack the incentive to work with universities on research projects because of the absence of clear benefits [81]. On the other hand, the present study reveals that government support moderates the relationship between universities' innovation climate and UICP. Abbas, Avdic [136] found that the government assumes a pivotal role in providing financial support to universities and establishing an innovation climate that aligns with the contemporary policy needs of various industries.

They also revealed that the government assisted universities in commercializing new research by organizing interactions with industry experts. Similarly, Boardman [137] showed that financing from the government boosted universities' industry participation and innovation output. Tseng, Huang [17] also advocated that government support may help universities perform better in innovation and encourage more cooperation between universities and industries. Moreover, recent evidence underscores the critical function of government in facilitating effective UIC. For instance, [138] revealed that subsidies make it easier for Chinese companies, especially those in high-tech fields, to work together with universities and research centers. Studies in the Chinese textile sector further indicate that government support stimulates internal research and development and fosters science-based collaboration, hence facilitating innovation [139].

One of the salient findings of this research is that input from society and the public significantly moderates the relationship between universities' innovation climate and UICP (H7). Several researchers have identified that end users, the public, citizen groups, or media public are the stakeholders who can co-create the desired innovations with the universities [47, 91, 94]. According to Roman, Varga [95], individuals can propose novel forms of innovation. Citizens, as end users, are now integral to every step of the innovation process, from ideation to execution. Local communities and interested parties have an impact on the development of research and teaching methods that can address current issues [53]. A fruitful collaboration between academia and industry in research endeavors can be achieved by actively involving end users and providing them opportunities to contribute insights and articulate their needs [95]. Based on examining six UIC case studies, Kunttu, Huttu [140] found that including users and consumers in collaborative research helped universities and industry partners align their mutual purposes and commercialize research outcomes. Increased public participation in innovation and research may help validate research paths and develop more welcoming, long-term inventions by aligning the goals of academics and industry leaders with public preferences [91]. Similar to the findings of this study, research in India (e.g., Bhattacharya & Arora, [141]) highlights the critical role of government facilitation in strengthening university–industry linkages, while studies in Indonesia (e.g., Nurzal, & Rosadi [142]) also identify motivational barriers and trust deficits as key constraints.

Implications of the research

Theoretical implications

Our research proffers several theoretical contributions. Our study provides novel insights into the intersection between the quadruple helix model and university-business linkage. Firstly, by applying the constructs of the quadruple helix model in promoting university–industry collaboration, the research enriches the quadruple helix framework. While previous studies have mainly dealt with QHM in enhancing the national innovation system, our study is one of the first attempts to use QHM to explain university–industry collaboration performance. Secondly, our research possesses methodological novelty. Compared with prior empirical work, which were primarily based on qualitative and interview-based studies, our study develops CB-SEM-based quantitative measures coupled with ANN analysis for identifying and empirically validating the antecedents of university–industry collaboration performance.

Thirdly, our research has verified the effects of government support and civic society engagement as significant moderators that interact with government and industry for better collaboration. Fourthly, our research has contextual uniqueness. Compared with extant literature, which primarily reflects on the contexts of developed economies, our study deals with Bangladesh, an interesting emerging economy context. From the perspective of emerging economies, our research is one of the very few studies that have delineated the enablers and barriers of university–industry collaboration with large sample-based quantitative surveys. Thus, our study responds to the call of previous triple helix and quadruple helix studies to conduct cause–effect relationship-based quantitative analysis. Finally, through ANN analysis, our research offers a fine-grained contribution to the literature by bringing forward and ranking several novel factors, such as the innovation climate of the university, orientation between university and business, and financial and non-financial motivation factors as significant predictors of university–industry collaboration performance. Our research has identified the "mismatch of orientation" as a significant barrier inhibiting academia–industry collaboration. Such evidence is commensurate with previous studies such as Bruneel, d'Este [85].

Practical implications

This study offers a number of implications for academics, practitioners, and decision-makers at regulatory agencies. Our analysis reveals that the university's innovation climate is a driving force in improving the efficacy of collaboration between academia and industry. Therefore, universities should establish innovation-related programs and courses, entrepreneurship contests and workshops, and sponsor venture competitions to enhance innovation climate and culture. The government and industries need to provide assistance and financial resources to universities to nurture an environment congenial for innovation, as extensive research indicates a strong correlation between financing and universities' ability to achieve notable innovation levels [17, 137]. Additionally, most of the universities in Bangladesh still need a formal Technology Transfer Office (TTO), which is hampering smooth communications between academics and industry experts. Universities need to set up TTOs staffed by experienced personnel who will maintain liaison with business professionals and invite them to different workshops, seminars, and other joint programs arranged by both parties. This ongoing networking effort is anticipated to address the lack of mutual trust and orientation between faculty members and industry professionals, which has been recognized as a significant obstacle to UIC in this study.

Furthermore, universities and industries need to provide financial and non-financial rewards to researchers involved in UIC to mitigate motivation-related barriers. The university administrations and the government need to take action to fix the dissonance between academic rewards and industry collaboration so that academics can be compensated for their work in U-I interactions. This suggests that modifications need to be made to the standards utilized for assessing faculty members' research and professional trajectories. The current evaluation system, which primarily focuses on publications, should be expanded to encompass a more comprehensive integration of research outcomes, including patents and collaborations with industry [72]. Additionally, the results encourage industry managers to move beyond short-term, transactional relationships with academia and toward long-term, strategic partnerships. [38]. Companies can make a real difference by helping to plan research agendas, offering internships, and being involved in university governance. Studies show that this kind of involvement greatly increases the spread of new technologies and their usefulness [143].

Moreover, our study's findings provide implications for policymakers to devise new policies, laws, and legal modifications related to UIC to provide a solid legal foundation for the quadruple helix model. The government also needs to establish different forums, such as crowdfunding platforms, where government officials, academics, industry experts, and civil society representatives can exchange views and information with each other and find solutions to existing problems. Targeted actions like tax exemptions for university–industry R&D, grants to set up TTOs, and innovation vouchers can encourage people to work together [144]. Due to the significant moderating effect of civil society in the UIC process revealed by this study, universities and industries need to involve the public while designing new products and services so that these new inventions can fulfill the demands of the end users. Furthermore, as innovation stresses a user-centered approach, civil society organizations should participate in policy forums and crowdfunding platforms that link researchers, entrepreneurs, and end users [145]. This inclusive model of innovation boosts legitimacy and responsiveness, both of which are crucial for sustainable knowledge ecosystems [146].

Limitations and future research directions

Although our research provides significant theoretical and methodological novelty as well as implications for academicians and policymakers, it bears several limitations. Firstly, the research was centered on an Asian country context. Therefore, the generalizability of the findings is limited to only emerging or developing country contexts and might not be applicable to developed country perspectives due to socio-cultural differences [147]. Therefore, future research can involve cross-country or cross-cultural comparisons in developed country contexts further to validate the predictability of the determinants of academia–industry collaboration. Additionally, as this study's sample was limited to faculty members from public universities in Bangladesh, the findings may not fully generalize to private universities or other national contexts [148]. Future research could broaden the sampling frame to include private institutions, cross-country comparisons, and diverse higher education systems to enhance the external validity of the results [149]. Secondly, our ANN model could predict with 71.3% accuracy. Therefore, future research can include additional predictors, preferably from social exchange theory, to augment the model's predictive relevance. Especially, more mediating variables can be tested. Thirdly, our research is relatively cross-sectional in nature and recorded the respondents' answers at a single point in time. Therefore, future surveys need to be longitudinal to determine the temporal effects of the responses. Finally, our study was quantitative, showing causal relationships among the variables. To understand the intricacies of the determinants of academia–industry collaboration and delineate the role of stakeholders in promoting collaboration, forthcoming studies should be qualitative, involving case studies and interviews.

Conclusion

Our research has verified the significant enablers and barriers of university–industry collaboration by applying the quadruple helix model through a hybrid, two-staged SEM-ANN approach with non-compensatory neural network perspective. We have examined the impacts of innovation climate, mutual organizational alignment, motivation constraints, and mismatch of orientation on the university–industry collaboration. Besides, the moderating effects of government support and civil society have been probed. The innovation climate, motivation constraints, and mismatch of orientation have the significant predicting power to influence collaboration. However, the alignment of mutual organizational goals had no impact. Our developed ANN model could predict the university–industry collaboration with 71.3% accuracy. Regarding the normalized importance, the university's innovation climate is the most significant predictor, followed by motivation constraint and the mismatch of orientation.

Appendix A

Measurement items

Appendix A: Identification of the relevant constructs and items

Constructs	Measurement items	Sources
University's innovation climate	The presence of entrepreneurship programs, courses and workshops can invite industries to collaborate	Tseng, Huang [17]
	If there is discussion and sharing of technological knowledge, there is greater interaction between industry and university	
	The university sometimes invites start-ups or innovative companies to share experience	
	If university provides incubation, business plan development, and grant application workshops, the collaboration will increase between firm and university	
	When university promotes multi-disciplinary collaboration among faculty members, the faculties engage in industrial collaboration	
	There is increasing emphasis on innovation and patents by university authority	
Alignment of mutual organizational goals (AMOG)	Agreement on the patient and IP (Intellectual Property) sharing between university and industry would accelerate the collaboration	Muscio and Vallanti [72], Ankrah, Burgess [73], Englund and Felice [75], Khadhraoui, Plaisent [112]
	Homogeneity in the attitudes and orientation between university and industry representatives promotes collaboration	
	Financial and non-financial rewards are important for the faculty members and industrial executives for increasing the motivations for collaboration	
	Mutual trust between university, industry and government would produce better collaboration	
	Long-term memorandum of understanding (MoU) with industry will promote effective research partnership	
Mismatch of orientation between university and industry (MOIU)	The dearth of understanding the market needs from the sides of universities and companies hampers the collaboration	Nsanzumuhire and Groot [81]
	Industry partners sometimes think that university research is more theoretical than practical	
	Unawareness of the perks derived from a collaborative relationship may lessen the potential of academia–industry collaboration	
	There is a lack of trust between university and industry for collaborative projects	
	There is lack of business interest in university because industry thinks that that university research is not focused on industrial applications	

Constructs	Measurement items	Sources
Motivation-related barrier (MRB)	Academics find little benefit in collaborating with industry in terms of career advancement	Nsanzumuhire and Groot [81]
	Collaborations with industry have conflict with teaching/research duties	
	Universities lack rewarding financial and non-financial endowments to the faculties for joint research with universities	
	Industries lack of motivation in doing joint research with university because firms don't find concrete benefits	
	The lack of understanding of industry-academia research causes less collaboration	
Government support (GVS)	Government's effort for joint fund mobilization with industry can enhance academia–industry collaboration	Bruneel, d'Este [85], Yun and Liu [113], Ma, Liu [114]
	Setting up technology transfer office (TTO), and science parks by government would accelerate academia–industry collaboration	
	Government's policy formulation for Academia–Industry joint research will facilitate collaboration	
	Governments' effort for developing public infrastructure would promote academia–industry collaboration	
	Government's initiative in establishing research institutions and ecosystem would promote collaboration	
Input from society and public (ISP)	Surveying customers about product requirements can help formulate better product innovations	Morawska-Jancelewicz [47], Schütz, Heidingsfelder [91], González-Martinez, García-Pérez-De-Lema [94]
	University' testing of products and software with end users would help the commercialization of research	
	Public should have the right to dictate in which segment the innovation is happening	
	Online platforms such as crowdsourcing can invite civil society and citizens for co-creating product ideas and markets	
	End users' inclusion by letting them share their ideas and demand would cause successful academia–industry research collaboration	
University–industry collaboration performance (UICP)	The amount of research work jointly conducted with industry has increased	Nsanzumuhire and Groot [81], Kunttu [115]
	The representatives from various industries and firms visit us to exchange mutual interests	
	The faculty members have the intention to undertake industry-specific research projects	
	While developing education curriculum and syllabus, university departments collaborate with industry executives in co-design	
	The university puts importance in academic entrepreneurship (spin-offs/start-ups)	
	The numbers of meetings, workshops, conferences, or other informal contacts are increasing with the industrial alumni	

Appendix B

Questionnaire

"Decoding University–Industry Collaboration: A SEM-ANN Quadruple Helix Approach"

Dear Respondent,

You are being cordially requested to participate as a respondent in a research study titled "**Decoding University–Industry Collaboration: A SEM-ANN Quadruple Helix Approach**." This questionnaire is developed for academic purposes only. The identity of the respondents will not be disclosed anywhere, and data will be analyzed and published as aggregate. Feel free to answer every question given below. Please place a tick mark on the answer best suited to you.

Section A: Demographic Information

Section B: University's innovation climate (UIC)

Section A: Demographic Information

1. University Name:
2. Department:
3. Your name:
4. Contact Number:
5. E-mail:
6. Gender: □ Male □ Female □ Others
7. Age: □ 26 - 30 □ 31 - 35 □ 36 - 40 □ 41 - 45 □ Above 45 years
8. Educational qualification (Do you have PhD?):
   □ **Yes** □ No
9. Years of university work experience:
   □ Less than 3 years
   □ 3 – 6 year
   □ 7 – 10 year
   □ 11– 14 year
   □ More than 14 years

Please encircle/put a tick/cross mark the number according to the extent of your agreement and disagreement with the statement.

(Note: 5 = strongly agree, 4 = agree, 3 = neutral, 2 = disagree, 1 = strongly disagree).

University's innovation climate (UIC)	Strongly agree (5)	Agree (4)	Neutral (3)	Disagree (2)	Strongly disagree (1)
1. The presence of entrepreneurship programs, courses and workshops can invite industries to collaborate	5	4	3	2	1
2. If there is discussion and sharing of technological knowledge, there is greater interaction between industry and university	5	4	3	2	1
3. The university sometimes invites start-ups or innovative companies to share experience	5	4	3	2	1
4. If university provides incubation, business plan development, and grant application workshops, the collaboration will increase between firm and university	5	4	3	2	1
5. When university promotes multi-disciplinary collaboration among faculty members, the faculties engage in industrial collaboration	5	4	3	2	1
6. There is increasing emphasis on innovation and patents by university authority	5	4	3	2	1

Section C: Alignment of mutual organizational goals (AMOG)

Please encircle/put a tick/cross mark the number according to the extent of your agreement and disagreement with the statement.

(Note: 5 = strongly agree, 4 = agree, 3 = neutral, 2 = disagree, 1 = strongly disagree).

Alignment of mutual organizational goals (AMOG)	Strongly agree (5)	Agree (4)	Neutral (3)	Disagree (2)	Strongly disagree (1)
7. Agreement on the patient and IP (Intellectual Property) sharing between university and industry would accelerate the collaboration	5	4	3	2	1
8. Homogeneity in the attitudes and orientation between university and industry representatives promotes collaboration	5	4	3	2	1
9. Financial and non-financial rewards are important for the faculty members and industrial executives to increase motivation for collaboration	5	4	3	2	1
10. Mutual trust between universities, industry and government would produce better collaboration	5	4	3	2	1
11. Long-term memorandum of understanding (MoU) with industry will promote effective research partnership	5	4	3	2	1

Section D: Mismatch of the orientations of industry and university (MOIU)

Please encircle/put a tick/cross mark the number according to the extent of your agreement and disagreement with the statement.

(Note: 5 = strongly agree, 4 = agree, 3 = neutral, 2 = disagree, 1 = strongly disagree).

Mismatch of the orientations of industry and university (MOIU)	Strongly agree (5)	Agree (4)	Neutral (3)	Disagree (2)	Strongly disagree (1)
12. The dearth of understanding the market needs from the sides of universities and companies hampers the collaboration	5	4	3	2	1
13. Industry partners sometimes think that university research is more theoretical than practical	5	4	3	2	1
14. Unawareness of the perks derived from a collaborative relationship may lessen the potential of academia–industry collaboration	5	4	3	2	1
15. There is a lack of trust between university and industry for collaborative projects	5	4	3	2	1
16. There is lack of business interest in university because industry thinks that that university research is not focused on industrial applications	5	4	3	2	1

Section E: Motivation-related barriers (MRB)

Please encircle/put a tick/cross mark the number according to the extent of your agreement and disagreement with the statement.

(Note: 5 = strongly agree, 4 = agree, 3 = neutral, 2 = disagree, 1 = strongly disagree).

Motivation-related barriers	Strongly agree (5)	Agree (4)	Neutral (3)	Disagree (2)	Strongly disagree (1)
17. Academics find little benefit in collaborating with industry in terms of career advancement	5	4	3	2	1
18. Collaborations with industry have conflict with teaching/research duties	5	4	3	2	1
19. Universities lack rewarding financial and non-financial endowments to the faculties for joint research with universities	5	4	3	2	1
20. Industries lack motivation in doing joint research with universities because firms don't find concrete benefits	5	4	3	2	1
21. The lack of understanding of industry-academia research causes less collaboration	5	4	3	2	1

Section F: Government support

Please encircle/put a tick/cross mark the number according to the extent of your agreement and disagreement with the statement.

(Note: 5 = strongly agree, 4 = agree, 3 = neutral, 2 = disagree, 1 = strongly disagree).

Government support	Strongly agree (5)	Agree (4)	Neutral (3)	Disagree (2)	Strongly disagree (1)
22. Government's effort for joint fund mobilization with industry can enhance academia–industry collaboration	5	4	3	2	1
23. Setting up technology transfer office (TTO), and science parks by government would accelerate academia–industry collaboration	5	4	3	2	1
24. Government's policy formulation for Academia–Industry joint research will facilitate collaboration	5	4	3	2	1
25. Governments' effort for developing public infrastructure would promote academia–industry collaboration	5	4	3	2	1
26. Government's initiative in establishing research institutions and ecosystem would promote collaboration	5	4	3	2	1

Section G: Input from society and public (ISP).

Please encircle/put a tick/cross mark the number according to the extent of your agreement and disagreement with the statement.

Input from society and public (ISP)	Strongly Agree (5)	Agree (4)	Neutral (3)	Disagree (2)	Strongly disagree (1)
27. Surveying customers about product requirements can help formulate better product innovations	5	4	3	2	1
28. University' testing of products and software with end users would help the commercialization of research	5	4	3	2	1
29. Public should have the right to dictate in which segment the innovation is happening	5	4	3	2	1
30. Online platforms such as crowd-sourcing can invite civil society and citizens for co-creating product ideas and markets	5	4	3	2	1
31. End users' inclusion by letting them share their ideas and demand would cause successful academia–industry research collaboration	5	4	3	2	1

Section H: University–industry Collaboration performance (UICP)

Please encircle/put a tick/cross mark the number according to the extent of your agreement and disagreement with the statement.

(Note: 5 = strongly agree, 4 = agree, 3 = neutral, 2 = disagree, 1 = strongly disagree).

University–industry collaboration performance (UICP)	Strongly agree (5)	Agree (4)	Neutral (3)	Disagree (2)	Strongly disagree (1)
32. The amount of research work jointly conducted with industry has increased	5	4	3	2	1
33. The representatives from various industries and firms visit us to exchange mutual interests	5	4	3	2	1
34. The faculty members have the intention to undertake industry-specific research projects	5	4	3	2	1
35. While developing education curriculum and syllabus, university departments collaborate with industry executives in co-design	5	4	3	2	1
36. The university puts importance in academic entrepreneurship (spin-offs/start-ups)	5	4	3	2	1
37. The numbers of meetings, workshops, conferences, or other informal contacts are increasing with the industrial alumni	5	4	3	2	1
38. The amount of research work jointly conducted with industry has increased					

Abbreviations

ANN	Artificial neural network
AMOG	Alignment of mutual organizational goals
AVE	Average variance extracted
CB-SEM	Covariance-based structural equation modeling
CFA	Confirmatory factor analysis
CR	Composite reliability
GFI	Goodness-of-fit index
GVS	Government support
HTMT	Heterotrait–monotrait ratio
ISP	Input from society and public
MOIU	Mismatch of orientation between university and industry
MRB	Motivation-related barriers
QHM	Quadruple helix model
RMSEA	Root mean square error of approximation
SEM	Structural equation modeling
SSE	Sum of squares for error
TTO	Technology transfer office
UIC	University's innovation climate
UICP	University–industry collaboration performance
U-I Collaboration	University–industry collaboration

Author contributions

M.H. conceptualized the research topic, collected data, and wrote the draft of the manuscript. S.M. also took part in the conceptualization of the research topic, conducted data collection, analysis, and writing of the draft. C.M. designed the research questionnaire and conducted data collection and writing of the literature review and conclusion parts. M.N.U supervised the research, wrote the discussion part, and amended the manuscript. M.S. conducted data collection and analysis, wrote the data analysis part and coordinated the research drafts. All the authors have read and approved the manuscript.

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Data availability

The data that support the findings of this study are available from the authors upon request.

Declarations

Ethical approval and consent to participate

The study was reviewed and approved by the Research Ethics and Compliance Board (RECB), under Review No: R25-03. All procedures performed in this study involving human participants were conducted in accordance with the ethical standards of the institutional review board and with the 1964 Helsinki Declaration and its later amendments. Informed consent was obtained from all participants prior to their inclusion in the study. Participation was entirely voluntary, and respondents were assured of the confidentiality and anonymity of their responses.

Consent for publication

The manuscript does not contain any individual person's data in any form (including personal details, images, or videos). Therefore, consent for publication is not applicable.

Competing interests

The authors declare no competing interests.

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