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SONG, Yang, BERGER, Ron, RACHAMIM, Matti, JOHNSTON, Andrew <http://orcid.org/0000-0001-5352-9563> and COLLADON, Andrea Fronzetti

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Modeling the industry perspective of university-industry collaborative innovation alliances: Player behavior and stability issues

Yang Song[1], Ron Berger[2], Matti Rachamim[2], Andrew Johnston[3] and Andrea Fronzetti Colladon[4]

Abstract

Many firms find it challenging to develop innovations, evidenced by the ever-mounting number of university-industry research alliances. This study examines the strategic choices of actors who participate in collaborative innovation alliances involving partnerships between industry and universities (U-I) based on a stochastic evolutionary game model. White noise was introduced to reflect uncertainty and the stochastic interferences caused by the differences between actors. Using the Itô stochastic differential equation theory, we analyze stability issues of player behaviors in the evolution of a collaborative innovation alliance. The results illustrate that improvements in innovation efficiency can contribute to U-I collaborative innovation alliances. High knowledge complementarity appears to be unbeneficial to the stability of these alliances, and controlling knowledge spillovers may suppress free-rider problems from both sides of the game. Our study contributes to innovation research by providing a decision-making reference for the design of U-I cooperation.

Keywords

University-Industry links, innovation efficiency, knowledge complementary, knowledge spillovers, stochastic evolutionary game

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Introduction

One of the main drivers of firm success in the present knowledge economy is the ability to innovate. While universities tend to support longer-term upstream research, industry-based innovation must satisfy firms' clients in the short run.[1] Typically, universities' focus is more on scientific challenges far from the market, pushing technological frontiers, and less on the commercialization of new products.[2] In addition, universities are considered more stable and reliable network partners because of their public funding.[3] University-industry (U-I) research partnerships are designed to generate outputs of high academic relevance and practical commercial-industrial application. Due to rapid growth in information technology and knowledge-based work, the concept of knowledge management and knowledge co-creation has gained momentum [4] in recent years. Researchers have shown that appropriate use of external knowledge has a positive impact on firms' innovation performance,[1,5–7] but that the effects of collaboration

[1]Economics School of Jilin University, Changchun, China
[2]Graduate School of Business Administration, Bar-Ilan University, Ramat-Gan, Israel
[3]Sheffield Hallam Business School, Sheffield University Management School, Sheffield, UK
[4]Department of Engineering, University of Perugia, Perugia, Italy

Corresponding author:
Andrea Fronzetti Colladon, Department of Engineering, University of Perugia, Via G. Duranti, 93, Perugia 06125, Italy.
Email: andrea.fronzetticolladon@unipg.it

may differ depending on the nature of the specific U-I alliance players involved.

It is essential to understand better U-I alliances as fundamental knowledge generators and drivers for industry success.[8] Within open innovation frameworks, the transfer of knowledge, expertise, and technology from U-I is commonly regarded as an important source of knowledge creation.[9,10] In U-I alliances, the aim is to tap into each other's resources and enrich one's mutual knowledge base.[11,12] By developing collaborative links with universities, industries can leverage skills and knowledge to enhance their capabilities, expand network reach, and improve industry competitiveness.[13–15] Empirical work shows that the benefits of U-I alliances can be increased sales, research productivity, patenting and learning.[16–19] Innovation is considered an important determinant of competitive advantage.[20] Universities are typically cited as "safer" institutions for industrial collaboration.[21] Therefore, most research-led universities have created specific knowledge commercialization departments to further U-I alliances.

Collaboration between U-I has received much attention from academics.[22] One advantage of collaborating with universities is their ability to generate new knowledge and approaches to solve problems.[23] Confronted with reduced funding from the government, universities seek U-I collaborations to compete in an environment increasingly dependent on market forces.[24] The transfer of knowledge between U-I may involve different types of research cooperation, such as intellectual property rights, spin-offs, start-ups, and technology transfer. To facilitate such transfers, both universities and industry companies need an open culture, absorptive capacities, and mutual trust.[25] By its nature, R&D collaboration takes a long time to yield mutual benefits.[26] As universities and companies have diverse goals and motivations in collaborating, there is concern that opportunistic behavior and problems between U-I may fail such collaborations.

Universities are portrayed in networking theory as key nodes in external knowledge networks for industry within open innovation systems.[27] Research suggests that university engagement varies and is typically considered less important by companies than other sources of knowledge.[17,28,29] Tensions in U-I collaborations undoubtedly exist as the industry seeks to commercially exploit knowledge,[13,28,30] while universities are more interested in exploring its frontiers.[14,31] Consequently, the process of U-I collaboration is not without friction[32] and demands further understanding. In this study, we investigate the evolution of knowledge exchange networks. We develop a model in which U-I actors share knowledge through R&D collaboration. Since such collaboration is costly for firms, they face a trade-off between the benefits of new partnerships and their costs.

While the literature has expanded over the past two decades, shedding significant light on the formation and facilitation of collaborative U-I alliances, there have been few attempts to model this activity to understand better the stability of these alliances.[33] To explore U-I alliances, we have chosen to utilize techniques from evolutionary game theory—which has proved its effectiveness in dealing with uncertainty and with those dynamic characteristics of firms endogenously generated by product innovations, processes, and organizational forms.[34] We argue that the research gap in the U-I cooperation literature stems from an incomplete understanding of implicit key constructs that affect the collaboration process itself. The motivation for developing a game theory modeling approach comes from the realization that most of the current literature on U-I innovation collaboration fails to adequately elucidate the underlying failure and success of seemingly comparable U-I alliances. For the specific context of U-I collaboration, Bruneel et al. [28] developed a game-based model to show that firms seek collaboration on projects that are more relevant to their core business, and are primarily interested in the most reputable and prestigious universities. Indeed, empirical evidence has shown that the quality of a university is a significant determinant of U-I innovation alliance success.[35,36]

Drawing on evolutionary game theory and human behavior modeling, which proved to be helpful for the understanding of various economic issues,[37–39] we propose a conceptual framework that considers three factors: (1) innovation efficiency: the ease at which new knowledge is turned into new outputs by the firm; (2) knowledge complementarity: the homogeneity of partners' knowledge base; and (3) knowledge spillovers: the extent to which unintentional sharing of knowledge takes place. Using this framework, we assess the circumstances under which firms follow an open innovation strategy through an alliance with a university or a closed strategy, where they work alone innovating in-house. Based on the assumption of bounded rationality, our model examines the evolution of the interaction between multiple U-I actors, providing a logical explanation for the mechanism of U-I innovation alliances' success or failure based on knowledge spillovers.

The study makes three main contributions: first, it examines when higher levels of innovation efficiency promote a collaborative innovation strategy; second, it shows that the lower the degree of complementarity of knowledge between U-I partners, the higher the probability that both parties will choose to form a collaborative innovation alliance; and third, it shows that when the level of knowledge spillovers is high, a closed innovation strategy is more likely to be selected to obtain higher individual returns.

The paper is structured as follows: the literature review outlines the theory of U-I alliances. We then discuss the use of game theory to model collaborative innovation among U-I alliances, presenting both the conceptual underpinnings and the assumptions of the model. Subsequently, we analyze the stochastic evolutionary game model and discuss the stability problem of the equilibrium solutions from a theoretical point of view. Finally, we present the results from the simulation model, taking different scenarios into account and discussing the practical and theoretical contributions of the findings. We conclude by summarizing practical implications and suggesting future research.

Literature review

Universities are increasingly regarded as "anchor institutions" within innovation systems, which play a key role in enabling the development of new products, processes, and technologies by supplying the knowledge required to innovate.[40–43] Knowledge is characterized as tacit, local, cumulative, and complex.[3] Historically, academic institutions focused on basic research where breakthrough concepts spill over into industry sporadically. Today, however, universities increasingly assume equity positions in firms using their intellectual property as a mechanism to generate revenues. Empirical evidence of the tangible benefits of U-I alliances is widespread. Researchers find that U-I alliances enhance firms' competitiveness.[13,29,44,45] Industry invests in internal R&D not only to generate innovation but also to develop absorptive capacities and identify external knowledge.[1] If a firm lacks internal resources, collaboration with outside partners becomes more attractive.[12,46]

With rapid changes in market demand and soaring development costs, it is increasingly difficult for firms to succeed by relying solely on internal capabilities and resources.[47] The extant literature suggests that the stability of U-I innovation alliances varies.[32] Indeed, instability may result from several factors. First, the U-I actors may be driven by different motives. The industry may be more focused on profit than on contributing to an existing body of knowledge.[9,14,30,31] Second, given the heterogeneity of U-I actors, tensions may arise from having different mindsets and work methods, thus limiting cooperation.[48,49] Third industry companies usually operate with stricter time constraints.[50] Fourth, different communication styles may cause misunderstandings, further undermining cooperation.[51] Finally, researchers in the industry may question the efficacy of academic research in solving practical problems.[52,53]

Researchers suggest that the stability of collaborative projects may hinge on the ability of U-I actors to understand each other's practices.[30,43,54] Knowledge complementarity between U-I actors, i.e., their closeness in terms of working practices, knowledge bases,[55] and technological capabilities, is a relevant factor for U-I collaboration success.[56–60] Such complementarity enables the actors to understand each other better, thus reducing uncertainty in the cooperation.[58,61,62] Empirical evidence suggests that universities appear to be more inclined to cooperate when projects are less aligned with their capabilities, as they comprise an opportunity to acquire new knowledge and skills.[63]

It is thought that universities' culture is dissimilar from that of industry.[26] Universities are seen as prime institutions for knowledge creation and dissemination. Nonetheless, they may be partially funded by the government, which may weaken their incentive to pursue profits and the ability to respond to changes.[25] Although aligned at times, U-I collaborations' efforts are often categorized by friction leading to frustration.[24] Universities are principally concerned with the assimilation and distribution of new knowledge and the education of their students. U-I collaborations concentrate on the shift from basic research to applied research.[64] Collaboration between U-I focuses not only on knowledge sharing but also on preparing the industry workforce.[64] Academics may see such collaborations as compromising their academic integrity, limiting the dissemination of research results, narrowing research issues, and encouraging faculty migration to industry.

Knowledge sourcing from external parties has long been acknowledged as instrumental in successful innovation.[65] It is a relational benefit stemming from strategic interorganizational networks that facilitate knowledge flow. Industry invests in internal R&D not only to generate innovations but also to develop the ability to identify external knowledge.[1] Some scholars claim that U-I knowledge spillovers are part of the open innovation mentality.[15,44] They argue that because this is an externality, developing formal alliances to access such sources of knowledge is unnecessary.[66–68] In other words, knowledge spillovers may produce less stable U-I alliances, as companies can source knowledge from their environment without formally engaging with a university partner.

Conversely, when knowledge spillovers are less prevalent, firms are driven toward formal U-I alliances with more stable partnerships.[59,69] Both the resource-based view and the knowledge-based view of the firm emphasize that access to external knowledge is essential to innovation.[70] However, such knowledge is not easily obtained, as it is often tacit or context-specific, thus necessitating the absorption of specific capabilities.[2,71]

Knowledge is a core competence in modern economies.[25] Companies often collaborate with universities to save costs, enhance their technological capacity and economic competitiveness, shorten their product life cycle, develop their human capital and obtain incentives for developing such collaborations.[72] They can get solutions to specific problems, subcontract R&D, reduce and share risks, enhance corporate image, and access research networks, new knowledge, cutting-edge technology, expertise, and complementary know-how.

Game model assumptions and formulation

The complexity of strategic alliances such as U-I collaborations has been addressed by relational theory [73] and transaction cost theory.[74] These theories referred to the transaction costs of managing collaborative relationships. In game theory, such collaborations are sometimes seen as a prisoner's dilemma.[75] A resource-based view of the firm was used to define why one initially cooperates and then stops.[76] An institutional theory exists under a supposition of finite resources,[77] claiming that organizations adapt to maximize their efficacy. Rational economic action was also illustrated by Van de Donk and Snellen.[78]

Smith and Price[79] were the first to propose the evolutionary game theory model. Unlike traditional game theory, the evolutionary game theory makes no complete rationality or information assumptions. Actors conduct repeated games by pairing randomly and ultimately achieving a dynamic and stable state.[80] Game theory models are generally utilized for decision-making processes. For example, Gandomi et al.[81] developed a game-theoretic model to guide the choice of the reward structure of customer loyalty programs. Huang et al.[82] created a stochastic game model that focused on the interaction between attackers and defenders in ICPSs and defined optimal defense strategies to minimize system losses. Akçura and Ozdemir[83] employed a game theory model to investigate how and when data-driven collaborations between manufacturers and retailers are beneficial. Hara and Matsubayashi[84] developed a stochastic game theory model to examine the strategic introduction of premium store brands through collaboration between a retailer and a national brand manufacturer. An et al.[85] developed an evolutionary game model to analyze the optimal interaction strategy between financial and regulatory institutions.

The present study utilizes an agent-based simulation to investigate the role of U-I links in innovation generation and diffusion. Innovation diffusion in networks is an attractive research topic for innovation economics and design. Indeed, spillovers can support economic development due to their positive impact on economic growth.[3] Whether U-I collaboration can achieve desired goals depends on many factors, such as a player's level of rationality, collaboration attitudes, expected output, and available resources.[28] U-I alliances help reduce the disadvantages of asymmetric information, moral hazard, and adverse selections.

On the other hand, U-I players' interests are not always aligned. The bounded rationality of U-I alliance participants makes it difficult to find an optimal strategy when facing complex problems. As a result, the alliance process is constantly changing and adjusting. Accordingly, our model considers recurrent games. If two parties find a minimal incentive to start collaborating, they enter the execution phase, where they begin to explore new knowledge areas. The aim is to tap into each other's resources. Existing absorptive capacities determine success. We consider a network formation process in which creating a new link requires a bilateral agreement between two parties. By contrast, the deletion of a link only requires a unilateral decision. Consistent with this mechanism, we implement the definition of pairwise stability as a network equilibrium criterion. We model explicitly the evolution process in which, at the beginning of each period, a pair of firms decides whether to form or delete a link based on knowledge spillovers.

At the core of our model is the argument that the stability of U-I alliances depends on innovation efficiency. It represents the industrial processes within the firm that transform the knowledge input into profits.[86] Therefore, innovation efficiency reflects firms' capacity to source, assimilate, absorb and process external knowledge, typically conceptualized as the organization's absorptive capacity.[87–89] In addition, innovation efficiency reflects a firms' ability to transform knowledge into something tangible (REFS). Therefore, higher levels of innovation efficiency may signify that the industry is good at absorbing knowledge from the U-I alliances.[69] In such a case, partnerships may be more stable, as they are likely to facilitate a successful transfer of knowledge between U-I actors. Conversely, low levels of innovation efficiency may be a sign of 'assimilation barriers,' which may impede the successful transfer of knowledge.[88] In such a case, the alliance may be less stable.

Evolutionary game theory can model strategic interactions where players choose cooperation strategies that provide an advantage (also in the future). Indeed, players know that their present actions may influence the future actions of other players.[38] Path dependence is one of the main features of complex economic structures and evolutionary games,[90] suggesting that history matters in the long-term progression of markets and innovation. This regards positive or negative feedback effects.[91] However, researchers should be cautious in inferring present conditions from past events, as historical environments shaping past conditions may no longer exist.[92,93] Therefore, choosing among different pasts can be seen as a stochastic process.

Game theory provides tools to model the innovation process resulting from collaboration in a business environment.[94] For example, Baldwin and von Hippel[95] have presented hybrid models to illustrate collaborative innovation dynamics and show that the benefits of open innovation can outweigh those of innovation obtained by a single producer. Similarly, Ritala and Hurmelinna-Laukkanen[96] compared coopetition and collaboration, suggesting that value-creation in coopetition depends on shared knowledge. In addition, Arsenyan et al.[97] claimed that a game theory approach could yield a better understanding of the mechanisms underlying collaboration, where trust and the possibility of co-learning play an important role.

Based on our literature review, our model is formulated on the following assumptions:

Assumption 1. We consider a game with two players: firms and universities. We select one player from each group at each game stage, indicating the firm as E and the university as U.

Assumption 2. Each player may choose open innovation or closed innovation. To form a successful alliance, they must both choose open innovation. By contrast, if one or both players choose closed innovation, the alliance fails, and the simulation ends.

Assumption 3. The players in the game are economically motivated, with bounded rationality. They aim to maximize their utility. It is not possible for a player to know the strategy choice of the other player in advance.

Assumption 4. Players are different in terms of innovation capabilities, and each pair of players has a certain level of knowledge complementarity.

Evolutionary game model formulation

Based on prior research, e.g, Anbarci et al.,[98] we define the innovation return function of player one E and player two U as:

$$\pi = AK^{\alpha} \tag{1}$$

In this function, $A > 0, 0 < a < 1$ and π represent the return from innovation. K represents a knowledge input (such as a patent). A is the innovation efficiency, representing the industrial process that transforms the knowledge input into profits. α is the output elasticity of knowledge input (such as patent conversion rate, etc.). Players one and two have different innovation capabilities, expressed by different coefficients of A, K, and α, which are distinguished by different subscripts, E and U. If the firm and the university form a knowledge sharing collaborative innovation alliance, we define the knowledge input as:

$$\widetilde{K} = [(K_E)^{\rho} + (K_U)^{\rho}]^{1/\rho} \tag{2}$$

Furthermore, ρ is the degree of knowledge complementarity in the collaborative innovation alliance with $0 < \rho \leq 1$. A lower value of ρ implies a higher degree of complementarity. The existing literature refers to the case of perfect substitutability when ρ is equal to 1, showing, in the case of two firms, that the marginal productivity of R&D investments is always independent of the investment made by the other firm.[99]

We also define $\beta \in (0, 1)$ as a knowledge spillover coefficient to reflect the transfer and absorption of knowledge among players. Based on assumption 2, each player can either form a collaborative U-I alliance or choose a closed-innovation strategy. Accordingly, there are four possible strategic combinations:

(1) Player one (the firm) chooses an open innovation strategy, and player two (the university) chooses a closed innovation strategy. In this case, player one will invest all its knowledge K_E in the collaborative innovation alliance. The knowledge spillover coefficient isPlayer two will obtain extra knowledge from player one: βK_E. Since player two chooses closed innovation, player one will not acquire extra knowledge. We also assume additional costs for the firm caused by the knowledge spillover,[100] denoted by C_E. Thus, the return function of player one, the firm, is π_{12}^{E}, and the return function of player two, the university, is π_{12}^{U}:

$$\pi_{12}^{E} = A_E K_E^{\alpha_E} - C_E \tag{3}$$

$$\pi_{12}^{U} = A_U [\beta K_E^{\rho} + K_U^{\rho}]^{\alpha_U/\rho} \tag{4}$$

(2) Player one (the firm) chooses a closed innovation strategy, and player two (the university) chooses an open innovation strategy. The additional cost to the university caused by the knowledge spillover is C_U. We derive the two return functions following the same logic of point 1:

$$\pi_{21}^{E} = A_E [K_E^{\rho} + \beta K_U^{\rho}]^{\alpha_E/\rho} \tag{5}$$

$$\pi_{21}^{U} = A_U K_U^{\alpha_U} - C_U \tag{6}$$

(3) Both U-I players choose open innovation. Both will invest all their knowledge, K_E and K_U, in the collaborative innovation alliance and obtain extra knowledge from the other player. It is worth noting that there is no knowledge spillover in this case, as both players share all their knowledge with the other partner. The return function is π_{11}^{E} for player one and π_{11}^{U} for player two:

$$\pi_{11}^{E} = A_E [K_E^{\rho} + K_U^{\rho}]^{\alpha_E/\rho} \tag{7}$$

$$\pi_{11}^{U} = A_U [K_E^{\rho} + K_U^{\rho}]^{\alpha_U/\rho} \tag{8}$$

(4) Both players choose closed innovation. In this case, although the two players formally set up an innovation alliance, they do not successfully share their knowledge. Therefore, we have the return function π_{22}^{E} for player one and π_{22}^{U} for player two:

$$\pi_{22}^{E} = A_E K_E^{\alpha_E} \tag{9}$$

Table 1. Return matrix for the players of the innovation alliance.

		University	
Firm		Open innovation: $y(t)$	Closed innovation: $1-y(t)$
	Open innovation: $x(t)$	π_{11}^{E} ; π_{11}^{U}	π_{12}^{E} ; π_{12}^{U}
	Closed innovation: $1-x(t)$	π_{21}^{E} ; π_{21}^{U}	π_{22}^{E} ; π_{22}^{U}

$$\pi_{22}^{U} = A_U K_U^{\alpha_U} \tag{10}$$

Based on the cases mentioned above, we have the return matrix for the innovation alliance presented in Table 1.

At time t, the ratio of sharing innovation alliances for the firm is $x(t), x(t) \in [0,1]$ and the ratio of receiving strategies is $1-x(t)$. Similarly, the ratio of sharing strategies for the university is $y(t), y(t) \in [0,1]$, and that of receiving strategies is $1-y(t)$. Therefore, the expected return for the firm is given by the following two equations:

$$u_H = y(t)\pi_{11}^{E} + (1-y(t))\pi_{12}^{E} \tag{11}$$

$$u_H = y(t)\pi_{21}^{E} + (1-y(t))\pi_{22}^{E} \tag{12}$$

The average return is:

$$\overline{u} = x(t)u_H + (1-x(t))u_B \tag{13}$$

Similarly, for the university, we have the following equations:

$$v_H = x(t)\pi_{11}^{U} + (1-x(t))\pi_{21}^{U} \tag{14}$$

$$v_B = x(t)\pi_{12}^{U} + (1-x(t))\pi_{22}^{U} \tag{15}$$

The average return is:

$$\overline{v} = y(t)v_H + (1-y(t))v_B \tag{16}$$

When including the dynamic change speed of $x(t)$ and $y(t)$, we adopt the dynamic equations from Amann and Possajennikov[101]:

$$\begin{aligned} dx(t) &= x(t)\cdot\left(u_H - \overline{u}\right)dt \\ &= x(t)\cdot[u_H - x(t)u_H - (1-x(t))u_B]dt \end{aligned} \tag{17}$$

$$\begin{aligned} dy(t) &= y(t)\cdot\left(v_H - \overline{v}\right)dt \\ &= y(t)\cdot[v_H - y(t)v_H - (1-y(t))v_B]dt \end{aligned} \tag{18}$$

The inappropriateness of a deterministic model

The last two equations are dynamic but do not consider stochastic inference. In real collaborative innovation alliances, player choices are more complex.[97,101] Many additional uncertain factors can affect players' behaviors, which we do not consider. Therefore, using a dynamic system without stochastic interference is inappropriate to study player behavior.[102] A collaborative innovation alliance is a complex system that evolves with uncertainty, influenced by numerous internal and external factors, such as knowledge input, knowledge complementarity, and knowledge output elasticity.[4,38] Unknown and difficult-to-model factors also play a role in player behaviors, such as individual risk appetite and the individual personalities of researchers and entrepreneurs.[103] At the same time, past collaboration outcomes (i.e., memory) may also affect future behaviors. Generally speaking, the greater the benefits of independent innovation, the easier it is for a participant to choose a closed innovation strategy. Additionally, changes in the external environment may impact the U-I innovation alliance, while political, economic, and cultural factors may influence the strategic choice of players.[94] In short, the choice of collaborative innovation is determined by a large set of factors, which are sometimes unknown or difficult to include in a model.[104] Uncertainty calls for random noise to be included in the model. As the deterministic dynamical system presented in the previous section is not sufficient to represent a credible model, in this paper, we chose to include random dynamics and introduce white noise into the game model to simulate more realistic settings. Accordingly, our model considers the impact of stochastic interference factors in the entire U-I innovation model.

Construction of a stochastic evolutionary game model

Stochastic analysis theory is used to study the evolutionary mechanisms of dynamic systems with stochastic process characteristics.[70] Stochastic dynamic systems are widely used in physical, biological, and other disciplines, more rarely in management (e.g.,.[105] Following a stochastic approach,[70,102,106] we present a variation of our dynamic model (equations (17) and (18)), including a stochastic component, which is helpful in modeling uncertainty:

$$\begin{aligned} dx(t) &= x(t)\cdot\left(u_H - \overline{u}\right)dt \\ &= x(t)\cdot[u_H - x(t)u_H - (1-x(t))u_B]dt \\ &\quad + \sqrt{(1-x(t))x(t)}d\omega(t) \end{aligned} \tag{19}$$

$$
\begin{aligned}
dy(t) &= y(t)\cdot\left(v_H-\overline{v}\right)dt \\
&= y(t)\cdot[v_H-y(t)v_H-(1-y(t))v_B]dt \\
&\quad+\sqrt{(1-y(t))y(t)}d\omega(t)
\end{aligned}
\tag{20}
$$

$\omega(t)$ is a one-dimensional standard Brownian movement, which means that at the time t, $\omega(t)$ is subject to a normal distribution $N(0{,}t)$, while $d\omega(t)$ is subject to a normal distribution $N(0{,}\Delta t)$. Therefore, $x(t)$ is also a random process. In fact, $\omega(t)$ and $x(t)$ are $\omega(t{,}\omega)$, and $x(t{,}\omega)$. ω is the sample event point in the random phenomenon, omitted for convenience. The existence of ω leads to the difference between equations (17), (18), (19), and (20): equations (19) and (20) constitute a stochastic system constructed according to the Itô stochastic differential equation.[107]

In building a dynamic evolutionary game model, without the stochastic component, we cannot exhaust all factors affecting the stability of an innovation alliance. For this reason, we include random phenomena in the model with $\omega(t)$, which is assumed to follow a normal distribution.

In addition, $\sqrt{(1-x(t))x(t)}$ and $\sqrt{(1-y(t))y(t)}$ determine the values of $x(t)$ and $y(t)$, which remain in the interval [0, 1]. Consequently, $\sqrt{(1-x(t))x(t)}\leq 1/2$ if and only if $1-x(t)=x(t)$ reaches its maximum, and $\sqrt{(1-y(t))y(t)}\leq 1/2$ only if $1-y(t)=y(t)$ reaches its maximum. This is seen as the maximum disturbance possible. Consequently, when the number of players choosing sharing and receiving strategies is equal, the innovation alliance is the least stable.

Existence of Equilibrium Solutions

Now, we analyze the dynamic characteristics of the players in the U-I collaborative innovation alliance model. Without losing the general premise, we discuss the following two situations:

Theorem 1. $x(0)=0$ and $y(0)=0$ are the stable equilibrium solutions of the evolutionary system.

Proof. When $t=0$ and we set $x(0)=0, y(0)=0$ into the equations (19) and (20), we have:

$$
\begin{aligned}
&0\cdot\left[0\pi_{11}^E+(1-0)\pi_{12}^E-0\pi_{21}^E-(1-0)\pi_{22}^E\right] \\
&\quad+\sqrt{(1-0)\cdot 0}=0
\end{aligned}
$$

$$\sqrt{(1-0)\cdot 0}=0$$

The solution of the equation is $x(t{,}0)=0$ and $y(t{,}0)=0$. This proves that if the alliance is at an initial state in which no player is willing to pursue an open innovation strategy, this state will remain stable, and the game will end. No matter what strategy a player chooses, it does not influence the strategic choice of the other. Consistently, when $x(t{,}0)=0$ and $y(t{,}0)=0$, we find the equilibrium solution of the evolutionary system and the model to be stable.

Theorem 2. $\pi_{11}^E=\pi_{21}^E, \pi_{11}^U=\pi_{12}^U, x(0)=1$ and $y(0)=1$ are the stable equilibrium solutions of our evolutionary model.

Alternatively, we assume that $t=0, x(t{,}0)=1, y(t{,}0)=1$ and obtain:

$$
\begin{aligned}
&1\cdot\left[1\cdot\pi_{11}^E+(1-1)\pi_{12}^E-1\cdot\pi_{21}^E-(1-1)\pi_{22}^E\right]dt \\
&\quad+\sqrt{(1-1)\cdot 1}d\omega(t)=0
\end{aligned}
$$

$$
\begin{aligned}
&1\cdot\left[1\cdot\pi_{11}^U+(1-1)\pi_{21}^U-1\cdot\pi_{12}^U-(1-1)\pi_{22}^U\right]dt \\
&\quad+\sqrt{(1-1)\cdot 1}d\omega(t)=0
\end{aligned}
$$

In this case, we find that: $\pi_{11}^E=\pi_{21}^E$ and $\pi_{11}^U=\pi_{12}^U$. Accordingly, we also have $x(t{,}0)=1$ and $y(t{,}0)=1$ as a stable equilibrium solution. This illustrates that if U-I players believe there is no difference between sharing and receiving, they will form a fully collaborative and stable U-I innovation alliance.

Stability analysis of the equilibrium solutions

In the following section, we discuss the stability problem we found in the equilibrium solutions and try to answer the following questions:

For a given initial value $x(0)=x_0$ (differently from the dynamic system, x_0 is not deterministic but a random value), if $x(t{,}x_0)$ is close to zero, when is x_0 also close to zero?

(1) When $t\to\infty$, what is the expected converge rate if $x(t{,}x_0)$ goes to zero?

The exponential function has a pivotal role in the control-system theory and has the properties illustrated in the following.

For $p>0$, and any random variable x_0 such as $\forall x_0\in[0,1]$, $x(t{,}x_0)$ is the solution of equation (3) and has the negative p$^{\text{th}}$ Lyapunov moment. Such that:

$$\overline{\lim_{t\to\infty}} t^{-1}\ \text{In E}|x(t{,}x_0)|^p<0,\forall x_0\in[0,1],$$

This means that the pth moment zero solution of equation (3) is exponentially stable. On the other hand, if

$$\underline{\lim_{t\to\infty}}\ t^{-1}\ \text{In E}|x(t{,}x_0)|^p>0,\forall x_0\in[0,1], \text{and}\ x_0\neq 0$$

(2) then the p$^{\text{th}}$ moment of the zero solution of the equation (3) is exponentially unstable. The above definitions show that the stochastic process $x(t{,}x_0)$ is shaped by the moment evolution. The evolution rate is compared to the exponential function, as illustrated in Figure 1 and Figure 2.

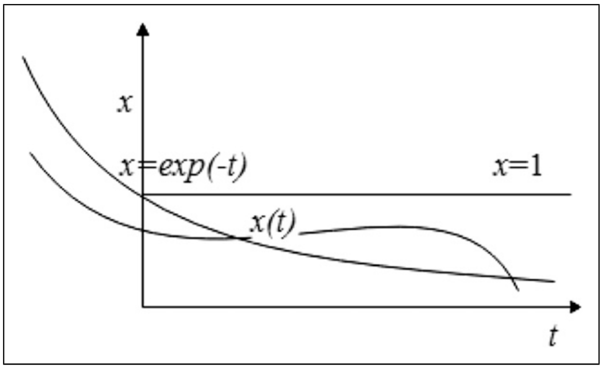

Figure 1. The p^th moment of the zero solution is exponentially stable.

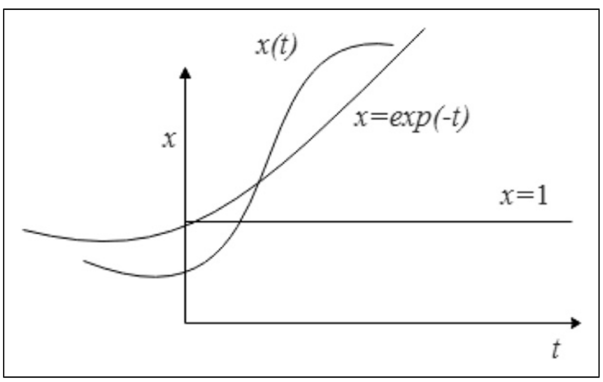

Figure 2. The p^th moment of the zero solution is exponentially unstable.

For any given x_0, Figure 1 illustrates that if the pth moment of the zero solution equation (3) is exponentially stable, then the absolute p$^{\text{th}}$ moment of $x(t,x_0)$, $\mathrm{E}|x(t,x_0)|^p$ exponentially goes to zero as $t \to \infty$, indicating that the negative exponential function can control it. Figure 2 illustrates that if the p$^{\text{th}}$ moment of the zero solution equation (3) is exponentially unstable, then the p$^{\text{th}}$ absolute moment of $x(t,x_0)$, $\mathrm{E}|x(t,x_0)|^p$ increases exponentially to infinity as $t \to \infty$, which represents the property of blowup. Combining the above definitions, we developed the conditions of stability or instability for equations (19) and (20).

Sufficiency criterion of alliance's stability and instability

Lemma. Given the stochastic differential equation:

$$dx(t) = f(t,x(t))dt + g(t,x(t))d\omega(t), x(t_0) = x_0$$

$x(t) = x(t,x_0)$ is the solution of the above equation. For convenience, we assume $x(t)$, $f(t,x)$, and $g(t,x)$ are scalars.

Let there be a smooth function $V(t,x)$ and normal number c_1,c_2. Let: $c_1|x|^p \le V(t,x) \le c_2|x|^p$. Let there be a normal number γ and let $LV(t,x) \le -\gamma V(t,x)$. Then, the p$^{\text{th}}$ moment zero solution of equation (4) is exponentially stable, and $E|x(t,x_0)|^p < (c_2/c_1)|x_0|^p e^{-\gamma t}$. Let there be a normal number γ and let $LV(t,x) \ge \gamma V(t,x)$. Then, the p$^{\text{th}}$ moment zero solution of equation (4) is exponentially stable and $E|x(t,x_0)|^p \ge (c_2/c_1)|x_0|^p e^{\gamma t}$. The solution is given by : $LV(t,x) = V_t(t,x) + V_x(t,x)f(t,x) + g^2(t,x)V_{xx}(t,x)/2$

The omitted proof can be derived from the general theory of stochastic differential equations.[108] To determine the stability of the interaction of players in a collaborative innovation alliance, we used the above lemma to draw the following conclusions for equations (19) and (20). If $V_t(t,x) = x$, $x \in [0,1]$ then $LV(t,x) = f(t,x)$, such that:

1. When $[u_H - x(t)u_H - (1-x(t))u_B] < 0$ the solution $x(t) = 0$ of equation (19) is exponentially stable.
2. When $[v_H - y(t)v_H - (1-y(t))v_B] < 0$ the solution $y(t) = 0$ of equation (20) is exponentially stable.
3. $x(t,0) = 0$ and $y(t,0) = 0$ are the equilibrium points.
4. When $[u_H - x(t)u_H - (1-x(t))u_B] > 0$ the solution $x(t) = 1$ of equation (19) is exponentially stable.
5. When $[v_H - y(t)v_H - (1-y(t))v_B] > 0$ the solution $y(t) = 1$ of equation (20) is exponentially stable.

The stability of the equilibrium solutions $x(t,0) = 0$ and $y(t,0) = 0$ represents the case where, as the game progresses, the proportion of players choosing an open innovation strategy diminishes gradually and exponentially approaches zero. In this case, the U-I players choose only to receive knowledge, eventually breaking the innovation alliance. As an alternative scenario, we have the stability of the equilibrium solutions with $x(t,0) = 1$ and$y(t,0) = 1$, representing the case where, as the game progresses, the proportion of U-I players choosing open innovation grows and exponentially approaches one. In this case, the U-I players choose the sharing strategies to stabilize the innovation alliance.

Numerical simulation

Matlab 2012 a software was used to carry out the numerical simulation of our model. We analyzed the factors that affect the U-I alliance's evolutionary path over time and those that impact alliance stability. The purpose was to examine game conclusions and the trends of considered variables.

The impact of innovation efficiency A on collaborative innovation alliances

Firms and universities possess different innovation resources, capabilities, knowledge, and innovation inputs.

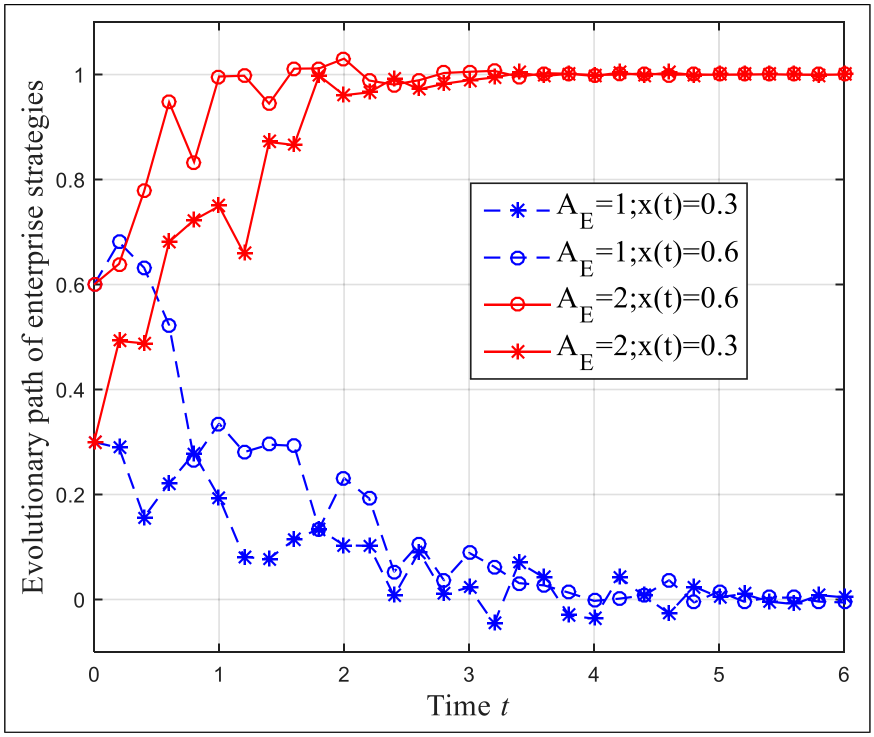

Figure 3. Innovation Efficiency and Firm's Evolutionary Path.

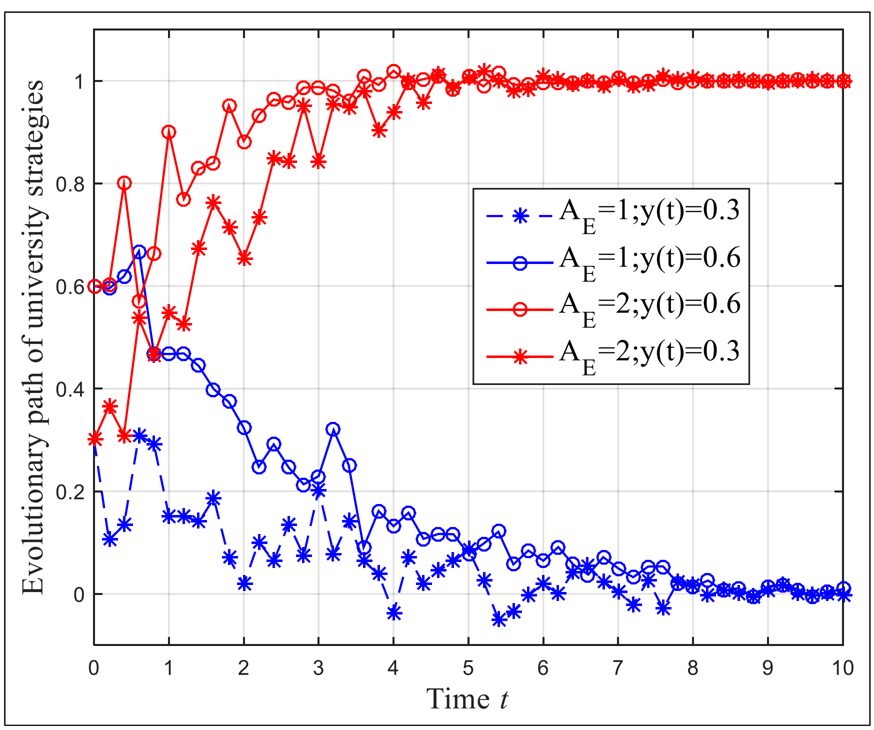

Figure 4. Innovation Efficiency and University's Evolutionary Path.

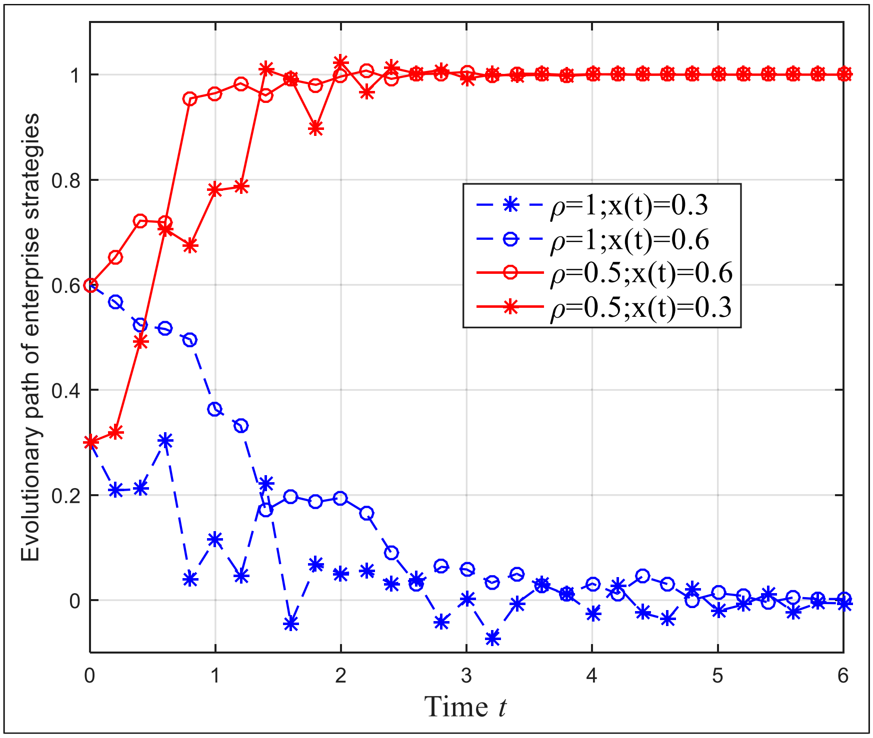

Figure 5. Complementarity of Knowledge on Enterprise's Evolutionary Path.

We choose as the parameters for the initial setting of the model: (1) the efficiency of the firm $A_E = 1$, (2) its knowledge input $K_E = 3$, and (3) as the output elasticity of the knowledge inpu $\alpha_E = 1$ t. The knowledge spillover coefficient is set to $\beta = 0.5$, and the spillover cost to $C_E = 2$. The innovation efficiency of the university is set to $A_U = 1$, its knowledge input to $K_U = 2$, and $\alpha_U = 1$; the additional cost is $C_U = 2$, and the degree of complementarity of knowledge $\rho = 1$.

Subsequently, we increase the firm's innovation efficiency to $A_E = 1$ to $A_E = 2$ and the efficiency of the university to $A_U = 1$ to $A_U = 2$. Figure 3 and Figure 4 show the evolutionary path of the two players' innovation strategies.

In Figure 3, the blue dotted curve is the evolutionary path of the firm's strategy when innovation efficiency $A_E = 1$. The * and ○ lines represent the different probabilities of choosing a sharing strategy, with $x(t) = 0.3$ and $x(t) = 0.6$ respectively. Due to the low innovation efficiency of the firm, we observe an evolution towards a receiving strategy. Therefore, when the efficiency of the innovation process is lower, i.e., more unlikely to produce a tangible effect on the business, the firm tends towards closed innovation. On the other hand, the red curve represents the evolutionary path of the firm's strategy when innovation efficiency is $A_E = 2$. In this case, there is an evolution towards a sharing strategy (regardless of its initial probability) because of the higher innovation efficiency. Furthermore, while the existence of random interference factors means that neither curve is smooth, they do not change the direction of the evolution.

Figure 4 confirms that these results are the same for universities: when innovation efficiency increases, strategies evolve toward open innovation; by contrast, when innovation efficiency is low, the preferred choice is a closed innovation strategy. Even in this case, the random interference factors do not change the direction of evolution. For both firms and universities, the transition speed toward an open strategy is significantly higher than toward a closed strategy. Firms tend to reach the equilibrium point faster than universities due to a higher knowledge input (3 instead of 2). Therefore, when higher initial levels of knowledge exist, collaborative innovation alliances tend to form more quickly.

The impact of the degree of complementarity of knowledge ρ on collaborative innovation alliances

Maintaining most of the simulation parameters of the previous section, we examined the effects of changing the degree of knowledge complementarity from $\rho = 1$ to $\rho = 0.5$. The results are reported in Figure 5 and Figure 6.

The blue dotted curve represents the evolution path of the firm when the degree of knowledge complementarity is $\rho = 1$. The * and ○ lines represent the different

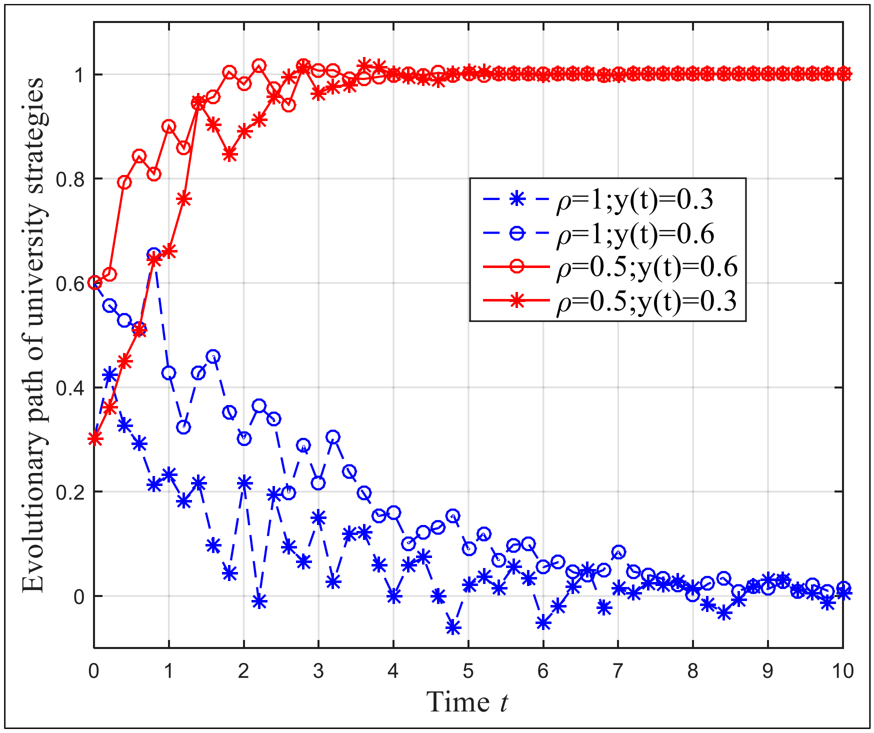

Figure 6. Complementarity of Knowledge on University's Evolutionary Path.

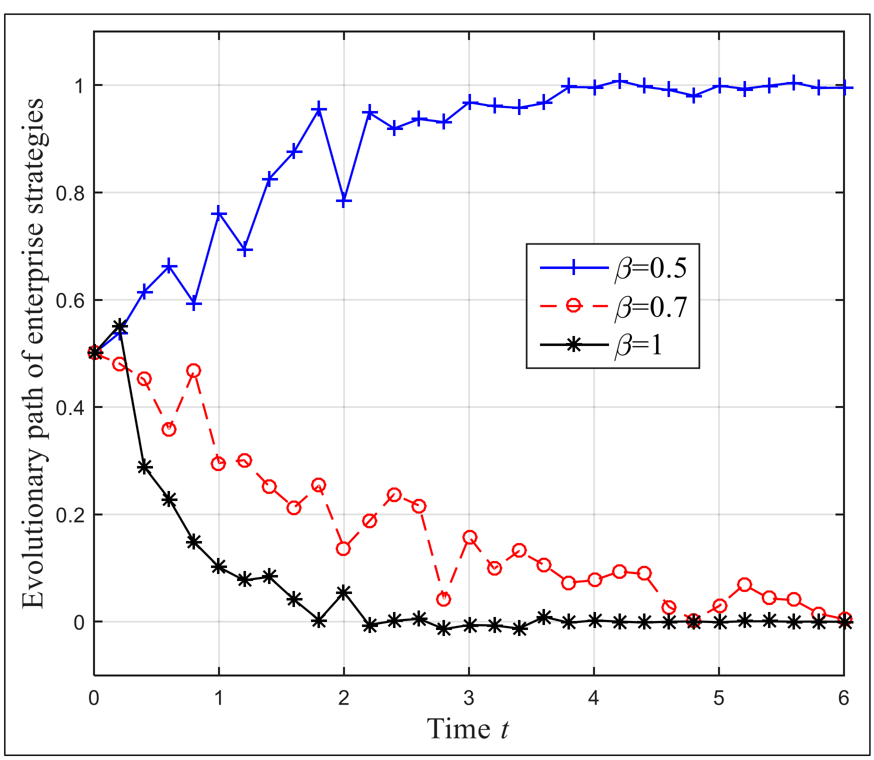

Figure 7. Knowledge Spillover on Enterprise's Evolutionary Path.

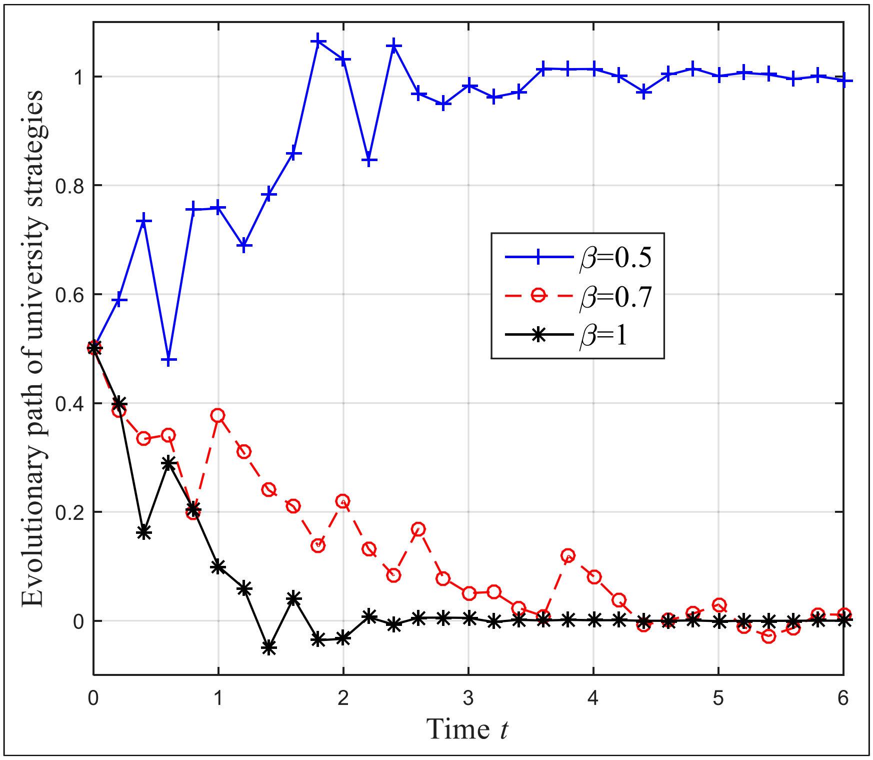

Figure 8. Knowledge Spillover on University's Evolutionary Path.

probabilities of choosing a sharing strategy, $x(t) = 0.3$ and $x(t) = 0.6$ respectively. With higher knowledge sharing, the firm's strategy evolves towards closed innovation, regardless of the initial probability of choosing an open innovation strategy. By contrast, when $\rho = 0.5$ the firm's choice evolves towards an open innovation strategy irrespective of the initial probability. Due to random interference factors, neither curve is smooth in the evolutionary path. However, the random interference factors do not ultimately change the direction of evolution.

As shown in Figure 6, the results are identical for universities: when the degree of knowledge complementarity is lower, both firms and universities tend to choose an open innovation strategy. Moreover, the evolution speed toward an open innovation strategy is significantly more rapid than a closed innovation strategy. Firms reach the equilibrium point faster than universities. This is because we set a higher knowledge input for firms. In this scenario, a higher knowledge input, signaling the need to invest in greater levels of knowledge, supports the faster formation of sharing-based alliances. Lastly, looking at the convergence speed in Figures 3, 4, 5 and 6, we note that a low knowledge complementarity is more effective than a high innovation efficiency in pushing collaborative innovation alliances.

The impact of knowledge spillover coefficient β on collaborative innovation alliances

Here, we set $\rho = 0.5$ and kept the other parameters as in *The impact of innovation efficiency A on collaborative innovation alliances*. We knew in advance that if $\beta = 0.5$ both players were likely to choose a sharing strategy. Figure 7 and Figure 8 present the effects of adjusting the spillover coefficient to 0.7 or 1.

In both figures, the blue curve represents the evolutionary path in the case of $\beta = 0.5$, the red curve the evolutionary path when $\beta = 0.7$, and the black curve the case of $\beta = 1$. All three curves start from the point where the probability of collaborative innovation is $x(t) = 0.5$. When the knowledge spillover coefficient is lower ($\beta = 0.5$), we observe an evolution towards a sharing strategy regardless of the initial probability of choosing an open innovation strategy. On the other hand, when the knowledge spillover coefficient increases, the final choice tends to be a closed innovation strategy. Even in this case, the random interference factors do not ultimately change the direction of the evolutionary process of the strategic innovation choice. These results suggest that higher knowledge spillovers can foster closed innovation strategies. The model suggests that when knowledge is "in the air",[109] there is little need for a formalized collaborative process. Therefore, firms will tend to innovate alone (i.e., choose a closed innovation strategy).

Discussion

U-I collaborations face many challenges due to high uncertainty and risks, significant pressure in terms of creativity and innovativeness, individually oriented employees, and project members resident at different locations.[110] Little systematic research has been conducted on how U-I barriers can be overcome as these relationships evolve.[60] Even more pronounced is the dearth of attempts in the literature to explain the mechanisms by which firms are better able to realize innovation-driven alliances.[111]

The present study aims at enhancing our understanding of how U-I alliances. Our findings explain how partners of these alliances can absorb knowledge and learn from each other. Using a game-based approach, we obtained three main results. Firstly, firms and universities tend to choose an open innovation strategy when there is high innovation efficiency. The more productive a firm is, the stronger its tendency to collaborate through an open innovation strategy. Secondly, the lower the degree of knowledge complementarity between U-I partners, the higher the probability that both firms and universities will successfully form an innovation alliance. Third, when the level of knowledge spillovers is high, a closed innovation strategy tends to be chosen to obtain higher individual returns. Consequently, the actors require a method for assessing the efficiency of their potential partners.[112]

University-industry R&D projects have grown considerably in recent years due to the search for new knowledge.[72] Policymakers increasingly stress U-I collaborations' importance and long-term impact on the industry.[113] Previous research in Spain, France, and Portugal showed that, out of 375 entrepreneurs interested in cooperating with universities, only 10% ended up teaming with them [114]. [115] claimed that the main problems in U-I alliances are a lack of structured communication with industry and between structures that implement collaboration and a lack of a unified system for such cooperation. Accordingly, the authors have developed a model for enhancing collaboration and relationship building. In many developed economies, governments offer substantial funding for R&D that incentivizes U-I collaboration and knowledge exchange.[72] The aim is to create innovative solutions that will result in economic growth. "Knowledge and technology transfer between academia and industry is expected to spur innovation, as this kind of collaboration combines not only heterogeneous partners but, more importantly, heterogeneous knowledge",[12] p. 42).

Our model offers insights into different factors influencing the formation of collaborative U-I. Results are aligned with previous studies (e.g., [116] that suggested that firms possessing greater capabilities to turn innovation inputs into revenues are more oriented toward an open innovation approach. This also sheds light on why suboptimal levels of open innovation have been found among firms.[117]

Universities should develop in parallel with industry and focus more on U-I collaboration activities.[23] U-I collaborations can benefit all their participants, enhancing their reputation, prestige, and responsiveness to government initiatives.[64] The Triple Helix model illustrates the importance of university-industry-government interaction in facilitating the conditions that lead to innovation in a knowledge-based society. In the future, effective management of "knowledge" will be a primary concern for both universities and firms.[25] The essential facets of knowledge management are the systematic collection, storage, sharing, diffusion, and reuse of information and knowledge.[118] Harmonized organizational culture and rewards are required to increase knowledge sharing in U-I teams. These teams need to manage the processes related to creating knowledge resources and identify the value of their intellectual capital for a sustained role in society and the global business arena.[119]

Universities and business companies have different organizational and knowledge-production structures,[26] leading to a high chance of conflict or misunderstandings in U-I collaborations.[72]

Producers, users, companies, and external actors can collaborate to create new value and knowledge,[22] also supported by public incentives. Through co-creation, actors expand their knowledge integration and innovation opportunities. In this view, our results contribute to practice, emphasizing the need to move beyond the triple constraints of time, cost, and quality and consider more strategic measures related to knowledge creation and sharing. Further insights derive from our analysis regarding the role of knowledge complementarity and its spillover effects. Our model suggests that these factors are more effective in forming collaborative innovation alliances in a U-I context than innovation efficiency. Therefore, as the model suggests, the lower the level of knowledge complementarity between U-I players, the greater the propensity to engage in open and collaborative partnerships. However, high levels of technological proximity between U-I players may be counter-productive.[58] This suggests an in-depth analysis of knowledge complementarities before setting up an alliance. Accordingly, there is an increasing debate on the closeness of partners' technological capabilities and how to promote partnerships.[43,54] By contrast, our model suggests that a certain distance between the U-I partners' knowledge base is required to promote a successful alliance. Thus, technological proximity is not necessarily the key, which could be the ability to absorb partners' knowledge.[87] Therefore, our findings extend the work of Bruneel et al.,[28] which suggests that universities appear to be more inclined to cooperate when knowledge is less aligned with their existing skills. This seems to contrast with the idea that greater knowledge complementarity between U-I partners reduces uncertainty and promotes collaboration.[57,120] Therefore, effective collaborations seem to require heterogeneous knowledge bases. Our model also suggests that the most effective way to promote collaborative innovation alliances between firms and universities is to reduce the likelihood of knowledge spillovers. Accordingly, a lack of informal knowledge exchange may encourage the creation of new alliances. Indeed, when knowledge is ‘in the air’ or freely available, there is less incentive to engage in formal partnerships, and actors usually proceed through an informal strategy.[18,121]

Conclusions

By collaborating with external partners, companies can gather diverse information and rapidly respond to market demands, using their limited innovation resources in the most fruitful way.[47] Collaboration between universities and industry has been recognized as an essential driver of technological innovation [2] and a critical component of the national innovation system.[20] As such, it appears to be indispensable to the survival of firms in the contemporary world.[122] Firms today utilize considerably more knowledge than they can create alone.[65]

The present study wants to enhance our understanding of U-I alliances, using a stochastic evolutionary game model and simulating the interactions of firms and universities, which operate in conditions of uncertainty and bounded rationality. The need for such research emerged from the realization that we do not have a thorough understanding of why some U-I innovation collaborations thrive while others fail.

Our study presents three main findings. First, a higher level of firms’ innovation efficiency encourages collaboration and promotes U-I innovation alliances. Second, the lower the knowledge complementary of U-I actors, the higher the probability that they will collaborate. The potential gains from accessing heterogeneous knowledge seem to push U-I actors toward an open innovation strategy. Third, higher knowledge spillovers tend to enhance the probability of a closed innovation strategy and make U-I innovation alliances less likely.

Our study has practical implications as it highlights the conditions under which firms are likely to increase collaboration with universities. Firms that are not merely innovators but still have high efficiency appear to be best suited for such alliances. Consequently, policymakers must identify not only innovators but also companies capable of commercializing innovation outputs. Furthermore, when promoting U-I alliances, policymakers should consider the knowledge complementarity of partners, ensuring that they are not too homogenous. Finally, policymakers should also consider the fluidity of knowledge within an innovation system to assess the level of spillovers. We found that firms and universities are less likely to engage in formal U-I alliances when such fluidity abounds.

The assumptions we made pose certain limitations to our research. Therefore, results must be interpreted within the framework of our assumptions and should be tested in real-world settings as a suggestion for further research. One limitation is our study only considers the impact of knowledge input on U-I innovation returns without incorporating other measures of impact (e.g.,.[123] There may be more factors influencing innovation output, which, if brought into play, would lead to a more complex game theory model, thus expanding the present research. Future studies might also explore the behaviors of academics in diverse contexts (e.g., different scientific fields or countries) or intertemporal transitions. Cooperation based on bilateral rewards and abstention from collaboration would be of both theoretical and practical interest.[124] Accordingly, future research might investigate other determinants and conditions of forming and maintaining U-I cooperation, such as firm size or the possibility of multiple alliances with heterogeneous partners. For example, our model was aspatial and did not consider the physical distance between U-I partners, a factor that results relevant for U-I innovation alliances.[35,125] Lastly, future studies could consider additional causes of external disturbance or changes in government policies.

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ORCID iD

Andrea Fronzetti Colladon https://orcid.org/0000-0002-5348-9722

References

1. Giannopoulou E, Barlatier P-J and Pénin J. Same but different? Research and technology organizations, universities and the innovation activities of firms. *Res Policy* 2019; 48: 223–233.
2. Song Y, Berger R, Yosipof A, et al. Mining and investigating the factors influencing crowdfunding success. *Technological Forecasting Social Change* 2019; 148: 119723.

3. Ahrweiler P, Pyka A and Gilbert N. A new model for university-industry links in knowledge-based economies. *J Product Innovation Management* 2011; 28: 218–235.
4. Li Y-M and Jhang-Li J-H. Knowledge sharing in communities of practice: A game theoretic analysis. *European J Operational Res* 2010; 207: 1052–1064.
5. Ferdinand J-P and Meyer U. The social dynamics of heterogeneous innovation ecosystems. *Int J Eng Business Management* 2017; 9: 184797901772161, DOI: 10.1177/1847979017721617
6. Martini A, Aloini D and Neirotti P. Degree of Openness and Performance in the Search for Innovation. *Int J Eng Business Management* 2012; 4: 37, DOI: 10.5772/54752
7. Mirza S, Mahmood A and Waqar H. The interplay of open innovation and strategic innovation: Unpacking the role of organizational learning ability and absorptive capacity. *Int J Eng Business Management* 2022; 14: 184797902110697, DOI: 10.1177/18479790211069745
8. Miotti L and Sachwald F. Co-operative R&D: why and with whom? *Res Policy* 2003; 32(8): 1481–1499.
9. Galán-Muros V and Plewa C. What drives and inhibits university-business cooperation in Europe? A comprehensive assessement. *R&D Management* 2016; 46(2): 369–382.
10. Perkmann M and Walsh K. University-industry relationships and open innovation: Towards a research agenda. *Int J Management Reviews* 2007; 9(4): 259–280.
11. Berger R. Entrepreneurial learning about the venture capitalist community. *Business & IT* 2018; 1: 2–12.
12. Rajalo S and Vadi M. University-industry innovation collaboration: Reconceptualization. *Technovation* 2017; 62–63: 42–54.
13. Bishop K, D'Este P and Neely A. Gaining from interactions with universities: Multiple methods for nurturing absorptive capacity. *Res Policy* 2011; 40(1): 30–40.
14. D'Este P and Perkmann M. Why do academics engage with industry? The entrepreneurial university and individual motivations. *The J Technology Transfer* 2010; 36(3): 316–339.
15. Perkmann M, Tartarik V, McKelvey M, et al. Academic engagement and commercialisation: A review of the literature on university–industry relations. *Res Policy* 2013; 42(2): 423–442.
16. Abreu M, Grinevuch V, Hughes A, et al. *Universities, business and knowledge exchange*. London: The Council for Industry and Higher Education, 2008.
17. Fontana R, Geuna A and Matt M. Factors affecting university-industry R&D projects: The importance of searching, screening and signalling. *Res Policy* 2006; 35(2): 309–323.
18. Hagerdoorn J, Link A and Vonortas N. Research partnerships. *Res Policy* 2000; 29(4–5): 567–586.
19. Lööf H and Broström A. Does knowledge diffusion between university and industry increase innovativeness? *The J Technology Transfer* 2006; 33(1): 73–90.
20. Wirsich A, Kock A, Strumann C, et al. Effects of University-Industry Collaboration on Technological Newness of Firms. *J Product Innovation Management* 2016; 33(6): 708–725.
21. Powell WW, Koput KW and Smith-Doerr L. Interorganizational collaboration and the locus of innovation: Networks of learning in biotechnology. *Administrative Science Quarterly* 1996; 41(1): 116–145.
22. Mathisen L and Jørgensen EJB. The significance of knowledge readiness for co-creation in university industry collaborations. *Innovation* 2021; 23: 534–551. DOI: 10.1080/14479338.2021.1882862
23. Puerta-Sierra L and Jasso J. University-industry collaboration. an exploration of an entrepreneurial university in mexico. *J Technology Management Innovation* 2020; 15(3): 33–39.
24. Azman N, Sirat M, Pang V, et al. Promoting university-industry collaboration in Malaysia: stakeholders' perspectives on expectations and impediments. *J Higher Education Policy Management* 2019; 41(1): 86–103.
25. Hu Y-F, Hou J-L and Chien C-F. A UNISON framework for knowledge management of university-industry collaboration and an illustration. *Computers Industrial Eng* 2019; 129: 31–43.
26. Kuwashima K. A role model of large-scale university-industry collaboration in Japan. *Annals Business Administrative Science* 2020; 19: 81–96.
27. Laursen K and Salter A. Searching high and low: what types of firms use universities as a source of innovation? *Res Policy* 2004; 33(8): 1201–1215.
28. Bruneel J, D'Este P and Salter A. Investigating the factors that diminish the barriers to university-industry collaboration. *Res Policy* 2010; 39(7): 858–868.
29. Dooley L and Gubbins C. Inter-organisational knowledge networks: synthesising dialectic tensions of university-industry knowledge discovery. *J Knowledge Management* 2019; 23(10): 2113–2134.
30. Lavie D and Drori I. Collaborating for knowledge creation and application: The case of nanotechnology research programs. *Organization Science* 2012; 23(3): 704–724.
31. Lam A. What motivates academic scientists to engage in research commercialization: "Gold", "ribbon" or "puzzle"?". *Res Policy* 2011; 40(10): 1354–1368.
32. Thanasopon B, Papadopoulos T and Vidgen R. The role of openness in the fuzzy front-end of service innovation. *Technovation* 2016; 47: 32–46.
33. Bozeman B, Rimes H and Youtie J. The evolving state-of-the-art in technology transfer research: Revisiting the contingent effectiveness model. *Res Policy* 2015; 44(1): 34–49.
34. Chatterjee K and Samuelson W. *Game Theory and Business Applications*. Boston, MA: Springer US (International Series in Operations Research & Management Science, 2014.
35. Laursen K, Reichstein T and Salter A. Exploring the effect of geographical proximity and university quality on university-industry collaboration in the United Kingdom. *Regional Studies* 2011; 45(4): 507–523.

36. Perkmann M, King Z and Pavelin S. Engaging excellence? Effects of faculty quality on university engagement with industry. *Res Policy* 2011; 40(4): 539–552.
37. Chakrabarti AS and Lahkar R. Productivity dispersion and output fluctuations: An evolutionary model. *J Economic Behavior Organization* 2017; 137: 339–360.
38. Friedman D. On economic applications of evolutionary game theory. *J Evolutionary Economics* 1998; 8(1): 15–43.
39. Sigmund K. *The Calculus of Selfishness*. Princetown, NJ: Princetown University Press, 2010.
40. Eom B-Y and Lee K. Determinants of industry-academy linkages and, their impact on firm performance: The case of Korea as a latecomer in knowledge industrialization. *Res Policy* 2010; 39(5): 625–639.
41. Goddard J, Coombes M, Kempton L, et al. Universities as anchor institutions in cities in a turbulent funding environment: vulnerable institutions and vulnerable places in England. *Cambridge J Regions, Economy Society* 2014; 7(2): 307–325.
42. Soh P-H and Subramanian AM. When do firms benefit from university-industry R&D collaborations? The implications of firm R&D focus on scientific research and technological recombination. *J Business Venturing* 2014; 29(6): 807–821.
43. Steinmo M and Rasmussen E. How firms collaborate with public research organizations: The evolution of proximity dimensions in successful innovation projects. *J Business Res* 2016; 69(3): 1250–1259.
44. Ankrah S and AL-Tabbaa O. Universities-industry collaboration: A systematic review. *Scandinavian J Management* 2015; 31(3): 387–408.
45. Gretsch O, Salzmann EC and Kock A. University-industry collaboration and front-end success: the moderating effects of innovativeness and parallel cross-firm collaboration. *R&D Management* 2019; 49(5): 835–849.
46. Song Y and Berger R. How gender affects collaborative innovation networks performance: The case of the Dutch fashion industry. *Int J Entrepreneurship Small Business* 2019; 36(4): 392–407.
47. Hou B, Hong J, Wang H, et al. Academia-industry collaboration, government funding and innovation efficiency in Chinese industrial enterprises. *Technology Analysis Strategic Management* 2019; 31(6): 692–706.
48. Bartunek JM and Rynes SL. Academics and Practitioners Are Alike and Unlike. *J Management* 2014; 40(5): 1181–1201.
49. Beech N, MacIntosh R and MacLean D. Dialogues between academics and practitioners: The role of generative dialogic encounters. *Organization Studies* 2010; 31(9–10): 1341–1367.
50. Walsh JP, Tushman ML, Kimberly JRRJ, et al. On the Relationship Between Research and Practice: Debate and Reflections. *J Management Inquiry* 2007; 16(2): 128–154.
51. Wasserman IC and Kram KE. Enacting the scholar-practitioner role: An exploration of narratives. *The J Applied Behavioral Science* 2009; 45(1): 12–38.
52. McGahan AM. Academic research that matters to manages: On zebras, dogs, lemmings, hammers, and turnips. *Academy of Management Journal* 2007; 50(4): 748–753.
53. Rasche A and Behnam M. As if it were relevant: A systems theoretical perspective on the relation between science and practice. *J Management Inquiry* 2009; 18(3): 243–255.
54. Aguiléra A, Lethiais V and Rallet A. Spatial and non-spatial proximities in inter-firm relations: An empirical analysis. *Industry & Innovation* 2012; 19(3): 187–202.
55. Rau C, Neyer A-K and Möslein KM. Innovation practices and their boundary-crossing mechanisms: a review and proposals for the future. *Technology Analysis Strategic Management* 2012; 24(2): 181–217.
56. Balland P-A, Boschma R and Frenken K. Proximity and innovation: From statics to dynamics. *Regional Studies* 2015; 49(6): 907–920.
57. Crescenzi R, Filippetti A and Iammarino S. Academic inventors: collaboration and proximity with industry. *The J Technology Transfer* 2017; 42(4): 730–762.
58. Knoben J and Oerlemans LAG. Proximity and inter-organizational collaboration: A literature review. *Int J Management Reviews* 2006; 8(2): 71–89.
59. Ponds R, Van Oort F and Frenken K. Innovation, spillovers and university-industry collaboration: An extended knowledge production function approach. *J Economic Geography* 2010; 10(2): 231–255.
60. Steinmo M and Rasmussen E. The interplay of cognitive and relational social capital dimensions in university-industry collaboration: Overcoming the experience barrier. *Res Policy* 2018; 47: 1964–1974.
61. Cowan R and Jonard N. The dynamics of collective invention. *J Economic Behavior Organization* 2003; 52(4): 513–532.
62. Petruzzelli AM. The impact of technological relatedness, prior ties, and geographical distance on university-industry collaborations: A joint-patent analysis. *Technovation* 2011; 31(7): 309–319.
63. Natalicchio A, Ardito L, Petruzzelli MA, et al. The origins of external knowledge inflows and the impact of university technologies. *R&D Management* 2018; 49(4): 639–651.
64. Jonbekova D, Sparks J, Hartley M, et al. Development of university-industry partnerships in Kazakhstan: Innovation under constraint. *Int J Educational Development* 2020; 79: 102291.
65. Huggins R and Prokop D. Network structure and regional innovation: A study of university-industry ties. *Urban Studies* 2017; 54(4): 931–952.
66. Fischer M, Varga A and Fritsch M. Spatial knowledge spillovers and university research: Evidence from Austria. *Annals Regional Science* 2003; 37(3): 303–322.
67. Jaffe AB. Real effects of academic research. *American Economic Review* 1989; 79(5): 957–970.
68. Jaffe AB, Trajtenberg M and Henderson R. Geographic localisation of knowledge spillovers as evidenced by patent citations. *The Quarterly J Economics* 1993; 108(3): 577–598.

69. Berger R and Zviling M. Innovation, learning, and synergy between entrepreneurs and venture capitalists. *Int J Synergy Res* 2013; 2(2): 91–106.
70. Tilman D. Niche trade-offs, neutrality, and community structure: A stochastic theory of resource competition, invasion, and community assembly. *Proceedings National Academy Sciences* 2004; 101(30): 10854–10861.
71. Gubbins C and Dooley L. Exploring Social Network Dynamics Driving Knowledge Management for Innovation. *J Management Inquiry* 2014; 23(2): 162–185.
72. Fernandes G, O' Sullivan D, Pinto BE, et al. Value of project management in university–industry R&D collaborations. *Int J Managing Projects Business* 2020; 13(4): 819–843.
73. Macneil IR. *The new social contract: an inquiry into modern contractual relations*. New Haven, CT: Yale University Press, 1980.
74. Williamson OE. *The economic institutions of capitalism: firms, markets, relational contracting*. New York: Free Press, 1985.
75. Roumboutsos A, Alemanb SA and Ågren R. Construction firms in public-private partnerships: a place to grow. *Construction Management Economics* 2017; 35(10): 627–640.
76. Das TK and Teng B-S. A resource-based theory of strategic alliances. *J Management* 2000; 26(1): 31–61.
77. Vanberg VJ. Institutional evolution through purposeful selection: The constitutional economics of John R. Commons. *Constitutional Political Economy* 1997; 8(2): 105–122.
78. Van de Donk WBHJ and Snellen ITM. Knowledge based systems in public administration: Evolving practices and norms. In: Snellen ITM (ed). *Expert systems in public administration: evolving practices and norms [online]*. Amsterdam: Elsevier Science; 1989.
79. Smith JM and Price GR. The logic of animal conflict. *Nature* 1973; 246: 15–18.
80. Shan H and Yang J. Sustainability of photovoltaic poverty alleviation in China: an evolutionary game between stakeholders. *Energy* 2019; 181: 264–280.
81. Gandomi A, Bazargan A and Zolfaghari S. Designing competitive loyalty programs: A stochastic game-theoretic model to guide the choice of reward structure. *Annals Operations Res* 2019; 280: 267–298.
82. Huang K, Zhou C, Qin Y, et al. Game-theoretic approach to cross-layer security decision-making in industrial cyber-physical systems. *IEEE Transactions on Industrial Electronics* 2020; 67(3): 2371–2379.
83. Akçura MT and Ozdemir ZD. Data-driven manufacturer-retailer collaboration under competition. *Enterprise Information Systems* 2019; 13(3): 303–328.
84. Hara R and Matsubayashi N. Premium store brand: Product development collaboration between retailers and national brand manufacturers. *Int J Production Economics* 2017; 185: 128–138.
85. An H, Yang R, Ma X, et al. An evolutionary game theory model for the inter-relationships between financial regulation and financial innovation. *The North American J Economics Finance* 2021; 55: 101341.
86. Song Y, Elsner W, Zhang Z, et al. Collaborative innovation and policy support: The emergence of trilateral networks. *Applied Economics* 2019; 52(34): 3651–3668.
87. Cohen WM and Levinthal DA. Absorptive capacity: A new perspective on learning and innovation. *Administrative Science Quarterly* 1990; 35(1): 128–152.
88. Phene A, Fladmoe-Lindquist K and Marsh L. Breakthrough innovations in the U.S. biotechnology industry: The effects of technological space and geographic origin. *Strategic Management J* 2006; 27(4): 369–388.
89. Zahra SA and George G. Absorptive capacity: A review, reconceptualization, and extension. *Academy Management Review* 2002; 27(2): 185–203.
90. Antoci A, Borghesi S and Galeotti M. Environmental options and technological innovation: An evolutionary game model. *J Evolutionary Economics* 2013; 23(2): 247–269.
91. Safarzyńska K and van den Bergh JCJM. Evolutionary models in economics: A survey of methods and building blocks. *J Evolutionary Economics* 2010; 20(3): 329–373.
92. Almirall E and Casadesus-Masanell R. Open versus closed innovation: A model of discovery and divergence. *Academy Management Review* 2010; 35(1): 27–47.
93. Ben Youssef S, Breton M and Zaccour G. Cooperating and non-cooperating firms in inventive and absorptive research. *J Optimization Theory Applications* 2013; 157(1): 229–251.
94. Gloor PA. *Swarm Creativity. Competitive advantage through collaborative innovation networks*. New York, NY: Oxford University Press, 2005.
95. Baldwin C and von Hippel E. Modeling a paradigm shift: From producer innovation to user and open collaborative innovation. *Organization Science* 2011; 22(6): 1399–1417.
96. Ritala P and Hurmelinna-Laukkanen P. What's in it for me? Creating and appropriating value in innovation-related coopetition. *Technovation* 2009; 29(12): 819–828.
97. Arsenyan J, Büyüközkan G and Feyzioğlu O. Modeling collaboration formation with a game theory approach. *Expert Systems Applications* 2015; 42(4): 2073–2085.
98. Anbarci N, Lemke R and Roy S. Inter-firm complementarities in R&D: A re-examination of the relative performance of joint ventures. *Int J Industrial Organization* 2002; 20(2): 191–213.
99. Kamien MI, Muller E and Zang I. Research joint ventures and R&D cartels. *The American Economic Review* 1992; 82(5): 1293–1306.
100. Acs ZJ, Braunerhjelm P, Audretsch DB, et al. The knowledge spillover theory of entrepreneurship. *Small Business Economics* 2009; 32(1): 15–30.
101. Amann E and Possajennikov A. On the stability of evolutionary dynamics in games with incomplete information. *Mathematical Social Sciences* 2009; 58(3): 310–321.
102. Goeree JK and Holt CA. Stochastic game theory: For playing games, not just for doing theory. *Proceedings National Academy Sciences* 1999; 96(19): 10564–10567.

103. Nambisan S and Baron RA. Entrepreneurship in innovation ecosystems: Entrepreneurs' self-regulatory processes and their implications for new venture success. *Entrepreneurship Theory Practice* 2013; 37(5): 1071–1097.
104. Swan J and Scarbrough H. The politics of networked innovation. *Human Relations* 2005; 58(7): 913–943.
105. Bellomo N and Delitala M. From the mathematical kinetic, and stochastic game theory to modelling mutations, onset, progression and immune competition of cancer cells. *Physics Life Reviews* 2008; 5(2): 183–206.
106. Fink AM. Equilibrium in a stochastic n-person game. *Hiroshima Mathematical J* 1964; 28(1): 89–93.
107. Øksendal B. *Stochastic Differential Equations: An Introduction With Applications*. Berlin, Heidelberg: Springer (Universitext), 2003.
108. Panik MJ. *Stochastic Differential Equations: An Introduction with Applications in Population Dynamics Modeling*. Hoboken, NJ: John Wiley & Sons, 2017.
109. Marshall A. *Principles of Economics*. London: Macmillan, 1890.
110. Fernandes G and O'Sullivan D. Benefits management in university-industry collaboration programs. *Int J Project Management* 2021; 39: 71–84.
111. Ryan P, Geoghegan W and Hilliard R. The microfoundations of firms' explorative innovation capabilities within the triple helix framework. *Technovation* 2018; 76-77: 15–27.
112. Johnston A and Huggins R. Partner selection and university-industry linkages: Assessing small firms' initial perceptions of the credibility of their partners. *Technovation* 2018; 78: 15–26.
113. Rossi F, De Silva M, Baines N, et al. Long-term innovation outcomes of university–industry collaborations: The role of 'bridging' vs 'blurring' boundary-spanning practices. *British J Management* 2020; 33: 478–501. DOI: 10.1111/1467-8551.12449
114. Fernández-López S, Calvo N and Rodeiro-Pazos D. The funnel model of firms' R&D cooperation with university. *Science Public Policy* 2019; 46(1): 45–54.
115. Zunda S, Zeps A and Strode S. Creation of sustainable model for building and maintaining a relationship between universities and entrepreneurs. *Business, Management Education* 2020; 18(1): 33–55.
116. Bae Y and Chang H. Efficiency and effectiveness between open and closed innovation: Empirical evidence in South Korean manufacturers. *Technology Analysis Strategic Management* 2012; 24(10): 967–980.
117. Hewitt-Dundas N and Roper S. Exploring market failures in open innovation. *Int Small Business Journal: Researching Entrepreneurship* 2017; 36(1): 23–40.
118. Rivera González G and Rivera González IA. Design, measurement and analysis of a knowledge management model in the context of a Mexican University. *Innovar* 2016; 26(59): 21–34.
119. Naser ASS, Shobaki AMJ and Amuna AYM. Knowledge management maturity in universities and its impact on performance excellence "comparative study". *J Scientific Eng Res* 2016; 3(4): 4–14.
120. Ponds R, van Oort F and Frenken K. The geographical and institutional proximity of research collaboration. *Papers Regional Science* 2007; 86(3): 423–443.
121. Owen-Smith J and Powell WW. Knowledge networks as channels and conduits: The effects of spillovers in the Boston biotechnology community. *Organization Science* 2004; 15(1): 5–21.
122. Gürpınar E. Organizational forms in the knowledge economy: a comparative institutional analysis. *J Evolutionary Economics* 2016; 26(3): 501–518.
123. Bonaccorsi A, Chiarello F and Fantoni G. SSH Researchers Make an Impact Differently. Looking at Public Research from the Perspective of Users. *Res Evaluation* 2021; 30(3): 269–289.
124. Shibayama S. Indirect reciprocity, direct reciprocity, and abstention: Case of academic cooperation under academic commercialism. In: Paper presented at the Indirect Reciprocity, Direct reciprocity, and Abstention: Case of Academic Cooperation under Academic Commercialism Sotaro Shibayama University of Tokyo 15th International Conference on Social Dilemmas, Zurich, Switzerland, 2013.
125. D'Este P, Guy F and Iammarino S. Shaping the formation of university-industry research collaborations: What type of proximity does really matter? *J Economic Geography* 2013; 13(4): 537–558.