Financial Payoff in Patent Alliance: Evolutionary Dynamic Modeling

Zixing Shen and Yanyan Shang

Abstract—**Originating from the strategic management theory, resource-based view of firm believes that firms rely on bundles of resources which enable them to gain competitive advantage. Patent, as an integral part of intellectual capital, is an important resource for organizations building capabilities. With the heterogeneous in nature and imperfectly mobile, patent and its management becomes increasingly crucial for organizations facing globalization, information transparency, and intensified competition in developing a sustainable competitive advantage. Drawing upon the literature on strategic alliance, resource-based view, and patent management, we study how sharing patents can create sharing value added and synergy value added that enable participants in the patent alliance to obtain better financial payoff. Specifically, in this paper, we use the evolutionary stable strategy and replicator dynamic from evolutionary game theory to model the synergy effects in patent alliance. Our evolutionary dynamic modeling shows that an evolutionary stable state converges when organizations share patents, and supports that both patent sharing value added and synergy value added from patent alliance would be financially beneficial to organizations.**

Index Terms—**Evolutionary game theory, evolutionary stable strategy (ESS), knowledge management, patent alliance, replicator dynamic (RD), resource-based view, strategic alliance.**

I. Introduction

THE STRATEGIC alliance is a voluntary agreement among two or more parties to pursue a set of agreed upon objectives need while remaining independent organizations. Traditional studies on strategic alliance are on perspective of transaction cost [1] explanation. However, these explanations usually focus on transaction process and price mechanism, which fails to capture the strategic and social factors that impetuses firms to format alliance [2]. In the literature [2], Eisenhardt and Schoonhoven studied on alliance formation from the resource-based view of strategic and social effects. The resource-based view theory [3]–[5] believes that firms are built upon a bunch of resources, which includes tangible resources such as fixed assets, inventory, and so forth, and intangible resources example as knowledge, copyright, network connections. These resources play vital roles in both requirements and opportunities of alliance formation [2].

A patent is an integral part of organization's intangible resource—intellectual capital [6]. As an exclusive right granted for an invention by the government [7], patent is heterogeneous in nature and not perfectly mobile [8], which perfectly meets the requirements of resource-based view [5]. A patent represents resource and capability that provides input in formulating business strategy [9], [10], helps organizations evaluate competitors' key technologies, and therefore, is critical for developing and maintaining competitive advantage [11], as evidenced in patent lawsuits [12]. Globalization, increasing information transparency, greater bargaining power of consumers [13], and intensified competition all pose challenges for organizations as to how to manage their patents to achieve better financial outcomes. However, little research has investigated patent management on financial payoff from the perspective of resource-based view of strategic alliance.

This paper explains the relevance and significance on patent management in strategic alliance from resource-based view, and proposes a dynamic modeling to examining firms' financial payoff before and after patent alliance formation. It has two primary contributions on patent management and patent measurement.

First, we build up an evolutionary dynamic game theory modeling to show how and why firms perform their strategy on formatting patent alliance over time.

Second, in this paper, we define a new kind of added value, we called synergy value added (SVA), which can only be generated through the collaborative R&D efforts of partners in patent alliance, to evaluate the financial payoff of firms.

The remainder of this paper is organized as follows. First, we describe the theoretical development of patent alliance and the motivation of this study. This is followed by the discussion of the evolutionary stable strategy (ESS) and replicator dynamic (RD) and why evolutionary game theory is appropriate for this study. Then, we present our model and results of our analysis. Finally, we conclude the paper with limitations and avenues for future research.

II. Theoretical Development

Strategy researches suggest that firms need to seek strategic partners when their threats are more than opportunities, and/or weaknesses are excessive than strengths. To understand the emergence of strategic alliance and its operation, scholars deploy a variety of theories and develop different models, including game theory [14], strategic behavior model [15], [16], and strategic decision-making model [17], [18], of which the transaction cost economics [19]–[21] occupies the principal theoretical approach to understanding the formation of a strategic alliance by emphasizing the transaction cost efficiency of interfirm cooperation. For example, scholars [14], [22], [23] believe that firms engage in strategic alliance due to proper payoff interests. As such, firms cooperate with partners when cooperative payoffs higher than that of operating alone.

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Originating from the strategic management literature, resource-based view of firm believes that firms rely on bundles of resources which enable them to gain competitive advantage [3]–[5], [8], [24]. Especially, those distinctive nonimitable resources and capabilities represent the heart of a firm competitive advantage [25]. The resources represent both tangible resources such as factory buildings, machines, cash, and so on, and intangible resources, examples as intellectual capital and reputation, while the capabilities refer to the ability of firms to deploy their resources combining with organizational process to generate competitive advantage [25], [26]. Resource-based view argues that the resources need to meet four requirements: 1) heterogeneity; 2) *ex post* limits to competition; 3) imperfect mobility; and 4) *ex ante* limits to competition [8], [25], in order to maintain a sustained competitive advantage. The heterogeneity of resources and capabilities underlying production leads to Richardian or monopoly rents [8], resulting in above-normal returns. Patent, as a manifestation of intellectual capital, is one kind of intangible resources of firms, which grants its owner an exclusive monopoly on ideas behind an invention for 20 years. It gives the owner firm a competitive advantage by the uniqueness of a superior resource. It also has the potential to build capabilities and add value to organizations because of the knowledge embedded in the process of developing patent and the patent itself.

Some scholars studied on strategic alliance from resource-based view, such as [2] and [27], arguing that addition to transaction cost, the strategic and social explanation of organizational phenomena and management team factors are the motivation of alliance formation. In the perspective of resource-based view, patent represents a resource that is heterogeneity which is underpinned by the appropriability of the patent. Because of the illegal nature of imitation, it matches the factor of limit *ex post* competition for resource-based view: imperfect imibability [8]. Although it is possible that firms can find substitutes for a patent or trade a patent, the cost of other resources and capabilities may be stupendous.

Due to the significant implications for assessing competitive position, identifying mergers and acquisitions (M&A) options, and managing human resource [10] of patent management, a lot of researches have been conducted to examine how to manage patents (e.g., [11], [28], [29]). It is argued that, compared with patent protection, patent alliance can help organizations, especially those in the high tech industry, obtain related knowledge which is usually protected by intellectual property rights, and thereby encourage innovation [30]. Patent alliance facilitates sharing resources and knowledge and developing organizational process [31]. It can also contribute to building the organizations' social capital [32]. Patent alliance, a form of strategic alliance [33]–[36], enables cooperative activities based on patent sharing and collaborative research and development, and has been studied from different perspectives such as choosing partners, forming alliances, creating networks, and designing governance mechanism. For example, some researchers (e.g., [31]) studied how to choose an alliance governance structure and reduce the coordination cost of the alliance. The role of social context and social capital in forming alliance has also received research attention (see, e.g., [32] and [37]–[39]). Contractor and Ra [40] studied "disclosure dilemma" (i.e., how much to disclose) resulted from information asymmetry and how knowledge attributes (codification, newness, complexity, and transferability) influence alliance governance. Even if the knowledge could be fully available and transferable, different learning capability [40], [41] and absorptive capacity [42] would influence how the alliance is structured [43].

However, the problem remains. In the literature, patent alliance has been primarily examined through the lens of transaction cost [19], [21], [44]–[46]. To the best of our knowledge, research on competitive advantages of patent alliance (e.g., financial payoff, market entry, organizational learning) has been lacking. This paper attempts to address this gap. Particularly, we study how sharing patents can create value that enables participants of patent alliance to obtain better financial payoff. We argue that there are two types of added values from patent alliance. The first one is the product from combining patents. Some patents couldnot yield any product/service unless they are combined with other patents. This kind of patents is called "subservient patent," and the patents with which they are combined are called the "dominant patent" [47]. If firm A owns a subservient patent, it does not gain any financial gains from this subservient patent directly. But if firm B owns a related dominant patent, and both two firms participate in a patent alliance, firm A will then be able to combine the two patents to offer a new product/service. We call the financial gains from the new product/service that uses both subservient and dominant patents for firm A patent sharing value added (ShVA) in this paper.

The other type of value added from patent alliance is the synergy from different patents. Synergy is from the Greek synergos, which means a combination of things that create more than the sum of their parts. Patent alliance can generate synergies by creating the new patents through knowledge sharing, and by reducing the time and cost through collaborative R&D effort. This part of value added would benefit all the firms who take part in the collaborative R&D activities which, according to resource-based view [4], [26] contributes to building sustained competitive advantages.

In this paper, we use evolutionary game theory to mathematically demonstrate the synergy effects in patent alliance. In the next section, we discuss evolutionary theory and why it is appropriate for this study.

III. ESS and RD

Evolutionary game theory studies the behavior of a large population of agents who repeatedly engage in strategic interactions. Changes in behavior in the population are driven either by natural selection or by the application of myopic decision rules by individual agents. While traditional game theory assumes agents are completely rational with perfect information, evolutionary game theory upholds that agents learn, adapt, and evolve with a focus on population dynamics rather than individual solutions.

Evolutionary game theory has two core concepts—ESS and RD. ESS is developed based on the work of Maynard Smith and Price [48], [49], and serves as the principal tool of analysis in evolutionary game theory. Two factors affect the ESS. The first factor is the randomness and mutation of agents. Mutation here means one or some individual agents choose a different tactic from most of the population stochastically. Selection mechanism is the second factor that affects ESS. It depicts the selection procedures from trial and error and is an inherent part of the evolutionary process. The initial trial and error helps find a solution to start with. The solution from the initial trial and error may not be the best one, and its payoff may be higher or lower than the population average. However, the payoff of the final solution derived after learning and imitating will be better than the population average. The second core concept of evolutionary game theory is RD [50]. RD constructs an explicit process model to capture the dynamics of strategy changes in the population. RD and ESS describe the dynamic evolutionary process to the stable equilibrium and the state of stable equilibrium itself, respectively.

Evolutionary game theory is widely used in fields such as biology [49], economics [51]–[54], anthropology [55], [56], sociology [57]–[59], philosophy [60]–[62], and political science [63], [64], and therefore, provides a common ground for research from a wide range of disciplines. It is appropriate for this study because ESS and RD of evolutionary game theory can capture dynamic process of learning and sharing exhibited by participants of the patent alliance in response to changing strategies chosen by other participants. As they study the dynamic decision-making process in a group setting as time goes by, ESS and RD can demonstrate how better payoff and synergy can be achieved in patent alliances.

IV. Model

In this session, we use RD and ESS to show how patent alliance offers better financial payoffs, and therefore, more desirable than patent protection. Patent ensures financial rewards of the owner by granting the exclusive monopoly over the use of the new machines, devices, or industrial methods. We call this patent value added (PVA). This is the financial reward inherent in patent regardless of patent management approaches. Patent alliance can create additional financial rewards. As described earlier in the Patent Management section, subservient patents, when stand alone, have very limited commercial value. But in combination with dominant patents, they can be commercialized to new product/services and generate new revenues. Patent alliance enables combining patents, and as a result, additional financial rewards can come from the products/services generated from the patents shared in patent alliance. We call this type of financial rewards as ShVA.

Patent alliance can create additional value that is from the collaborative R&D efforts of patent alliance members [4], [65]–[68]. By enabling updating and sharing patent information, patent alliance allows its members to get the latest technological developments in the field. This can help save time and resource spent on R&D. Moreover, firms who have similar products/services or complementary products/services can collaborate in developing new products/services. This can reduce the cost of recruiting and training technical personnel for new product/service development, and accelerate the process of new product/service development. Here, we call it SVA. Summarized in Table I are the financial rewards for the different patent management structures.

TABLE I
Financial Rewards Table

Patent Management Structure	Financial Rewards
Patent Protection	PVA
Patent Alliance	PVA + ShVA + SVA

PVA describes the payoff for a firm that transfers a patent into a commercial product/service. Let π express the PVA of a firm, then

$$\mathrm{PVA} = \pi. \tag{1}$$

ShVA comes from products/services created by combining two or more patents from different firms participated in patent alliance. It is determined by the technical value of patents shared, the number of patents shared in patent alliance, and the difficulty in converting patents to commercial products. The higher technical value of patents shared is, the more beneficial patents are to patent alliance members. As aforementioned that one product/service may need several patents, the larger number of patents shared in the patent alliance, the greater value is created. The difficulty in converting patents is related to the commercializability of patents and technical capabilities possessed by firms. The more commercializable patents are, the more values these patents bring to patent alliance members. Technical capabilities reflect organizations' R&D ability and relevant knowledge, expertise, and experiences, and they enable the actual commercialization of patents. Therefore,

$$\mathrm{ShVA} = \beta\alpha p \tag{2}$$

where

β difficulty in converting patents to commercial products;
α number of patents shared in patent alliance;
p technical value of patents.

SVA is from the collaborative R&D efforts of patent alliance members. The degree of dependence among firms in commercializing products/services for patents determines the size of the synergy. Generally, the more dependent that the firms are in product/service development, the more SVA creates for them. Knowledge level and R&D ability of the firm is another factor which influences the SVA. When patent alliance members exploit new products/services together, the knowledge level and absorptive ability determines the cost, time, and effort on development. In addition, technical value of patents shared, and the number of patents shared in patent alliance, as described in the previous paragraph, contribute to the SVA as well. Therefore,

$$\mathrm{SVA} = \delta p + \gamma\alpha \tag{3}$$

where

δ degree of dependence of firms in commercializing products from patents;
γ knowledge level and R&D ability of the firm.

TABLE II
DECISION MATRIX FOR THE TWO PLAYERS

Firm A	**Firm B**	
	Patent Sharing	Without Patent Sharing
Patent Sharing	$\pi_A + \beta_A \alpha_B p_B + \delta_{AB} p_B + \gamma_A \alpha_B - l_A p_A, \pi_B + \beta_B \alpha_A p_A + \delta_{BA} p_A + \gamma_B \alpha_A - l_B p_B$	$\pi_A - l_A p_A, \pi_B + \beta_B \alpha_A p_A + \delta_{BA} p_A + \gamma_B \alpha_A$
Without Patent Sharing	$\pi_B - l_B p_B, \pi_B + \beta_B \alpha_A p_A + \delta_{BA} p_A + \gamma_B \alpha_A$	π_A, π_B

Firms face risks of losing technological advantages and competitive edges when they share patents in patent alliance. They must decide how much to share as well as how critical the patents to be shared in patent alliance with their core business. A key factor to consider here is the degree that the firm relies on the patent to generate profits. We call this risk factor of patent sharing. Besides, the technical value of shared patents is also relevant to the risk. The risk factor of patent sharing and the technical value of shared patents both have a direct, positive effect on the firms' risks in patent sharing (R)

$$R = lp \tag{4}$$

where $l =$ Risk factor of patent sharing.

Next, we use a two-firm model example to illustrate synergy effects in patent alliance. In order to specify the payoff of each member in patent alliance, let us suppose that two firms—firm A and firm B—are in the same industry, so patents of each firm can benefit to one another. Table II shows the decision matrix of two players in a traditional game theory model. Both firms A and B can choose to share patents to maximize the financial payoff.

We can extend to *n*-dimension to model the scenario of multiple firms. Let us suppose there is a population consisting of many distinct firms *i* $(i = (1, 2, \ldots, n))$. As we are interested in the process through which each firm makes the final choice via learning and imitation, we add a new variable—the probability of patent sharing, a_i, $a_i \in [0, 1]$. If

π_i PVA of the ith firm;
π_i Technical value of patents of the ith firm;
α_i Number of patents shared in patent alliance of the ith firm;
β_i Difficulty in converting patents to commercial products of the ith firm;
δ_{ij} Degree of dependence from the ith firm to the jth firm in commercializing products from patents;
γ_i Knowledge level and R&D ability of the ith firm;
l_i Risk factors of patent sharing of the ith firm;
a_i Probability of patent sharing of the ith firm.

All of them meet prerequisites $i, j \in (1, 2, \ldots, n)$.

Then, the factors that influence patent financial payoff for each firm would be defined as follows:

$$\mathrm{PVA}_i = \pi_i \tag{5}$$

$$\mathrm{ShVA}_i = \beta_i \sum_{j,j\neq i}^{n} \alpha_j p_j \tag{6}$$

$$\mathrm{SVA}_i = \sum_{j,j\neq i}^{n} \delta_{ij} p_j + \gamma_i \sum_{j,j\neq i}^{n} \alpha_j \tag{7}$$

$$R_i = l_i p_i. \tag{8}$$

The payoff of the ith firm would be

$$\mathrm{Payoff}_i = \pi_i + \beta_i \sum_{j,j\neq i}^{n} \alpha_j p_j + \sum_{j,j\neq i}^{n} \delta_{ij} p_j + \gamma_i \sum_{j,j\neq i}^{n} \alpha_j - l_i p_i. \tag{9}$$

As mentioned earlier, the RD [50] studies the dynamic process of game players. It includes a system of nonlinear first-order differential equation in the continuous case and a system of nonlinear differential equations in the discrete case, as well as the asymptotic behavior. RD equation is a differential equation that describes the probability or frequency of a particular strategy that has been chosen in a population.

Given an evolutionary game, in pure strategy $S = (s_1, s_2, \ldots, s_n)$, the proportion of the population playing strategy s_i at time *t*, denoted *x*, has dynamics described by differential equation: $\frac{dx}{dt} = x\left(U_{s_i} - \bar{U}\right)$, where U_{s_i} represents the expected payoff of selecting strategy s_i at time *t*, and $\bar{U}$ is the average payoff of the population at time *t*.

We define u_i^s to express the payoff of the *i*th firm when they chose patent sharing and synergy

$$\begin{aligned} u_i^s = &\sum_{j,j\neq i}^{n} a_j \\ &\times \left(\pi_i + \beta_i \sum_{j,j\neq i}^{n} \alpha_j p_j + \sum_{j,j\neq i}^{n} \delta_{ij} p_j + \gamma_i \sum_{j,j\neq i}^{n} \alpha_j - l_i p_i \right) \\ &+ \sum_{j,j\neq i}^{n} (1 - a_j)(\pi_i - l_i p_i). \end{aligned} \tag{10}$$

And we define u_i^n to express the payoff of the *i*th firm if they did not choose patent sharing and synergy

$$u_i^n = \sum_{j.j\neq i}^{n} a_j \pi_i + \sum_{j,j\neq i}^{n} (1 - a_j)\pi_i = \pi_i. \tag{11}$$

The average payoff of the i^{th} firm is

$$\begin{aligned} \bar{u}_i &= a_i u_i^s + (1 - a_i) u_i^n \\ &= a_i \left[\sum_{j,j\neq i}^{n} a_j \left(\pi_i + \beta_i \sum_{j,j\neq i}^{n} \alpha_j p_j + \sum_{j,j\neq i}^{n} \delta_{ij} p_j \right.\right. \end{aligned}$$

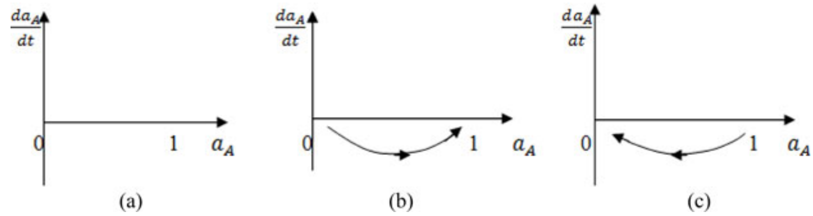

Fig. 1. RD Phase Diagram for Firm A. *X*-axis a_A stands for the probability of patent sharing of firm A, and *Y*-axis is the derivative of probability of patent sharing of firm A (a_A) at time *t*. (a) $a_B = a_B^*$; (b) $a_B > a_B^*$; and (c) $a_B < a_B^*$.

$$+ \gamma_i \sum_{j,j\neq i}^{n} \alpha_j - l_i p_i \Bigg) + \sum_{j,j\neq i}^{n} (1-a_j)(\pi_i - l_i p_i) \Bigg]$$

$$+ \pi_i(1-a_i) = \pi_i + a_i \Bigg[\beta_i \sum_{j,j\neq i}^{n} a_j \sum_{j,j\neq i}^{n} \alpha_j p_j$$

$$+ \sum_{j,j\neq i}^{n} a_j \Bigg(\sum_{j,j\neq i}^{n} \delta_{ij} p_j + \gamma_i \sum_{j,j\neq i}^{n} \alpha_j \Bigg) - l_i p_i \Bigg]. \tag{12}$$

Based on the Taylor's RD equation, we can take equation for the *i*th firm

$$\frac{da_i}{dt} = a_i \left(u_i^s - \bar{u}_i \right). \tag{13}$$

Taking formula (10) and (12) into (13), we can get the new equation as

$$\frac{da_i}{dt} = a_i (1-a_i) \Bigg[\beta_i \sum_{j,j\neq i}^{n} a_j \sum_{j,j\neq i}^{n} \alpha_j p_j$$

$$+ \sum_{j,j\neq i}^{n} a_j \Bigg(\sum_{j,j\neq i}^{n} \delta_{ij} p_j + \gamma_i \sum_{j,j\neq i}^{n} \alpha_j \Bigg) - l_i p_i \Bigg]. \tag{14}$$

Given (14) $=$ 0, the general solution of this equation would be calculated

$$a_i^* = 0 \quad \text{or} \quad a_i^* = 1$$

or

$$\sum_{j,j\neq i}^{n} a_j = \frac{l_i p_i}{\beta_i \sum_{j,j\neq i}^{n} \alpha_j p_j + \sum_{j,j\neq i}^{n} \delta_{ij} p_j + \gamma_i \sum_{j,j\neq i}^{n} \alpha_j}.$$

Again, we take Firms A and B as an example here

$$\frac{da_A}{dt} = a_A (1-a_A) \times \left[a_B \left(\beta_A \alpha_B p_B + \delta_{AB} p_B + \gamma_A \alpha_B \right) - l_A p_A \right]. \tag{15}$$

$$\frac{da_B}{dt} = a_B (1-a_B) \times \left[a_A \left(\beta_B \alpha_A p_A + \delta_{BA} p_A + \gamma_B \alpha_A \right) - l_B p_B \right]. \tag{16}$$

Given (15) and (16) both equal to 0, we can get five stable equilibria

$$O(0,0), A(1,0), B(0,1), C(1,1),$$
$$D\left(\frac{l_B p_B}{\beta_B \alpha_A p_A + \delta_{BA} p_A + \gamma_B \alpha_A}, \frac{l_A p_A}{\beta_A \alpha_B p_B + \delta_{AB} p_B + \gamma_A \alpha_B} \right).$$

Only when $0 < \dfrac{l_B p_B}{\beta_B \alpha_A p_A + \delta_{BA} p_A + \gamma_B \alpha_A}$,

$$\frac{l_A p_A}{\beta_A \alpha_B p_B + \delta_{AB} p_B + \gamma_A \alpha_B} < 1, \text{ point D exists.}$$

The Jacobian matrix put forward by Friedman [69] is used to analyze the local stability of stable equilibrium. If point D exists, then we can get the Jacobian matrix of formula (15) and (16). Given the symbol of the determinant and trace of five aforementioned stable equilibria, we can calculate the local stability of those five stable equilibria (see the equation at the bottom of the next page). Table III shows the calculation results. As shown in Table III, Points O and C are the two ESSs points, Point D the saddle point, and Points A and B unstable points

Fig. 1 shows the RD phase diagram for firm A, in which the *X*-axis a_A stands for the probability of patent sharing of firm A, and *Y*-axis is the derivative of probability of patent sharing of firm A (a_A) at time *t*. Fig. 1(a) shows the derivative of a_A at time t, where the firm B's probability of patent sharing a_B is equal to its value at saddle point a_B^*. Fig. 1(b) depicts the dynamic process where a_B is greater than a_B^*, and Fig. 1(c) shows the dynamic process where a_B is smaller than a_B^*. In this case, firms A and B are in equal status. Based on the symmetry principle, we can get the ESS for firm B. The RD phase diagram for firm B should be the same as shown in Fig. 1, except the conditions for three subgraph are: $a_A = a_A^*$, $a_A > a_A^*$, and $a_A < a_A^*$, respectively.

Combining the dynamic evolutionary process of two firms into one, we can get the dynamic evolutionary diagram as shown in Fig. 2. In Fig. 2, Points O and C, two ESSs, represent the state of defecting (patent protection) and of cooperating (patent alliance), respectively. A firm can choose either the defecting strategy or cooperating strategy to start with. As time goes by, it learns through trials and errors and changes its strategies to achieve a stable state. The initial choice may be at any point in the area of OACB, including Points A, B, C, D, and O. Point M is the probability of patent sharing for firms A and B at a particular point of time. It can be anywhere in the area of OACB and its location varies over time. The benefits and risks of sharing patents affect the change of strategy. For example,

TABLE III
ANALYSIS OF LOCAL STABILITY

Stable Equilibra	Determinant of J	Symbol of D	Trace of J	Symbol of T	Local Stability
O(0,0)	$l_A p_A l_B p_B$	+	$-l_A p_A - l_B p_B$	−	ESS
A(1,0)	$l_A p_A \begin{pmatrix} \beta_B \alpha_A p_A + \delta_{BA} p_A \\ +\gamma_B \alpha_A - l_B p_B \end{pmatrix}$	+	$l_A p_B - l_B p_B + \beta_B \alpha_A p_A$ $+\delta_{BA} p_A + \gamma_B \alpha_A$	+	N/A
B(0,1)	$l_B p_B \begin{pmatrix} \beta_A \alpha_B p_B + \delta_{AB} p_B \\ +\gamma_A \alpha_B - l_A p_A \end{pmatrix}$	+	$l_B p_B - l_A p_B + \beta_B \alpha_A p_A$ $+\delta_{BA} p_A + \gamma_B \alpha_A$	+	N/A
C(1,1)	$\begin{pmatrix} \beta_B \alpha_A p_A + \\ \delta_{BA} p_A \\ +\gamma_B \alpha_A - l_B p_B \end{pmatrix} \begin{pmatrix} \beta_A \alpha_B p_B + \\ \delta_{AB} p_B \\ +\gamma_A \alpha_B - l_A p_A \end{pmatrix}$	+	$-\begin{pmatrix} \beta_B \alpha_A p_A + \delta_{BA} p_A \\ +\gamma_B \alpha_A - l_B p_B \\ +\beta_A \alpha_B p_B + \delta_{AB} p_B \\ +\gamma_A \alpha_B - l_A p_A \end{pmatrix}$	−	ESS
D $\left(\frac{l_B p_B}{\beta_B \alpha_A p_A + \delta_{BA} p_A + \gamma_B \alpha_A}, \frac{l_A p_A}{\beta_A \alpha_B p_B + \delta_{AB} p_B + \gamma_A \alpha_B}\right)$	$J_D{}^*$	−	0	N/A	Saddle Point

$J_D^* = \frac{l_A p_A l_B p_B (\beta_B \alpha_A p_A + \delta_{BA} p_A + \gamma_B \alpha_A - l_B p_B)(\beta_A \alpha_B p_B + \delta_{AB} p_B + \gamma_A \alpha_B - l_A p_A)}{(\beta_B \alpha_A p_A + \delta_{BA} p_A + \gamma_B \alpha_A)(\beta_A \alpha_B p_B + \delta_{AB} p_B + \gamma_A \alpha_B)}$.

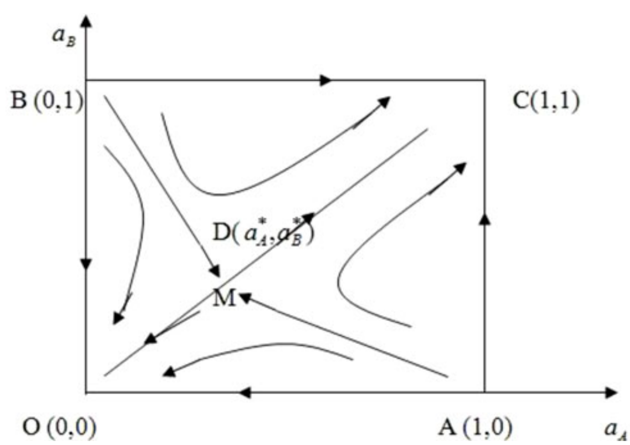

Fig. 2. Dynamic evolutionary diagram between two Firms. *X*-axis and *Y*-axis stand for the probability of patent sharing for Firms A and B, respectively.

as shown in Table III, the higher the risk of patent sharing is, the bigger area of MABC is. When the system moves to Point O, it is highly possible that the system will converge to Point O. In contrary, if the risk cost of patent sharing is smaller than the value add of patent sharing, it is more likely to converge on Point C.

V. DISCUSSIONS

Our model shows that each firm that reacts to changes in the external environment has two choices which are stable: cooperating (patent alliance) when all the other firms choose for cooperating, and defecting (patent protection) when all other firms defecting.

Given the payoff expression: $\mathrm{Payoff}_i = \pi_i + \beta_i \sum_{j,j\neq i}^{n} \alpha_j p_j + \sum_{j,j\neq i}^{n} \delta_{ij} p_j + \gamma_i \sum_{j,j\neq i}^{n} \alpha_j - l_i p_i$, the payoff of each firm is affected by the variables(e.g., α_j, p_j, δ_j) and numbers of other firms in the alliance (the value of "*n*" in the formula shows the number of other firms in the alliance). In the payoff formula, for the $i\mathrm{th}$ firm, there are *n* firms selecting cooperating, namely the $j\mathrm{th}\,(j \in [1, n])$ firm, can benefit it by adding value to the $i\mathrm{th}$ firm from patent sharing, and the whole value added is the summary of all of those *n* firms' value added.

The difference for the payoff of the $i\mathrm{th}$ firm between cooperating and defecting is $\Delta = \beta_i \sum_{j,j\neq i}^{n} \alpha_j p_j + \sum_{j,j\neq i}^{n} \delta_{ij} p_j + \gamma_i \sum_{j,j\neq i}^{n} \alpha_j - l_i p_i$. When $\beta_i \sum_{j,j\neq i}^{n} \alpha_j p_j + \sum_{j,j\neq i}^{n} \delta_{ij} p_j + \gamma_i \sum_{j,j\neq i}^{n} \alpha_j > l_i p_i$, there is $\Delta > 0$, which means the $i\mathrm{th}$ firm would get more payoff if it chooses cooperating over defecting. In the meanwhile, other firms would learn the experience of the $i\mathrm{th}$ firm. Driven by better profits, more and more firms in the alliance will copy the strategy of the $i\mathrm{th}$ firm. The expression of Δ shows that the more firms choose cooperating, the bigger the value of $\beta_i \sum_{j,j\neq i}^{n} \alpha_j p_j + \sum_{j,j\neq i}^{n} \delta_{ij} p_j + \gamma_i \sum_{j,j\neq i}^{n} \alpha_j$. However, the negative factor $l_i p_i$ is fixed. So when $j \to \infty$, there is $\beta_i \sum_{j,j\neq i}^{n} \alpha_j p_j + \sum_{j,j\neq i}^{n} \delta_{ij} p_j + \gamma_i \sum_{j,j\neq i}^{n} \alpha_j \succ l_i p_i$, meaning $\Delta = \beta_i \sum_{j,j\neq i}^{n} \alpha_j p_j + \sum_{j,j\neq i}^{n} \delta_{ij} p_j + \gamma_i \sum_{j,j\neq i}^{n} \alpha_j - l_i p_i \succ 0$. All the firms in the alliance will move to stable point C, which represents the patent alliance, for maximizing their own financial payoff.

Eisenhardt states that "the greater the number of competitors, the greater the rate of alliance formation," which has been explained and proved by her work [2]. Our research model certifies a similar statement in patent alliance formation, which is the greater the number of alliance members, the bigger the alliance growth. Eisenhardt's work focuses on alliance formation, yet, our model emphasizes firms behaviors on prompting the alliance formation. As such, other than using a statistical prediction model, our model captures the dynamic evolutionary process of firm's decision making. Admittedly, at the formatting stage of a strategic alliance, the partner's decision can be changed in any minutes. Our model shows that a firm begins with a predecision and then modified its decision under the firm interest, and finally, makes its ultimate decision with the time

$$J = \begin{Bmatrix} (1-2a_A)\left[a_B\left(\beta_A \alpha_B p_B + \delta_{AB} p_B + \gamma_A \alpha_B\right) - l_A p_A\right] & a_A\left(1-a_A\right)\left(\beta_A \alpha_B p_B + \delta_{AB} p_B + \gamma_A \alpha_B\right) \\ a_B\left(1-a_B\right)\left(\beta_B \alpha_A p_A + \delta_{BA} p_A + \gamma_B \alpha_A\right) & (1-2a_B)\left[a_A\left(\beta_B \alpha_A p_A + \delta_{BA} p_A + \gamma_B \alpha_A\right) - l_B p_B\right] \end{Bmatrix}$$

change. It helps us to have a better understanding of why and how firms form a patent alliance.

Patent information is widely used by firms for strategy planning and technology management [10], [70]–[73]. Studies on patent management are most focused on patent quality and patent strength and how patent provides competitive position for a firm who owns the property rights. For example, Ernst [10], [72] studies on how patent applications change firm's performance and how information employs for monitoring competitor, assessing technology, as well as managing R&D portfolio. Similar to our study, Ernst suggests using patent information for identifying potential sources for external generation of knowledge through M&A. It emphasizes that patent indicators such as the numbers of patent owned by a firm in all the patent quantity in the industry, technology share, dynamic development of technology share over time, and patent growth can be used in assessment of M&A options. In our model, we argue that the patent synergy value cannot be neglected in considering alliance formation. Patent synergy value is collaborative R&D efforts amongst alliance members. According to the resource-based view and knowledge-based view of the firm [3], [26], [27], knowledge is a resource that is imperfect mobility because of even if implicit knowledge is tradable and transferable, it is much more valuable within the firm that currently deploys them than other deployment [25]. Patent synergy value is only generated when firms formatted alliance; knowledge required by patent invention is still embedded in their original environment. With proposing the patent synergy value in our model, we add to knowledge base some indicators of patent information measurement.

VI. Conclusion

In this paper, we have explained how synergies can be created in patent alliance, and why patent alliance is more financially viable from a resource-based view of strategic alliance. To this end, we mathematically demonstrated that value in a patent alliance can help patent alliance participants gain better financial payoffs and how participants facilitate the formation of a patent alliance over time. Our research identifies the SVA in patent alliance, and provides support to the collaborative approach to patent management from the perspective of financial gains.

Our study is not without limitations. First, we do not include all three generic strategies in game theory. Of the three generic game theory strategies—defecting, cooperating, and refuting, we study defecting and operating, because we think it is extremely difficult, if not impossible, for a firm to survive by adopting refuting strategy in which the influences of the external environment are disregarded. However, by dismissing refuting strategy, we do not evaluate the all possible scenarios in patent alliance.

The second limitation is related to our assumption that there are a large number of patent alliance participants. As we have shown earlier, the financial payoffs of patent alliance depend on whether the ShVA and SVA are greater than the risk cost or not. According to the payoff formula, only a large number of participants could generate enough added values to offset the risk cost. The risk cost may be greater than the value added in a patent alliance that has only few participants.

Future research can evaluate different assumptions and variables in the payoff equation and examine how they affect the convergence of ESS models. Such scrutiny can help improve the understanding of members' behaviors in patent alliance. Another avenue for future research is to analyze members' behaviors in patent alliance by other economic methods such as regression equation. The triangulation of different research methods will offer a deeper and more comprehensive understanding of members' behaviors in patent alliance.

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References

[1] R. H. Coase, "The nature of the firm," *Economica*, vol. 4, pp. 386–405, 1937.

[2] K. M. Eisenhardt and C. B. Schoonhoven, "Resource-based view of strategic alliance formation: Strategic and social effects in entrepreneurial firms," *Org. Sci.*, vol. 7, pp. 136–150, 1996.

[3] B. Wernerfelt, "A resource-based view of the firm," *Strategic Manag. J.*, vol. 5, pp. 171–180, 1984.

[4] J. Barney, "Firm resources and sustained competitive advantage," *J. Manag.*, vol. 17, pp. 99–120, 1991.

[5] R. M. Grant, "The resource-based theory of competitive advantage: Implications for strategy formulation," *Calif. Manag. Rev.*, vol. 33, pp. 114–135, 1991.

[6] T. Stewart and C. Ruckdeschel, "Intellectual capital: The new wealth of organizations," *Perform. Improvement*, vol. 37, pp. 56–59, 1998.

[7] WIPO. (2011). What is a patent. [Online]. Available: http://www.wipo.int/patentscope/en/patents_faq.html#patent

[8] M. A. Peteraf, "The cornerstones of competitive advantage: A resource-based view," *Strategic Manag. J.*, vol. 14, pp. 179–191, 1993.

[9] S. Macdonald, "When means become ends: Considering the impact of patent strategy on innovation," *Inform. Econ. Policy*, vol. 16, pp. 135–158, 2004.

[10] H. Ernst, "Patent information for strategic technology management," *World Patent Inform.*, vol. 25, pp. 233–242, 2003.

[11] E. Gelle and K. Karhu, "Information quality for strategic technology planning," *Ind. Manag. Data Syst.*, vol. 103, pp. 633–643, 2003.

[12] J. Pepitone. "Yahoo and Facebook settle patent brawl," [Online]. Available: http://money.cnn.com/2012/07/06/technology/yahoo-facebook-patent-settle/index.htm

[13] M. E. Porter, "Towards a dynamic theory of strategy," *Strategic Manage. J.*, vol. 12, pp. 95–117, 1991.

[14] A. Parkhe, "Strategic alliance structuring: A game theoretic and transaction cost examination of interfirm cooperation," *Acad. Manag. J.*, vol. 36, pp. 794–829, 1993.

[15] M. E. Porter, *Competitive Advantage: Creating and Sustaining Superior Performance*. New York, NY, USA: Simon & Schuster., 2008.

[16] J. Hagedoorn and R. Narula, "Choosing organizational modes of strategic technology partnering: International and sectoral differences," *J. Int. Bus. Stud.*, vol. 27, pp. 265–284, 1996.

[17] T. Das and B.-S. Teng, "Managing risks in strategic alliances," *Acad. Manag. Executive*, vol. 13, pp. 50–62, 1999.

[18] T. K. Das and B.-S. Teng, "Trust, control, and risk in strategic alliances: An integrated framework," *Org. Stud.*, vol. 22, pp. 251–283, 2001.

[19] J. F. Hennart, "A transaction costs theory of equity joint ventures," *Strategic Manag. J.*, vol. 9, pp. 361–374, 1988.

[20] J.-F. Hennart, "The transaction costs theory of joint ventures: An empirical study of Japanese subsidiaries in the United States," *Manag. Sci.*, vol. 37, pp. 483–497, 1991.

[21] O. E. Williamson, "Comparative economic organization: The analysis of discrete structural alternatives," *Administ. Sci. Quart.*, vol. 36, pp. 269–296, 1991.

[22] R. Axelrod and W. D. Hamilton, "The evolution of cooperation," *Science*, vol. 211, pp. 1390–1396, 1981.

[23] M. A. Nowak, "Five rules for the evolution of cooperation," *Science*, vol. 314, pp. 1560–1563, 2006.

[24] E. T. Penrose, *The Theory of the Growth of the Firm*. New York, NY, USA: Oxford Univ. Press, 1959.
[25] K. Cabrera-Suárez, P. De Saá-Pérez, and D. García-Almeida, "The succession process from a resource-and knowledge-based view of the family firm," *Family Bus. Rev.*, vol. 14, pp. 37–46, 2001.
[26] J. B. Barney, "Resource-based theories of competitive advantage: A ten-year retrospective on the resource-based view," *J. Manag.*, vol. 27, pp. 643–650, 2001.
[27] T. K. Das and B.-S. Teng, "A resource-based theory of strategic alliances," *J. Manag.*, vol. 26, pp. 31–61, 2000.
[28] A. Arora and M. Ceccagnoli, "Patent protection, complementary assets, and firms' incentives for technology licensing," *Manag. Sci.*, vol. 52, pp. 293–308, 2006.
[29] B. Yoon and Y. Park, "A text-mining-based patent network: Analytical tool for high-technology trend," *J. High Technol. Manag. Res.*, vol. 15, pp. 37–50, 2004.
[30] T. E. Stuart, "Network positions and propensities to collaborate: An investigation of strategic alliance formation in a high-technology industry," *Administ. Sci. Quart.*, vol. 43, pp. 668–698, 1998.
[31] R. Gulati and H. Singh, "The architecture of cooperation: Managing coordination costs and appropriation concerns in strategic alliances," *Administ. Sci. Quart.*, vol. 43, pp. 781–814, 1998.
[32] G. Duysters and C. Lemmens, "Alliance group formation enabling and constraining effects of embeddedness and social capital in strategic technology alliance networks," *Int. Stud. Manag. Org.*, vol. 33, pp. 49–68, 2003.
[33] B. Borys and D. B. Jemison, "Hybrid arrangements as strategic alliances: Theoretical issues in organizational combinations," *Acad. Manag. Rev.*, vol. 14, pp. 234–249, 1989.
[34] P. S. Ring and A. H. Van De Ven, "Structuring cooperative relationships between organizations," *Strategic Manag. J.*, vol. 13, pp. 483–498, 1992.
[35] R. N. Osborn and C. C. Baughn, "Forms of interorganizational governance for multinational alliances," *Acad. Manag. J.*, vol. 33, pp. 503–519, 1990.
[36] A. Parkhe, "Partner nationality and the structure-performance relationship in strategic alliances," *Org. Sci.*, vol. 4, pp. 301–324, 1993.
[37] S. A. Chung, H. Singh, and K. Lee, "Complementarity, status similarity and social capital as drivers of alliance formation," *Strategic Manag. J.*, vol. 21, pp. 1–22, 2000.
[38] H. Hoang and F. T. Rothaermel, "The effect of general and partner-specific alliance experience on joint R&D project performance," *Acad. Manag. J.*, vol. 48, pp. 332–345, 2005.
[39] G. Walker, B. Kogut, and W. Shan, "Social capital, structural holes and the formation of an industry network," *Org. Sci.*, vol. 8, pp. 109–125, 1997.
[40] F. J. Contractor and W. Ra, "How knowledge attributes influence alliance governance choices: A theory development note," *J. Int. Manag.*, vol. 8, pp. 11–27, 2002.
[41] P. Kale, H. Singh, and H. Perlmutter, "Learning and protection of proprietary assets in strategic alliances: Building relational capital," *Strategic Manage. J.*, 2000.
[42] W. M. Cohen and D. A. Levinthal, "Absorptive capacity: A new perspective on learning and innovation," *Administ. Sci. Quart.*, vol. 35, pp. 128–152, 1990.
[43] B. S. Teng and T. Das, "Governance structure choice in strategic alliances: The roles of alliance objectives, alliance management experience, and international partners," *Manag. Decision*, vol. 46, pp. 725–742, 2008.
[44] D. Teece and G. Pisano, "Collaborative arrangements and global technology strategy: Some evidence from the telecommunications equipment industry," *Res. Technol. Innov., Manage. Policy*, vol. 4, pp. 227–256, 1989.
[45] W. Shan, "An empirical analysis of organizational strategies by entrepreneurial high-technology firms," *Strategic Manage. J.*, vol. 11, pp. 129–139, 2006.
[46] J. F. Hennart, "The transaction costs theory of joint ventures: An empirical study of Japanese subsidiaries in the United States," *Manage. Sci.*, vol. 37, pp. 483–497, 1991.
[47] J. Lerner and J. Tirole, *Efficient Patent Pools*. Cambridge, MA, USA: Natl. Bureau Econ. Res. 2002.
[48] J. Maynard Smith, "The theory of games and the evolution of animal conflicts," *J. Theor. Biol.*, vol. 47, pp. 209–221, 1974.
[49] J. Maynard Smith and G. R. Price, "The logic of animal conflict," *Nature*, vol. 246, pp. 15–18, 1973.
[50] P. D. Taylor and L. B. Jonker, "Evolutionary stable strategies and game dynamics," *Math. Biosci.*, vol. 40, pp. 145–156, 1978.
[51] D. Friedman, "Evolutionary games in economics," *Econometrica*, vol. 59, pp. 637–666, 1991.
[52] A. J. Robson and F. Vega-Redondo, "Efficient equilibrium selection in evolutionary games with random matching," *J. Econ. Theory*, vol. 70, pp. 65–92, 1996.
[53] H. Gintis, "The evolution of private property," *J. Econ. Behav. Org.*, vol. 64, pp. 1–16, 2007.
[54] M. Slade and B. C. Eaton, *Evolutionary Equilibrium in Market Supergames*. Vancouver, BC, Canada: Univ. British Columbia, 1990.
[55] T. Ellingsen, "The evolution of bargaining behavior," *Quart. J. Econ.*, vol. 112, pp. 581–602, 1997.
[56] E. Dekel and S. Scotchmer, "On the evolution of optimizing behavior," *J. Econ. Theory*, vol. 57, pp. 392–406, 1992.
[57] R. Axelrod and W. D. Hamilton, "The evolution of cooperation," *Science*, vol. 211, pp. 1390–1396, 1981.
[58] R. Axelrod and D. Dion, "The further evolution of cooperation," *Science*, vol. 242, pp. 1385–1390, 1988.
[59] W. Nakahashi, "The evolution of conformist transmission in social learning when the environment changes periodically," *Theor. Popul. Biol.*, vol. 72, pp. 52–66, 2007.
[60] J. M. K. Alexander, *The Structural Evolution of Morality*. Cambridge, MA, USA: Cambridge Univ. Press, 2007.
[61] C. Boehm, "The evolutionary development of morality as an effect of dominance behavior and conflict interference," *J. Social Biol. Syst.*, vol. 5, pp. 413–421, 1982.
[62] P. H. Hawley, "Strategies of control, aggression, and morality in preschoolers: An evolutionary perspective," *J. Exp. Child Psychol.*, vol. 85, pp. 213–235, 2003.
[63] A. Gifford, "The evolution of the social contract," *Constitutional Political Econ.*, vol. 13, pp. 361–379, 2002.
[64] R. Axelrod, "An evolutionary approach to norms," *Amer. Political Sci. Rev.*, pp. 1095–1111, 1986.
[65] D. C. Hambrick, *The Top Management Team: Key to Strategic Success*. New York, NY, USA: Columbia Univ., 1987.
[66] J. B. Barney, "Organizational culture: Can it be a source of sustained competitive advantage?" *Acad. Manag. Rev.*, vol. 11, pp. 656–665, 1986.
[67] B. Klein and K. B. Leffler, "The role of market forces in assuring contractual performance," *J. Political Econ.*, vol. 89, p. 615, 1979.
[68] M. E. Porter, *Competitive Strategy: Techniques for Analyzing Industry and Competitors*. New York, NY, USA: Free Press, 1980.
[69] J. H. Friedman, "Multivariate adaptive regression splines," *Annals Statist.*, vol. 19, pp. 1–67, 1991.
[70] D. Archibugi and M. Planta, "Measuring technological change through patents and innovation surveys," *Technovation*, vol. 16, pp. 451–519, 1996.
[71] B. L. Basberg, "Patents and the measurement of technological change: a survey of the literature," *Res. Policy*, vol. 16, pp. 131–141, 1987.
[72] H. Ernst, "Patent applications and subsequent changes of performance: Evidence from time-series cross-section analyses on the firm level," *Res. policy*, vol. 30, pp. 143–157, 2001.
[73] H. Ernst, *Evaluation of Dynamic Technological Developments by Means of Patent Data*. New York, NY, USA: Springer, 1999.

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