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Rule-based System of Inbound Open Innovation Based on Variable Precision Rough Sets

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Abstract: Open innovation paradigm has been distinguished into two dimensions: inbound open innovation and outbound open innovation. The rule-based system of inbound open innovation has been mainly researched in this study. After reviewing previous researches in terms of knowledge decision making theories of information system, this study establishes a four-dimensional decision mode of inbound open innovation and introduces an identification method of inbound open innovation paradigm based on Variable Precision Rough Sets (VPRS). With respect to data analysis, this study chooses the software ROSETTA system. Via completing, discretizing, reducing, generating rules and filtering, the rule-based system is built and testified by the testing samples.

Key words: Rule-base, decision mode, rough set, open innovation

INTRODUCTION

Chesbrough and Crowther (2006) have distinguished these two dimensions of the open innovation paradigm, including inbound open innovation and outbound open innovation. From current literature, inbound open innovation is more common in enterprise practice. Hence, it is necessary to summary inbound open innovation processes from as many industries as possible. This study explore deeply inbound open innovation paradigm based on Variable Precision Rough Sets (VPRS).

Compared to outbound open innovation, both theoretical research and practices highlight inbound open innovation currently. Spithoven *et al.* (2010) studied the ability of absorbing external knowledge in traditional industries in case of inbound open innovation. Parida *et al.* (2012) analysed impact of inbound open innovation activities on innovation performance in high-tech SMEs. Some literatures analysed open innovation paradigm of diverse industries. Bianchi *et al.* (2011) study organizational modes of open innovation in the bio-pharmaceutical industry. Chen (2012) analyzed how to operate open innovation from perspective of organizational structure in China. In addition, the process of open innovation varies as industry and enterprise size changes according to Vanhaverbeke (2006) and Chiaroni *et al.* (2010). Therefore, Lichtenthaler (2011) thought that a better understanding is needed for research and practice with respect to inbound open innovation. Accordingly, this study focuses on developing a four-dimensional mode for organizing inbound open innovation in firms, including enterprise background (e.g., industries scale, etc.), organizational mode (e.g., in-licensing, non-equity alliances, etc.), partner type (e.g., rivals, users, government, etc.) and phases of the R&D process (e.g., basic research, applied research, etc.).

FOUR DIMENSIONAL DECISION MODE OF INBOUND OPEN INNOVATION

The previous research stated that open innovation practices are affected by enterprise background, scale, industries and development phrase (Chesbrough and Crowther, 2006; Bianchi *et al.* 2011).To address inbound open innovation process successfully, this study develop four-dimensional decision mode (Fig. 1). The variables will be described following.

First, The organizational modes for inbound open innovation include in-licensing, minority equity investment, acquisition, joint venture, R&D contract and research funding, procurement of technical and scientific services and non-equity alliances (Lichtenthaler, 2011; Bianchi *et al.* 2011).

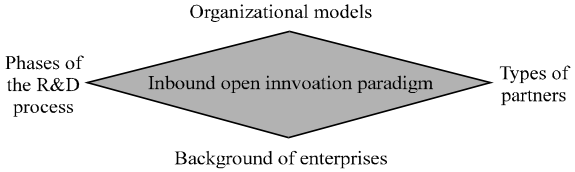

Fig. 1: Four-dimensional decision mode of inbound open innovation

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Second, firms use these organizational modes to establish relationship with a number of heterogeneous actors in inbound open innovation. firms interact with partners to acquire external knowledge, such as customers, suppliers, competitors, consultants, private R&D institutes, universities and other higher education, government and public research (Perkmann and Walsh, 2007).

Third, the organizational modes which a firm selects, as well as the partner types with which it establishes relationship vary substantially along the phases of the R&D process in inbound open innovation (Bianchi *et al*., 2011). The common phases of R&D process can be divided into basic research, applied research, commercialization (Chiesa, 2001).

Fourth, Open innovation have been regarded as primary to high-tech industries (Chesbrough and Crowther, 2006). Although, the sampled firms have saliently increased their attitude in leveraging external sources of innovation to complement their internal R&D activities, the inbound open innovation practices are not widely used in the traditional and mature industries. Hence, enterprise background is a key dimension in inbound open innovation.

RESEARCH METHOD

Variable precision rough set model: Variable Precision Rough Set Model (VPRS) was put forward by Ziarko (1993) based on Rough set which was raised by Pawlak (2002). VRPS is important to knowledge acquisition and overcome the noise data of information system.

Definition 1: S = (U, A, V, f), A = C∪D, B⊆A, X⊆U, β∈(0.5, 1], the β- lower approximation of the set X⊆U is defined as:

$$\underline{R_B^{\beta}}(x)=\left\{x\in U\left|\frac{|X\cap[x]_B|}{|[x]_B|}\geq\beta\right.\right\}=\cup\left\{[x]_B\left|\frac{|X\cap[x]_B|}{|[x]_B|}\geq\beta\right.\right\}$$

the β-upper approximation of the set X⊆U is defined as:

$$\overline{R_B^{\beta}}(x)=\left\{x\in U\left|\frac{|X\cap[x]_B|}{|[x]_B|}>1-\beta\right.\right\}=\cup\left\{[x]_B\left|\frac{|X\cap[x]_B|}{|[x]_B|}>1-\beta\right.\right\}$$

The Rough sets based on the β- lower approximation and the β-upper approximation is Variable Precision Rough Set Model (VPRS) (Ziarko, 1993).

Filtering decision rules: The parametric, including accuracy (α>β), coverage (α>β) and support (α>β), can measure significance of rules.

The formulas see as follow:

$$\text{Accuracy}(\alpha\rightarrow\beta)=\frac{\text{Support}(\alpha,\beta)}{\text{Support}(\alpha)} \quad (1)$$

$$\text{Coverage}(\alpha\rightarrow\beta)=\frac{\text{Support}(\alpha,\beta)}{\text{Support}(\beta)} \quad (2)$$

$$\text{Support}(\alpha\rightarrow\beta)=\text{Support}(\alpha,\beta) \quad (3)$$

$$\text{support}(\alpha)=\text{card}\left[\left\{x_i\in U\left|\bigcap_{a_i\in Red}f(x_i,a_i)=\gamma_i\right.\right\}\right] \quad (4)$$

$$\text{support}(\beta)=\text{card}\left[\left\{x_i\in U\left|\bigcap_{b_i\in D}f(x_i,b_i)=\tau_i\right.\right\}\right] \quad (5)$$

$$\text{support}(\alpha,\beta)=\text{card}[\{x_i\in U|[\bigcap_{a_i\in Red}f(x_i,a_i)=\gamma_i]\cap[\bigcap_{b_i\in D}f(x_i,b_i)=\tau_i]\}] \quad (6)$$

RESULTS

This study investigated 44 inbound open innovation programs in high-technology industries, traditional and mature industries in China. The high-technology industries have 26 out of 44 firms; the pharmaceuticals industries have 5; while 13 programs in mature and/or traditional industries. The interviews were held primarily with vice presidents of R&D or business unit executives. This study chooses ROSETTA for data analysis. There are four steps: information system representation, complete and discretize, reduce, generate rules and filter.

Information system representation: According to Rough sets, the information system of inbound open innovation in this study is as follow. x_i is the investigated firms (i = 1, 2...44); c_m are attributes of the four-dimensional mode of inbound open innovation (m = 1, 2..27). The values that c_m takes are 1 (yes) and 2 (no). The decisional set D in this study indicates that firms improve innovation performance by inbound open innovation. The value of "greatly improved" is 1; the value of "no improved" is 2. There are 34 yeses and 10 numbers.

Lower approximation and upper approximation: Rough sets have not to any additional information and prior knowledge which describe information by means of lower approximation and upper approximation. The result indicated that objective set can accurately describe attributes set (Table 1).

Table 1: Lower and upper approximation and its accuracy of the information system

Class No.	No. of objects	Lower approximation	Upper approximation	Accuracy
1	34	34	34	1
2	10	10	10	1

Table 2: Parts of reduce and its support of the information system

No.	Reduce	Support	Length	No.	Reduce	Support	Length
1	{C8, C21, C22, C25}	100	4	11	{C8, C12, C15, C20, C22}	100	5
2	{C8, C14, C20, C25}	100	4	12	{C7, C8, C18, C20, C22}	100	5
3	{C8, C14, C20, C27}	100	4	13	{C3, C8, C18, C20, C22}	100	5
4	{C8, C14, C20, C21}	100	4	14	{C8,C12, C15, C20, C25}	100	5
5	{C8, C14, C20, C22}	100	4	15	{C3, C5, C8, C12, C20, C21}	100	6
6	{C8, C10, C14, C20, C24}	100	5	16	{C9, C12, C14, C18, C20, C24}	100	6
7	{C8, C12, C20, C21, C24}	100	5	17	{C8, C12, C14, C21, C26, C27}	100	6
8	{C1, C8, C14, C20, C24}	100	5	18	{C10, C16, C20, C21, C26, C27}	100	6
9	{C2, C8, C14, C20, C24}	100	5	19	{C3, C8, C12, C20, C21, C25}	100	6
10	{C8, C11, C20, C22, C24}	100	5	20	{C3, C8, C12, C19, C20, C27}	100	6

Table 3: Rules and its coverage of open innovation paradigm (D = 1)

Rule	LHS support	LHS coverage	RHS coverage	LHS length
C1(2) AND C10(2) AND C21(1) AND C22(1) => Results(1)	11	0.250	0.324	4
C4(2) AND C8(2) AND C21(1) AND C22(1) => Results(1)	12	0.273	0.353	4
C1(2) AND C10(2) AND C12(1) AND C22(1) => Results(1)	14	0.318	0.412	4
C8(2) AND C20(1) AND C21(1) AND C22(1) => Results(1)	11	0.250	0.324	4
C8(2) AND C14(1) AND C21(1) AND C22(1) => Results(1)	11	0.250	0.324	4
C1(2) AND C10(2) AND C22(1) AND C23(1) => Results(1)	12	0.273	0.353	4
C10(2) AND C18(1) AND C20(1) AND C22(1) => Results(1)	13	0.295	0.382	4
C10(2) AND C14(1) AND C22(1) AND C24(1) => Results(1)	12	0.273	0.353	4
C8(2) AND C18(1) AND C20(1) AND C22(1) => Results(1)	11	0.250	0.324	4
C10(2) AND C14(1) AND C20(1) AND C22(1) => Results(1)	12	0.273	0.353	4
C1(2) AND C10(2) AND C11(1) AND C22(1) => Results(1)	13	0.295	0.382	4
C2(1) AND C4(2) AND C10(2) AND C12(1) AND C22(1) => Results(1)	12	0.273	0.353	5
C2(1) AND C4(2) AND C10(2) AND C11(1) AND C22(1) => Results(1)	11	0.250	0.324	5
C3(2) AND C8(2) AND C14(1) AND C20(1) AND C21(1) => Results(1)	13	0.295	0.382	5
C8(2) AND C12(1) AND C20(1) AND C21(1) AND C26(1) => Results(1)	12	0.273	0.353	5
C1(2) AND C10(2) AND C14(1) AND C22(1) AND C26(1) => Results(1)	12	0.273	0.353	5
C1(2) AND C10(2) AND C18(1) AND C19(1) AND C22(1) => Results(1)	11	0.250	0.324	5
C1(2) AND C2(1) AND C8(2) AND C21(1) AND C22(1) => Results(1)	11	0.250	0.324	5
C1(2) AND C10(2) AND C18(1) AND C22(1) AND C26(1) => Results(1)	14	0.318	0.412	5
C2(1) AND C4(2) AND C10(2) AND C18(1) AND C22(1) => Results(1)	13	0.295	0.382	5
C1(2) AND C2(1) AND C10(2) AND C18(1) AND C22(1) => Results(1)	13	0.295	0.382	5
C4(2) AND C11(1) AND C18(1) AND C21(1) AND C22(1) => Results(1)	12	0.273	0.353	5
C2(1) AND C10(2) AND C20(1) AND C22(1) AND C23(1) => Results(1)	11	0.250	0.324	5

*C_i (i = 1, 2,...27) represent mature and/or traditional, high-technology, pharmaceuticals, mining crude-oil production, multinational enterprises, large enterprises, medium-sized enterprises, maturity stage, development stage, growing stage, R&D contracts and research funding, purchase of technical and scientific services, non-equity alliances, in-licensing, minority equity investments, acquisitions, joint ventures, private R&D institutes, users, suppliers, other firms, universities and other higher education, rivals, government and public research, basic research, applied research, commercialization

Reduce: This study adopt VPRS ($\beta = 0.8$). To improve efficiency of reduce, this study adopt genetic algorithm and get 71 reduce (Table 2).

Generate rules and filter: This study generated 1442 rules initiatly. Some rules are valid, others are untypical. To raise effectiveness and accuracy, this study filter the decision rules according to the principles: accuracy $(\alpha \rightarrow \beta) \geq 0.8$, coverage $(\alpha \rightarrow \beta) \geq 0.05$, support $(\alpha \rightarrow \beta) \geq 10$. Then this study get 23 rules of inbound open innovation paradigm (Table 3). All the rules represented inbound open innovation greatly improved innovation performance (D = 1). "RHS Coverage" shows proportion of investigated firms coveraged by the rules. "RHS Coverage" are higher than 25% in this research. It shows that the rules coverage all investigated firms. In short, the rules can represent successful inbound open innovation paradigm.

Test: This study tests the rules by 24 pretreated samples which adopt successful inbound open innovation paradigm. The test results show that 22 samples can be distinguished correctly based on the rules. The others cannot be distinguished. The precision of the rule-based system (Table 3) is 91.67%.

CONCLUSION

This study defined a four-dimensional decision mode of inbound open innovation; and then investigated

44 cases, as well as collected data from the four dimensions. Given the use in analyzing ambiguous description of objects, VPRS is fit for summarizing key factors of successful inbound open innovation paradigm. With respect to data analysis, this study chose the software ROSETTA. After completing, discretizing, reducing, generating and filtering rules, the rule-based system is built. Finally the methods testified by the test samples. The test results show that the rules base can represent inbound open innovation paradigm. However, from the results this study found that industrial type is not the critical factors impacting the success of inbound open innovation.

As an attempt to applying quantitative studies on opening up the innovation process, by virtue of investigation and variable precision rough sets theory, this study aims at providing some reference for practice in inbound open innovation. However, there still exist many limitations, as result of difficulties in data collecting. Future work, in terms of collecting data about fail cases of open innovation, is required for a comprehensive analysis.

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