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Managerial cognition, strategic behavior and innovation: biopharmaceutical R & D

Abstract

In biopharmaceutical industry, R & D managers are open to new knowledge and technology to achieve innovation. On the other hand, R & D managers keep core knowledge in confidentiality to outrun competitors in claiming intellectual properties, patents or market exclusivities. For understanding innovation in this industrial success logic, it is essential to understand R & D managerial cognitive and behavioral constructs and build a relational model for optimization in the pursuit of innovation. The cognitive belief and behavioral choice of R & D manager's remains understudied even though these managers are at the frontline of new scientific knowledge and its interpretation into new therapeutics. This study surveyed data from questionnaires completed by 88 R & D biopharmaceutical managers. The statistical analyses of the data provided R & D managerial constructs and an Innovative Managerial Model (IMM). The model draws a relational map between constructs and shows that innovation is optimized when external collaborations, strategic cognition, managerial openness to networking and managerial openness to new technologies are factored into the therapeutic development process. The study's findings offer practical implications to boost R & D managerial innovativeness while filling the missing R & D managerial input in the current R & D productivity model.

Keywords: innovation, managerial cognition, strategic behavior, pharmaceutical industry, ansoff's success hypothesis, managerial model

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Abbreviations: IMM, innovative managerial model; NME, new molecular entity; FDA, food and drug administration; NBFs, new biotechnology firms; CSOs, chief scientific officers; CTOs, chief technology officers; CMOs, chief medical officers; CEOs, chief executive officers; SEM, structural equation modeling; R^2, squared multiple correlation; CFI, comparative fit index; RMSEA, root mean square error of approximation; ROAs, return of assets

Introduction

The innovative managerial model (IMM) anticipates serving as a managerial mental map and tool for R & D managers to achieve innovation in an effective and efficient way. In the biopharmaceutical industry, firms are valued by innovation,[1,2] which leads to legal rewards, such as industrial-level market exclusivity or patents. Essentially, the legal rewards bring financial rewards by enabling the firms to dominate the market for a specific time without copycats or competitors. From strategic management's perspective, innovation is the outcome of managerial strategic processes, not solely dependent on the serendipity of science.[3] In other words, innovation is a managerial achievement attained by exploring all possible resources. Aggressively searching for new knowledge, new technology and collaborations with external partners has become common practice in the new drug development process.[4–7] In a deeply interwoven way, R & D managerial cognition plays a role in this innovation process where decisions are made by managerial beliefs about the linkage between the choice of strategic behaviors and the subsequent impact of those behaviors on outcomes.[8] Despite their significance, R & D managerial cognitive and behavioral constructs are severely understudied in strategic management, which has traditionally emphasized ideal models of strategic thinking without managerial input.[9–13]

The aim of this study was to connect 'the missing link' between managerial constructs and innovation and test a relational model in pursuit of innovation to resolve the unsettling issues of measuring managerial cognition. The foundation of this research was the assertion that managerial cognition causes a variance between strategic behavior and innovation. Subsequently, this research expanded on Ansoff's theoretical frameworki[1] and advanced the study of managerial cognitionii[2].

Managerial cognition in new drug development

Innovation is the outcome of interactions and cooperation among different types of agents commanding complementary resources and competencies.[14–16] Particularly, the development of a new drug is an accumulation of interdisciplinary knowledge from external sectors and internal departments.[3,17–20] Vivid case studies demonstrate how biopharmaceutical R & D managerial decision-making involves multi-sources, both internal and external experts and is a multi-step process. In the biopharmaceutical industry, R & D managers compete with rivals by navigating through intellectual property protection and legal rewarding systems.[21] Thus, managers continuously make sense of internal and external actors, which coincide with the definition of managerial cognition.[22–24] R & D managerial cognitive interplay is embedded in the process of drug development.

In the early phase of a new molecular entity (NME) development, R & D managers interpret raw scientific knowledge into a medical

[i]See references 41, 62-66 and 104 for detailed information on Ansoff's Theoretical Framework.

[ii]Numerous managerial cognition studies have taken a longitudinal approach of using archival data and examining firms' responses to industrial change, particularly new technology emergence.[22,50,105–107]

context to generate curative, symptomatic, preventive and substitutive therapeutics.[25]In the final phases of a successful drug development, R & D managers predict innovative therapeutic drugs and create a new market with new customers and a new market position.[26] Intuitively, R & D managers are able to see the creation of completely new therapeutics. In new therapeutic potential development, R & D managers attempt to 'reframe' existing drugs to target a new disease. This is understood as *efficient innovation*, a much shorter and often less expensive path to drug approval and market launch. For instance, repositioning existing drugs to target an orphan disease is a type of efficient innovation process.[27]

Subsequently, R & D managerial cognition functions as a key component in this process; managerial cognition repositions an already known therapeutic from a known area into a new therapeutic area. It is highly likely that managerial cognition plays a role in interpreting raw scientific knowledge into a medical context and creating new therapeutic drugs in a new market with new customers. Supposedly, R & D managerial cognition functions as a mental model of the linkage between the choice of actions and the subsequent impact of those actions on outcomes.

Research questions and hypotheses

This study posed three research questions in the context of biopharmaceutical R & D:

I. Does strategic behavior have a reliable relationship with innovation?

II. Does managerial cognition have a reliable relationship with innovation*?* If so, what is R & D managerial cognition?

III. Does R & D managerial cognition have a reliable relationship with strategic behavior? While Ansoff's theory framed the research questions, the implications of managerial practice and previous scholarly studies helped shape the details of the relational constructs in each question.

Hypothesis 1: Numerous R & D external collaboration studies have been controversial. Some researchers have pointed out the consof R & D external collaboration related to managerial challenges regarding cost, high uncertainty and high unpredictability.[28–30] On the other hand, many researchers have noted the benefits of R & D external collaboration include accessibility to new technology and flexibility of operation.[4,31–36] Despite the complexities of R & D collaboration, this present study hypothesized that R & D collaboration has a reliable relationship with achieving innovation. Thus, this hypothesis supported the notion that collaboration is a biopharmaceutical R & D strategic behavior to achieve innovation. Hypothesis 1 addressed the first research question: *Does R & D strategic behavior have a reliable relationship with innovation?*

H1: There is a reliable relationship between R & D collaboration and innovation

Hypotheses 2 thru 5: Many studies have investigated the 'uniqueness' of innovation,[37] innovation management,[3,38] the cognitive model of innovation[39] and the unique managerial mental template.[40–42] Considering these studies together, research question 2 led to the hypothesis that strategic cognition, managerial openness to new technology, managerial openness to networking and managerial openness to information sharing are R & D managerial cognitions for innovation. With this hypothesis, Hypotheses 2 thru 5 addressed the second research question: *Does managerial cognition have a reliable relationship with innovation?*

H2: There is a reliable relationship between innovation and R & D managerial openness to networking

H3: There is a reliable relationship between innovation and R & D managerial openness to information sharing

H4: There is a reliable relationship between innovation and R & D managerial openness to new technology

H5: There is a reliable relationship between innovation and R & D managerial strategic cognition.

Hypotheses 6 thru 9: Despite managerial challenges, well-performed R & D external collaboration can speed up innovation and improve its efficiency.[15,34] Prior studies have implied R & D managerial cognition is important to carry out collaboration.[4,43,44] However, there is lack of research regarding the significance of R & D collaborations toward innovation and managerial impact on executing effective R & D collaborations. Thus, it is clear R & D collaboration needs a 'unique managerial cognition' iii[3] to manage higher uncertainty, unfamiliarity and frequent change at an operational level.[45] Many recent studies have researched the relationship between managerial cognition and strategic behavior in a broad spectrum, such as industrial events[46] or market entry behavior.[47–50] However, these study results did not directly exhibit a clear relationship between managerial cognition and strategic behavior in creating value; specifically, value such as innovation. This is important since managerial decision-making comprises of rational and intuitive decisions that are conscious and subconscious processes.[51] This paper hypothesized that R & D collaboration is an exemplar of R & D strategic behavior in pursuit of innovation. Hypotheses 6 thru 9 addressed the third research question: *Is there a reliable relationship between R & D strategic behavior and R & D managerial cognition?*

H6: There is a reliable relationship between R & D collaboration and R & D managerial openness toward networking

H7: There is a reliable relationship between R & D collaboration and R & D managerial openness toward information sharing

H8: There is a reliable relationship between R & D collaboration and R & D managerial openness toward new technology

H9: There is a reliable relationship between R & D collaboration and R & D managerial strategic cognition.

Variables and definitions

The variables in this study were innovation, R & D collaboration and R & D managerial cognition. Their construct validity was checked by factor analysis (principle component).[52] Within the R & D managerial cognition variable, there were four specific cognitions hypothesized and tested: strategic cognition, managerial openness to networking, managerial openness to information sharing and managerial openness to technology. The following sections discuss each variable in more detail.

Innovation: The U.S. Food and Drug Administration (FDA) are res-

[iii]Though it was originally termed "additional management", herein, it seems to be indicative that there needs to be a unique managerial cognition to run R&D collaboration due to high uncontrollability.

ponsible for approving new drugs to enter the marketplace. In relation to innovation, it is fundamental to examine how industrial success comes from radical innovation and incremental innovation. For instance, a new molecular entity (NME) has never been therapeutically used in market, while a new therapeutic potential is an improvement on a previous drug in terms of efficacy or patient compliance. However, in the pharmaceutical industry, there is no significant distinction between radical innovation (NME) and incremental innovation (a therapeutic potential).[53] In practice, incremental innovation can be advantageous since it shortens time to market a new drug and absorb costs due to FDA's speedy review process. Therefore, current industrial trends in pursuit of innovation are shifting toward a new therapeutic potential, which is incremental innovation through knowledge expansion.[3] New drug discovery and development is how R & D managers generate innovative knowledge (new treatment), innovative mechanisms (processes) and innovative products.[53–55]

R & D strategic behavior: R & D external collaboration: In the biopharmaceutical industry, R & D external collaboration frequently occurs during the drug development process. R & D managers collaborate to obtain newly emerging technologies or scientific knowledge after they identify a potential for emerging technology, but lack the necessary internal experts to proceed alone.[4,33,34] Essentially, from a strategic management viewpoint, external collaboration provides accessibility to new technologies, skills and knowledge; at the same time, it involves a high uncertainty of operations and an unpredictable outcome.[45,56] Therefore, it is clear that R & D collaboration needs a 'unique managerial cognition' that manages higher uncertainty, unfamiliarity and frequent change.[45] Table 1 illustrates the merits and demerits of collaboration according to Piachaud.[45]

Table 1 Merits and demerits of pharmaceutical collaboration

Merits of collaboration	Demerits of collaboration
Obtaining greater flexibility	Dependence on the supplier
Buy-in specialized knowledge and skills	Lack of shared vision and objectives
Facilitation of the rapid exploitation of technology	Loss of control over suppliers
Gaining a window on new technologies	Loss of critical skills
Freedom to concentrate on core functions	Problems of evaluating supplier performance
Risks spread	Need for a new management mindset
Cost reduction	Problems of monitoring supplier performance
Increase time to market	Class of culture

Source, Piachaud[45]

R & D managerial cognition: Innovation management is a rather chaotic process.[3,38] This innately differs from efficiency management, which involves a linear process that needs operational capabilities: 'repeatable patterns of action' in the use of assets to produce products to a market.[57] By comparison, innovation involves divergent and convergent processes.[37] Accordingly, a cognitive model of innovation consists of an intellectual process of pattern recognition and pattern extrapolation,[39] which is similar to a new drug development process: pattern recognition of the known therapeutic molecule, pattern extrapolation of unknown therapeutic molecule by continued tests, interpretation of results and managerial belief and problem solving as mediators.

In relation to innovation, R & D managers may have a unique mental template to cognitively identify a new therapeutic potential and create market value for it.[39,42] This unique mental template might have appeared as an 'explorative and exploitive capability',[58] a 'paradoxical cognition'[40] or a 'strategic mindset and openness'.[41] Based on Ansoff's work, this paper argues that R & D managerial cognition consists of strategic cognition and managerial openness to strategic issues for innovation, specifically new technology, networking and information sharing. This conceptual breakdown allowed for the measuring of managerial cognition's interplay with strategic issues, strategic behaviour and innovation.

Strategic cognition: This paper argues that strategic cognition is a managerial cognition iv[4] involving strategic decision-making and strategic behavior.[59–61] Strategic cognition plays a role in interpreting strategic issues (technology and regulation), identifying competitors and strategizing goals among competitors v[5].[62–67] R & D managers with strategic cognition proactively engage in a large number of external factors, such as new technologies, regulatory agencies and pursuing goals based upon their mental map of the industry, the firm's competitiveness and competitors. They are more likely to be map-makers than map-users.[67]

Managerial openness to new technology: New technology (and/or new scientific knowledge)vi[6] is vital in the biopharmaceutical industry. This became evident in the 1980s when new biotechnology firms (NBFs) specializing in molecular biology, a new technology at the time, successfully entered the industry.[14,68,69] This changed the industrial dominant logic, because the dominant pharmaceutical firms at the time mainly relied on chemistry as scientific knowledge in new drug development. Consequently, for firms to remain competitive, all pharmaceutical R & Ds had to increase their capabilities in molecular biology to compete with NBFs and produce new drugs, forming a new pattern of industry evolution.[15] Accordingly, managerial openness to new technology is important since R & D managers must evaluate and make decisions on the impact of adopting a newly emerging technology.[5,70–72] While R & D managers are highly involved in the decision-making process of whether to implement new technology or not, no direct study has investigated the relationship between managerial openness to new technology and innovation. Thus, this paper argues that R & D managerial openness to new technology is an R & D managerial cognition that keenly interprets the values and potentials of new technology and subsequently adopts them.

Managerial openness to networking: Early studies on networking

[iv] See also "strategic aggressiveness" discussed in Ansoff and McDonnell[65] and Lorton[108] that refers to the firm's behavior.

[v] Ansoff emphasized how managers see industrial boundaries such as SBU and SBA and industrial logic as business environments, while he measured industrial velocity from level 1 to level 5 based on industrial change, its predictability, discontinuity and rapidity.

[vi] In the biopharmaceutical industry, technology seems to be understood as new scientific knowledge for the drug development process, as new biotechnology firms are referred to as companies capable of molecular biology, cell biology and protein and peptide chemistry. Hence, herein, technology and scientific knowledge are used without differentiation.[109,110]

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have not provided strong empirical evidence of its direct relationship to innovation.[73,74] However, recent studies have shown that innovation is influenced by formal networking, specifically open innovation policy,[75] number of external knowledge sources[2,76] and the innovation locus process.[43,73] In regards to cognition and networking, Nelson and Mathews[77] established a network analysis that became an important precedent for examining the relationship between cognitive and social processes at the organizational level. Further, other studies have shown relevance between networking and cognitive structure at the pharmaceutical R & D level.[15,78] This implies that formal networking involves a cognitive map change at an industrial level where R & D actively searches for new scientific knowledge and technologies. On the other hand, informal networking is expected to be more relevant with R & D managers' cognitive beliefs and cognitive experiences in inter-department and intra-department networking.[79–81]

This current research expanded the study of innovation and R & D managerial openness to networkingvii[7] by arguing that managerial openness to networking is an R & D managerial cognition that includes R & D managers' cognitive beliefs and experiences about problem solving, idea generation and communication in inter-department and intra-department networking. This expands on the early finding by Tushman and Scanlan[82] that communication and interaction between R & D departments is a contributor to innovation.

Managerial openness to information sharing: Online communication accommodates innovation by providing R & D professionals access to acquire, translate and disseminate external information.[83–86] Within organizations, online communication systems serve as non-hierarchical and informal communication channels that help management with multi-level transfers of knowledge.[87–91] While prior studies have emphasized the significance of online communication within an organization,[87,88] this paper argues that R & D managerial openness to online information sharingviii[8] contributes to innovation and collaboration. In a related study, Sundgren et al.[80] did not find a direct relationship between openness to online information sharing and creativity of R & D professionals; however, this present study reexamined this variable in an innovation context.

Data collection and statistical methodology

Data in this study was obtained through questionnaires completed by R & D pharmaceutical managers across the United States. Data collection began by searching the websitesix[9] of 600 companies in the biotechnology and pharmaceutical industry. The companies were reviewed for structure (headquarters, department and regional offices), location (address of R & D, headquarters, U.S. regional offices) and R & D activity of firms (publication, podcast, lectures and presentation videos) to determine which companies matched the sample study criteria of biopharmaceutical companies in the United States. If a company had no physical U.S. division, or if they had only a distribution channel without R & D, they were excluded.

Of the remaining companies and websites, the names, positions, email addresses and postal addresses of target managers were collected. Targeted managers included chief scientific officers (CSOs), chief technology officers (CTOs), chief medical officers (CMOs), chief drug development officers, chief business development officers, chief executive officers (CEOs), directors of business, directors of laboratories, project managers and scientists in R & D. The online survey was available on Survey Monkey immediately following IRB approval and was distributedx[10] via email and postal mail to the qualified companies and managers. The survey email contained three different survey links, ensuring respondents anonymity. In the postal mailed surveys, a return envelope was included with my address enclosed. Out of 600 questionnaires mailed, 34 returned via postal mail and were manually inputted into Survey Monkey. A total of 95 targeted managers participated in the survey; however, 7 surveys were omitted due to incomplete answers. Therefore, 88 surveys were used for data analysis.

To measure inter-relationships among variables, descriptive statistics, correlation, factor analysis, multivariate regression analysis and sequential regression modeling were conducted. Each variable was evaluated on a 5–point Likert scale and the reliability of each variablexi[11] was measured using the Cronbach-alpha (reliability coefficient). After checking the reliability, factor analysis (principle component) was conducted to examine if there were any underlying dimensions.[52] Thus, each variable was factor-analyzed separately before looking into inter-relationships.

Results and discussion

The descriptive statistic results for each variable are outlined in Table 2: openness to technology (0.734), openness to information sharing (0.820), openness to networking (0.797), strategic cognition (0.604) and collaboration (0.759). These coefficients are all higher than 0.6, which is the bar standard for variable reliability.[92] The first research question (R1) investigated the relationship between R & D strategic behavior and innovation: *Is there a reliable relationship between R & D strategic behavior and innovation?*

As Table 3 shows, there was a reliable relationship between R & D collaborationxii[12] and innovation (r=0.230*, Sig.=0.021, n=78). Hypothesis 1 was supported. The second research question (R2) investigated the relationship between innovation and four managerial cognitions: *Is there a reliable relationship between R &*

vii The direct construct of R & D managerial openness to networking was partly borrowed from recent R & D literature studies.[79,80]

viii The direct construct of R&D managerial openness to online information sharing was partly borrowed from recent R&D literature studies.[79,80]

ixWebsites were found by using a variety of resources: Yahoo Finance, *Contract Pharma*, directories, websites and events of BIOCOM, American Chemical Society (ACS), American Association of Pharmaceutical Scientists Association (AAPS), Pharmaceutical Research and Manufacturers of America (PhRMA), Bay Bio and the Licensing Executive Society (LES).

xIn the first round, the survey was sent to representative email addresses of the companies, such as contact@company.com or info@company.com. In the second round, 400 emails and 300 letters were sent to the address of the firms, but to unidentified managers addressed as "Dear managers, scientists and professionals"; this was because some managers' information was not accessible on the website. In the third round, 500 surveys were emailed directly to managers and sent via postal mail to 300 managers.

xiManagerial openness to networking and managerial openness to information sharing came from creativity management,[79,80] the innovation variable came from an innovation study by Chandy et al.,[111] and openness to technology came from technology management.[112] Notably, openness to networking and information sharing did not show a reliable relationship with organizational creativity in Dewitt's study. However, based on the literature review and industrial idiosyncrasy, openness to networking and openness to information sharing were expected to have a relationship with innovation. Strategic cognition was taken from Lorton's[108] work on strategic aggressiveness and strategic posture in strategic management. R & D collaboration came from research by Thakur.[113]

xiiThis refers to the number of R & D external collaborations companies operate within five years.

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D managerial cognitions and innovation? Table 3 shows the results of hypotheses 2 through 5 (H2~H5). Correlation tests revealed that all four R & D managerial cognitions showed a reliable relationship with innovation. Strategic cognition had the strongest relationship with innovation (r=0.357**, Sig.=0.001, n=81 at the 0.01 level, 1-tailed: H5). Managerial openness to new technology was the next strongest (r=0.329**, Sig.=0.001, n=80, at the 0.01 level, 1-tailed: H4), followed by managerial openness to networking (r=0.302**, Sig.=0.04, n=76, 1-tailed: H2) and openness to information sharing (r=0.226*, Sig.=0. 025, n=76, at the 0.05 level, 1-tailed: H3). Except for openness to information sharing, all three were significant at the 0.01 level (1-tailed). All four hypotheses (H2, H3, H4, and H5) were supported. The third research question (R3) concerned the relationship between R & D managerial cognition and R & D strategic behavior: *Is there a reliable relationship between R & D strategic behavior and R & D managerial cognition?*

Table 3 also provides a detailed analysis of the H6-H9 correlations. There was no reliable relationship between R & D collaboration and R & D managerial openness to networking (r=-0.027, Sig.=0.408, n=75); thus, hypothesis 6 was not supported. There was no reliable relationship between R & D collaboration and R & D managerial openness to information sharing (r=0.015, Sig.=0.448, n=75), and hypothesis 7 was not supported. There was no reliable relationship between R & D collaboration and R & D managerial openness to new technology (r=0. 052, Sig.=0.325, n=79). Hypothesis 8 was not supported. There was no reliable relationship between R & D collaboration and R & D strategic cognition (r=0. 233*, Sig.=0.018, n=81), so hypothesis 9 was not supported.

Table 2 Descriptive statistics of the study variables: innovation, R & D collaboration, strategic cognition, openness to new technology, openness to new networking, openness to information sharing

	N	Minimum	Maximum	Mean	Standard deviation
Innovation	82	1	5	2.4675	0.93969
R & D collaboration	82	1	5	3.0366	1.6212
Strategic cognition	86	1.67	5	3.3837	0.85178
Openness to new technology	84	1	5	3.2905	0.85159
Openness to new networking	80	1.4	5	3.7225	0.85477
Openness to information sharing	78	1.86	5	3.7802	0.80143
Valid N(list wise)	69				

Table 4 outlines all the hypotheses results. As the table shows, all four cognitions had a reliable relationship with innovation; as a result, they formed the basis for the innovative managerial model (IMM).

Table 3 Pearson's correlation between the variables, including significance level and sample size

1.Innovation	*R*	1	0.230*	0.357**	0.329**	0.302**	0.226*
	Sig. (1-tailed)		0.021	0.001	0.001	0.004	0.025
	N	82	78	81	80	76	76
2.R & D collaboration	*R*	0.230*	1	0.233*	0.052	-0.027	0.015
	Sig. (1-tailed)	0.021		0.018	0.325	0.408	0.448
	N	78	82	81	79	75	75
3.Strategic cognition	*R*	0.357**	0.233*	1	0.330**	0.390**	0.301**
	Sig. (1-tailed)	0.001	0.018		0.001	0	0.004
	N	81	81	86	83	80	77
4.Managerial openness to new technology	*R*	0.329**	0.052	0.330**	1	0.371**	0.340**
	Sig. (1-tailed)	0.001	0.325	0.001		0	0.001
	N	80	79	83	84	78	77
5. Managerial openness to new networking	*R*	0.302**	-0.027	0.390**	0.371**	1	0.654**
	Sig. (1-tailed)	0.004	0.408	0	0		0
	N	76	75	80	78	80	75
6. Managerial openness to information sharing	*R*	0.226*	0.015	0.301**	0.340**	0.654**	1
	Sig. (1-tailed)	0.025	0.448	0.004	0.001	0	
	N	76	75	77	77	75	78

*Correlation is significant at the 0.05 level (1-tailed)

**Correlation is significant at the 0.01 level (1-tailed)

r=Pearson's correlation

Sig.=Significance coefficient

N=Number of sample who answered corresponding questions

Missing value was deleted as pair wise

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Table 4 Results of hypotheses based on Pearson's correlation findings

H1 Supported	H1: There is a reliable relationship between R & D collaboration and innovation (5years: r=0.230*, Sig.=0.021, n=78).
H2 Supported	H2: There is a reliable relationship between innovation and R & D managerial openness toward networking (r=0.302**, Sig.=0.04, n=76).
H3 Supported	H3: There is a reliable relationship between innovation and R & D managerial openness toward information sharing (r=0.226*, Sig.=0.025, n=76).
H4 Supported	H4: There is a reliable relationship between innovation and R & D managerial openness toward new technologies (r = 0.329**, Sig.=0.001, n=80).
H5 Supported	H5: There is a reliable relationship between innovation and R & D managerial strategic cognition (r = 0.357**, Sig.= 0.001, n=81).
H6 Not supported	H6: There is a reliable relationship between R & D collaborations and R ° D managerial openness toward networking (r= ¯0.027, Sig.=0.408, n=75).
H7Not supported	H7: There is a reliable relationship between R & D collaborations and R & D managerial openness toward information sharing (r = 0.015, Sig.=0.448, n=75).
H8 Not supported	H8: There is a reliable relationship between R & D collaborations and R & D managerial openness toward new technology (r=0. 052, Sig.=0.325, n=79).
H9 Supported	H9: There is a reliable relationship between R & D collaborations and R & D managerial strategic cognition (r=0. 233*, Sig.=0.018, n=81).

Innovative managerial model (IMM)

This section discusses how the regression models were statistically experimented and, consequentially, how the Innovative Managerial Model (IMM) was created. Since all four cognitions and R & D collaboration correlated with innovation, multivariate regression models were tested to investigate the unique contribution of each capability towards innovation. In validating the four R & D managerial cognitions with innovation, all of the hypothesized cognitions (managerial openness to networking, managerial openness to new technology, managerial openness to information sharing and strategic cognition) showed a reliable relationship with innovation. When using Runyon et al.[93] magnitude scale levels and all study relationship results, except openness to information sharing, were at a medium level.

Before starting regression models, the missing values were deleted as list wise. In the sequential regression test, strategic cognition, managerial openness to networking, managerial openness to new technology and openness to information sharing were inserted from highest to lowest correlations. Table 5 illustrates the results of the five tested multiple regression models. Model 5 included all five predictors and was the best-fit model for innovation with the highest R squared value of the five models (R Square=0.241).

When strategic cognition was the only predictor (Model 1), the R squared was 0.140. This implies that Model 1 can predict 14% of innovation with constant and strategic cognition. Model 2 included both strategic cognition and managerial openness to networking and the R squared value was 0.181; this means that 18% of innovation can be predicted by strategic cognition and managerial openness to networking. When a third factor, openness to new technology, was included in the model, results showed that strategic cognition, managerial openness to networking and openness to new technology can together predict 0.204or 20.4% of innovation. Model 4 added openness to information sharing and the R squared value only went up slightly from Model 3 to 0.213. This result demonstrates that openness to information sharing contributes less than the other factors. When R & D collaboration entered into Model 5, it proved to be the best fitting model with 24.1%predictability. Considering the dynamic nature of innovation and the inclusion of four managerial cognitions and R & D collaboration, 24.1% predictability (R Squared) provides a relevant model.

The IMM is expressed with one dependent variable ($Y_{innovation}$), whereas independent variables are strategic cognition, managerial openness to networking, managerial openness to new technology, managerial openness to information sharing and R & D collaboration. As expected, strategic cognition was a strong predictor of innovation. Table 6 shows the coefficient of each variable, innovation and four R & D managerial constructs, which is formulated into a multivariate equation as below.

$$Y_{innovation} = 0.221X_{\substack{strategic\\cognition}} + 0.259X_{\substack{managerial\\openness\ to\\networking}} + 0.173X_{collaboration} + 0.184X_{\substack{openness\ to\\new\ technology}} - 0.121X_{\substack{openness\ to\\information\ sharing}}$$

$$X_{strategic\ cognition} = Strategic\ cognition$$

$$X_{managerial\ openness\ to\ networking} = Managerial\ openness\ to\ networking$$

$$X_{openness\ to\ new\ technology} = Managerial\ openness\ to\ new\ technology$$

$$X_{openness\ to\ information\ sharing} = Managerial\ openness\ to\ information\ sharing$$

$$X_{collaboration} = R\ \&\ D\ Collaboration$$

$$Y_{innovation} = Innovation$$

The IMM explains 24.1% of innovation by combining R & D collaboration and four R & D managerial cognitions. Consequently, a managerial mental model defines the conditions under which normative prescriptions, based on the respective theoretical models, should be used in practice.[63] In this empirical model, innovation is predicted when R & D managers are strategically cognizant, open to networking, open to new technology and executing external collaboration within five years.

To confirm the multi-inter-relationships among variables, structural equation modeling (SEM) was conducted. It was intended to check the hypothesized model fit to verify whether managerial cognition impacted R & D collaboration and innovation. The predictors were

strategic cognition, managerial openness to networking, managerial openness to technology, managerial openness to information sharing and R & D collaboration. They were configured into the hypothesized model shown in Figure 1.

The bottom table of squared multiple correlations presents the squared multiple correlation (R^2) of the endogenous variables. These values represented the amount of variance accounted for in the model. As Table 7 shows, the model accounted for 23.2% of the variance of innovation.

Table 5 Statistics summary of the 5 models tested to find the innovative managerial model (IMM)

Model	R	R squared	Adjusted R squared	Std. error of the estimate	Change statistics					Durbin watson
					R squared change	F change	df1	df2	Sig. F change	
1	0.375a	0.14	0.128	0.8971	0.14	10.951	1	67	0.002	
2	0.426b	0.181	0.156	0.88216	0.041	3.289	1	66	0.074	
3	0.452c	0.204	0.168	0.87633	0.023	1.881	1	65	0.175	
4	0.461d	0.213	0.164	0.87845	0.008	0.688	1	64	0.41	
5	0.491e	0.241	0.181	0.86941	0.028	2.337	1	63	0.131	1.626

a. Predictors, (Constant), Strategic cognition

b. Predictors, (Constant), Strategic cognition, managerial openness to networking

c. Predictors, (Constant), Strategic cognition, managerial openness to networking, managerial openness to new technology

d. Predictors, (Constant), Strategic cognition, managerial openness to networking, managerial openness to new technology, managerial openness to information sharing

e. Predictors, (Constant), Strategic cognition, managerial openness to networking, managerial openness to new technology, managerial openness to information sharing, R & D collaboration

f. Dependent variable, innovation

Missing value is deleted as list wise, while the modeling is built with sequential regression method

Table 6 Innovative managerial model coefficients

Model 5	Un standardized coefficients		Standardized coefficients	T	Sig.	95.0% Confidence interval for B		Collinearity statistics	
	B	Std. error	Beta			Lower bound	Upper bound	Tolerance	VIF
(Constant)	0.168	0.616		0.272	0.787	-1.064	1.399		
Strategic cognition	0.242	0.138	0.221	1.751	0.085	-0.034	0.517	0.758	1.319
Openness to networking	0.281	0.164	0.259	1.716	0.091	-0.046	0.609	0.53	1.888
Openness to new technology	0.197	0.13	0.184	1.512	0.135	-0.063	0.457	0.811	1.233
Openness to info sharing	-0.145	0.177	-0.121	-0.821	0.415	-0.498	0.208	0.554	1.804
R & D collaboration	0.1	0.066	0.173	1.529	0.131	-0.031	0.232	0.94	1.064

Dependent variable, innovation

Table 7 Squared multiple correlations of IMM

	Estimate
Collaboration	0.054
Innovation	0.232

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Chi-square of SEM was 0.733 (Degrees of freedom=3, Probability level=.860). According to the fit indexes, CMIN=0 .755 stands for minimum discrepancy as indexed by chi-squared.[94] Additionally, other model fit indexes were tested, such as NFI (.992), Comparative Fit Index (CFI) (1.000) and Root Mean Square Error of Approximation (RMSEA) (0.000). They suggest a good fit to the data (Table 8).

Main findings, contributions and limitations

Research findings support the study's premise that R & D managerial cognition, R & D strategic behavior and innovation are interrelated. Most significantly, findings showed innovation requires high-levels of R & D managerial strategic cognition. To my knowledge, this is the first study to connect R & D managers' strategic cognition with innovation. Moreover, managerial strategic cognition is coalescent with R & D collaboration in pursuit of innovation, showing inter-relationships with managerial openness to information sharing, networking and new technology. Conclusively, innovation is optimized by strategically executing R & D collaboration and by having R & D managers with high levels of strategic cognition. These combined results demonstrate that four R & D managerial cognitions boost innovation. Figure 2 illustrates the multifaceted relationships between R & D managerial cognition, innovation and R & D collaboration.

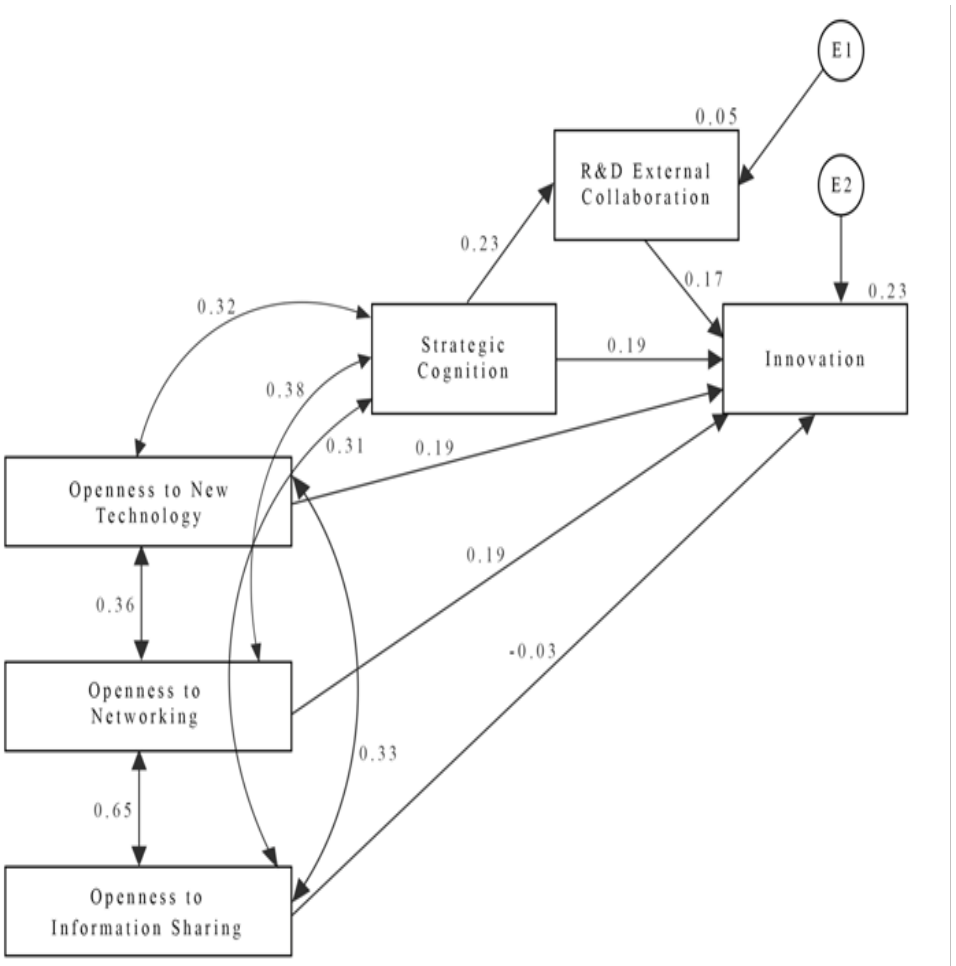

Figure 1 SEM modeling, R & D managerial cognitions, R & D external collaboration and innovation.

Contribution to ansoff's success paradigm and strategic management research: This study contributes to strategic management research by providing new avenues for future researchers to investigate the relationships between managerial cognition, strategic behavior and innovation. Moreover, this research developed managerial constructs, advanced empirical data and contributed to Ansoff's Success Paradigm, which previously had no specifications on managerial capability, except brief descriptions such as cognitive novelty, transformation and culture of management capability.[65] Additionally this study provides managerial constructs for future researchers to investigate their relationships with dynamic capability.[58,95]

Contribution to R & D productivity model: Previous studies have addressed low productivity in the biopharmaceutical industry from an economical view point.[21,96–100] The best and most productive approach to this industrial issue would be to increase R & D productivity. The IMM improves the *R & D Productivity Model* that consists of effectiveness, efficiency and reduction of time and cost in the R & D pharmaceutical industry context. In other words, in order to increase R & D productivity, R & D needs to raise the number of newly approved drugs and the amount of value each new drug creates, while decreasing time and cost. Essentially, this is what R & D managers do, since they make decisions in every step from the initial selection of drug candidates to the design of a clinical trial and interpretation of clinical

data. Paul et al.[101] admitted there is no substitute for R & D managers' scientific and clinical intuition in order to advance a molecule into late-phase clinical development. IMM shows what R & D managers should cognitively believe and how they should strategically behave to achieve innovation. Hence, IMM completes the R & D Productivity Model by adding the missing part.

Contribution to R & D practitioners: The IMM prescribes the optimizing condition for innovation in practice. As Axelord mentioned,[101] cognitive maps assist decision-makers with policies in the present by deriving explanations of the past and predicting the future. As long as innovation is predicted by managerial cognition and strategic behavior, policy makers and practitioners create processes that facilitate networking, update new technology and execute strategic collaborations. In addition, this study supported the work of Fiol & Huff[102] by providing an R & D managerial cognition map, thus building on their proposal that a cognitive map needs different map sets for managers to make better decisions. In the process of achieving innovation, R & D managerial cognition and strategic behavior can serve as a self-measurement for R & D innovation capability.

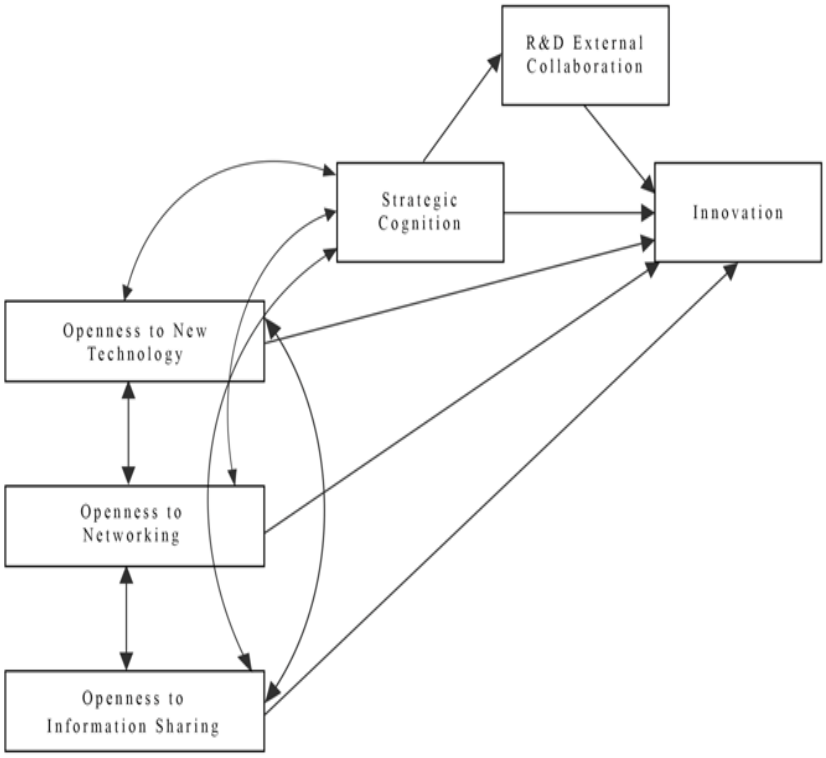

Figure 2 IMM (Innovation Managerial Model), R & D managerial cognitions, strategic behavior and innovation.

Managerial Cognition, Strategic Behaviour and Innovation

Table 8 Model fit indexes

Model	CMIN	DF	P	NFI delta1	RFI rho1	CFI	RMSEA	CMIN/DF
IMM	.755	3	.86	.992	.945	1	0	.252
Saturated model	0	0		1		1		
Independence model	96.69	21	0	0	0	0	0.205	4.604

Limitations: As with most research, this study had limitations. While the study's data was collected from diverse companies in biopharmaceutical R & D, future research could look deeper into R & D managerial input at a company level. Comparison between companies or longitudinal data collection may provide a new angle of the connection between R & D managerial cognition, strategic behavior and innovation. Additionally, the study's framework can be extended to general management, strategic behavior and performance measure.

Another limitation involved R & D strategic behavior not exhibiting a reliable relationship with other managerial cognitions. R & D collaboration is only one exemplar among merger and acquisition (M & A), in-licensing, off shoring R & D, etc. For example, M & A is used when the acquisition can secure market share and reduce inefficient R & D operation. Subsequently, M & A is less technology-driven and less strategic than R & D collaboration.[34] Future research should develop a measurement to investigate innovative behavior, such as technology absorption, formal networking and R & D budgets. Return of Assets (ROAs) is too general to test the proposition.[103] Regardless, there is a need for additional studies regarding R & D managerial influence in relation to strategic behavior and innovation. Lastly, innovation was investigated from a managerial view, which unveiled the impact of R & D managers on innovation. Considering the multi-dimensions of innovation, this study did not provide a holistic picture of innovation. Future innovation studies should also focus on managerial cognition in diverse settings of strategic behavior and performance.

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Conflict of interest

Author declares that there is no conflict of interest.

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