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A System Dynamics Approach to Designing Technological Innovation Management Model in Downstream Petrochemical Industries

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Abstract: Special attention to the relative advantages of the economy is the best way toward economic development in every country. Owing to its considerable natural oil and gas resources, Iran has a high potential for the development of these industries. In the value chain process of these God-given resources, a wide diversity of final downstream petrochemical products has a significant charm and scope for technological innovation and development. In the absence of a systematic perspective, all the planning and costs in this field will fail. Therefore, the purpose of this study is to design and analyze the dynamic model of technological innovation management in petrochemical downstream industries in Iran. A questionnaire was designed by analyzing the research literature and the opinions of the experts; then, the factors were investigated using verification factor analysis and structural equations with Smart PLS; the final 26 indicators were categorized in four domains including firm, industry, national, and international. Next, using system thinking and Vensim PLE 6.4, the technology innovation management structure was designed in the downstream industries. The behavior of key variables was also predicted for a 7-year time horizon. Finally, it was used to formulate the technology innovation management scenario.

Keywords: Technology Innovation; Innovation Management; Downstream Petrochemical Industries; System Dynamic

1. Introduction

With its huge oil and gas resources, Iran is at the forefront of gas reserves and the world's fourth largest oil reserves (by the end of 2016) (2017, EIA). The oil and gas industry has recently faced several challenges. For example, the production cost of one barrel of oil has risen by 60% over the past 10 years (Tidey, 2015) or oil prices have dropped by almost 70% since its peak in 2014 (Decker et al., 2016). International factors (e.g. the devaluation of RMB in China and sanctions on Iran (Sebastian, 2015), as well as shale oil extraction) have led to greater volatility in oil prices and increased instability in this industry. Thus, in the absence of explicitly-explained resources development strategies, the development plans may lead to the destruction rather than taking appropriate use of resources. The importance of the petrochemical industry and its relative advantages for the country is undeniable. Moving from upstream to downstream, the contribution of technology will intensify to factors of production, investment, the employment increase rate, and the margin of profit for productive activities (Sedghiani et al., 2016). So far, Iran's petrochemical industry model has followed the pattern of resource exploitation in a project-oriented approach rather than the development-oriented one (Islamic Republic of Iran Research Center of 2015). In fact, this industry has not been considered as the engine of development in the country, while the developed countries have developed technology based on technology development and sale. In this way, their income is equivalent to or greater than what countries rich in oil resources. The serious challenge in the present situation is that in spite of the efforts and costs spent on research, development, and innovation in downstream industries, the final results have been scientific research papers and a limited number of technological innovation (patent or product). In this regard, this research is aimed at proposing a technological innovation management model for the downstream petrochemical industries using a dynamic system to present the effects and final consequences affecting the technological innovations in this sector. So, the main research question is: what is the model of technological innovation management in the downstream petrochemical industries of Iran? What measures should be taken to improve the current situation? Previous studies have shown that research on the effective factors in the management of technological innovation in downstream petrochemical industries has failed to focus on the part .Therefore, the novelty of the current research is that it addressed the innovation aspect of the mentioned technology. Another novelty lies in the modeling and dynamic system approach used in this study.

2. Literature review

The present paper is particularly concentrated on the literature in the field of innovation management practices. Tide et al. believed that innovation is in an attempt to make things better than their current condition. In this context, technological innovation is a form of innovation occurring in the technical systems of an organization with a direct relation to the work of the organization. The Study by Hassani et al. (2017) highlighted the importance of innovation and technology and their measurable effects on the oil and petrochemical industries. However, by outlining processes of innovation, Salerno et al. (2015) showed that there is no particular innovation process suitable for all types of innovation projects. In another research, Alex et al (2016) sought to determine the importance of innovation included in leadership, human capital, capabilities and competencies, the process of manufacturing products and new services, and the learning process to assess the innovation capability of companies active in the Romanian automotive industry. Lancker et al. (2016) identified the important and influential factors in the management of the development processes of biotechnology innovation. They proposed a set of management principles of innovative processes in bio-economy which were classified into three groups: relevant shareholder groups in the development of innovation, strategy and network management and organizational characteristics. Strese and others (2016) conducted a comparative study on the relationship between the roles of organizational culture dimensions in managing innovation in different national cultures. Kralisch et al. (2017) followed the successful transfer of ideas to sustainable innovations using innovation management in the pharmaceutical and chemical industries. They finally propose a step-by-step approach to define the criteria of operational management, financial management, environmental performance, and social performance with the assessment of sustainability and multi-criteria decision analysis. Ferreira et al. (2015) carried out research based on the Tide model and strategy on the basis of the variables of strategy, organization, process, learning, training, and networking to examine the capacity of innovations within the framework of innovation management structures. Golembiewski et al. (2015) investigated the concept of innovation in the sustainable development of the bio-economy and found a variety of challenges, including basic and complex knowledge, technological development and commercialization, and the development of the market. In another study by Rubio, Marin (2015), an innovation management survey of market performance has been designed to identify consumer effectiveness. Morever, Seo and Chae (2016) examined the effective ways of managing innovation and maximizing the performance of Korean companies with regard to the level of market dynamics. Vishnevskiy et al. (2014) proposed a combination of forward-thinking and a coherent roadmap for managing the innovations in Russian companies. According to Lendel et al. (2015), the key factor for the successful innovation processes is the presence of a supportive environment for innovation. Solaimani et al. (2019) proposed the Lean philosophy, which integrates a firm's “hard” and “soft” processes, as a promising way to upgrade the firm innovativeness. Five Lean principles relevant to the field of innovation management (i.e. leadership, learning culture, employee appreciation, learning routines, and collaborative networks) were discussed. XU et al (2014) argued that large-scale Chinese enterprises should develop a comprehensive innovation management system and a collaborative innovation network to promote their innovation performance. Furthermore, Aarikka-stenroos (2017) presented a comprehensive picture of innovation management in massive networks with a wide variety of actors throughout the entire innovation process. They ultimately analyzed two basic and gradual innovation processes of an empirical conceptualization of seven key managerial activities, including motivation, resource provision, target setting and reform, consolidation, reinforcement, coordination, control, and empowerment throughout the process of innovation. In addition, Nagano et al. (2014) introduced an integrated model for innovation management in three dimensions: organizational factors, innovation process, and resources in the development of Brazilian products. Hecksher et al. (2012) study was devoted to creating a way to manage the research, development, and innovation of the Brazilian Electricity Services Company. Their innovative method involved reforming the organizational structure of R&D activities, adapting a systematic model for innovation education, and application of the operating model to systematize the processes of reflection with partners to make innovation proposals. Based on Niewöhnera et al. (2019), due to the rapid globalization and digitalization, SME need to face various challenges in their innovation management. Concerning these challenges, agile methods are gaining increasing importance. In contrary to this background, the submission is focused on the analysis of the interaction of innovation management in SMEs, digitalization and agility. In another study by Cap et al. (2019), the collaboration in inter-organizational networks was introduced as the major driver of innovation. Nevertheless, reliable methods for managing innovation networks are still scarce. They filled this gap by providing an approach to increase the innovation output by intensifying the collaboration in networks. The study by Serpell and Alvarez (2014) was aimed at identifying the major innovation drivers for innovation management in construction companies, including technology, organizational structure, culture and human capital, and R & D. Mir et al. (2016) analyzed the relationship between the standard UNE16600 innovation management systems, the capacity for innovation and business performance. Their findings suggested a significant positive relationship between the standard management innovation system and innovation capacity and business performance. Badrinas and Vila (2015) reported culture, leadership, resources, and innovation as the key factors in the success of innovation systems. Palmqvist and Unevik (2015) investigated the decisive factors in the Swedish innovation management system to manage the organizational structure, innovation strategy, culture innovation, estimation and management of innovation performance, collaboration and communication, resource management, endless innovation process, and reversible process. Silva et al. (2016) also introduced the needs of customers, the market need, the communications network, the organization environment, employee participation, and leadership style as the effective factors of the innovation development in small and medium-sized enterprises related to the Brazilian technology. Li and colleagues (2017) addressed the elements of innovation in the technology innovation process and introduced nine dimensions of innovation: spatial, environmental, structural, operational dimensions, mechanism, material, dynamic, process, and human-machine relationship in the technology innovation process. Bellegard and Prates (2017) assessed the main factors determining the necessary skills in the process of technology innovation, including the strategic plan of technology, intellectual property management, technology forecasting, and monitoring, and the management of research, and development projects, some of which are internal and some are environment-related. Altmann and Engberg (2015) claimed that the uncertainty variable in the process of innovation can strongly influence the effective human resource management for technological innovation. Choi et al. (2015) proposed a new paradigm to simultaneously pursue the product and process innovations which gave rise to sustainable growth. They have used the dynamic modeling tool for a comprehensive model taking into account the relationship between R&D investment factors, technological innovations, and financial performance. Hamidi and Benabdeljlil (2015) studied the relationship between management innovation and technological innovations (process and product) among the Moroccan companies. Researchers believed that companies capable of driving technological innovation are more likely to have managerial innovations. Lager (2016) examined the methods and tools used in the process industry for better management of innovation and technology. To this end, he examined the methods and tools used in the process industry to improve effectiveness, such as the technology map, the development of research and development strategies and the balance of technology. Lee and Om (1994) tried to provide a conceptual framework for the management of technological innovation. They ultimately proposed a balanced and integrated framework for technological innovation management, including five categories of people, task, technology, structure, and strategy-like based on the Hellrugel model. Moreover, Walrave and Raven (2016) developed a dynamic system model based on "innovation engines" by the dynamic modeling of technology innovation management systems. They succeeded by considering the concept of "innovation engines", including the engine of technology and science pressure, the engine of entrepreneurship, the engine of the construction system and the market engine. Hashem (2016) sought to evaluate the performance of innovation management dimensions using the Chess model and statistical analysis of the Analytic Hierarchy Model (AHP). The factors influencing the innovation management process of the company, according to their priority, included innovation strategy, management systems, project management, innovation culture, product innovation, business, process innovation, and technological innovation. The results obtained by Sedghiani Baghcheh et al (2016) suggested that the knowledge-based business developers in the middle and downstream petrochemical industry should have the proper alliance management, business and brand empowerment, technological capabilities, the ability to risk finance and manage risky projects with two key prerequisites of high industrialization and credibility. Hedayati and Khamseh (2016) evaluated and ranked the factors affecting innovation management with a native model in the power plant repair company. Their results revealed that the organizational factors had the highest while the national factors possessed the lowest rank in this industry. Behzadi Moghaddam (2016) emphasized the evaluation and analysis of the components of service innovation management based on the Joe Tidd model at Shuttle. He believed that the company performed relatively better in the dimension of the process in comparison with other aspects. Talebi (2016) examined the performance management innovation in the New Energy

Organization (SANA) based on the Joe Tidd model and indicated the priority of innovation management in the organization. Fazeli (2016) identified the effective factors of innovation management based on the Verhaeghe & Kfir Model at Iran Khodro Company. His results showed the priority of the transfer of technology over the other dimensions. Tohidi et al. (2015) prioritized the impact of each system engineering processes on the enhancement of the innovation capability in the aerospace industry using TOPSIS multi-criteria decision-making techniques. Sadeghi and Khamseh (2018) proposed an innovation management model for petrochemical companies producing polyethylene products with a new polyethylene product approach. The results of their study indicated the priority of the technology criterion, organizational factors, system, and the market factor. Majidi Kalibar et al. (2014) identified the effective factors in the development of technological innovation for two categories of internal factors including human capital, organizational culture, organizational strategy, research and development activities, performance evaluation system and environmental factors including capital funds risky transit, growth centers, science and technology parks, academic and research centers, network and power and specialty clusters of the firm. Furthermore, Ghasemi Aghababa et al. (2015) presented their business model of technology innovation management for the National Iranian Gas Company. The results of their study revealed that the business model of the research and technology management of the National Iranian Gas Company seeks to support technological and innovative support from their customers (different management headquarters of the National Gas Company and subsidiaries), which, by spending research and public funds (value-driven), try to achieve effectiveness.

3. Method

In terms of objectives, this research is an applied one while from the information collection point of view, it can be categorized as a descriptive survey. First, in order to achieve the goals of the study, a total of 34 effective indicators in technological innovation management were identified in downstream petrochemical industries and the final questionnaire was designed based on the extensive library studies including domestic and foreign authoritative papers and publications, as well as field research using semi-structured interviews with experts. The reliability of the questionnaire was confirmed by Cronbach's alpha; whereas its validity was verified by the experts. Then, a confirmatory factor was performed using the Smart PLS software. In order to confirm or reject the analysis variables of the research, four factors including firm, industry, national and international were classified into 26 indicators. Next, using system thinking and Vensim PLE 6.4, the technology innovation management structure was designed for the downstream industries. Next, the behavior of key variables was predicted over a 7-year time horizon. Finally, it was used to formulate the technology innovation management scenario. Fig. (1) represents the conceptual model of the research and the classification of the effective factors of technological innovation management in downstream petrochemical industries.

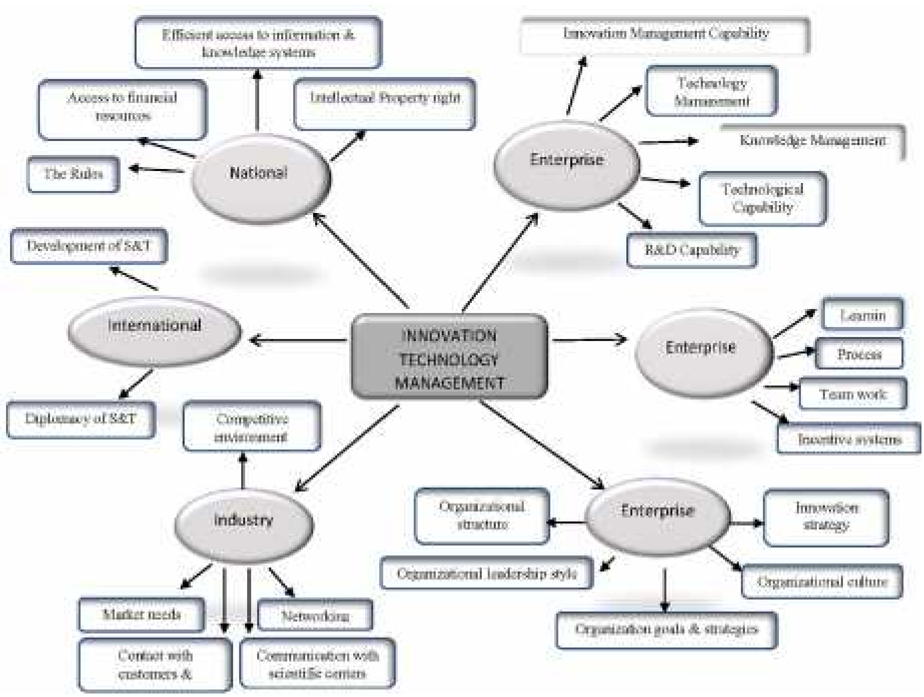

Fig. 1. The conceptual model

In this way, the most important factors were specified and considered as the model input. Subsequently, a technological innovation management model was developed based on the system dynamicity using the experts' viewpoints, and the relationships between the variables were recognized. Then, a simulated model of the system was developed using causal loops diagram and flow diagrams. After that, the developed model was validated in terms of structure and behavior.

4. Findings

To identify the factors influencing downstream technology innovation, 34 main indicators were filtered by the experts. Then, the research model was analyzed using Smart Pls for validation purposes. All the questions with a factor load<0.7 were excluded from the research model, and indices with a factor load of ~0.7 and other variable index variables were included in the model (Hair, 2006). Eight indicators of the model were eliminated to enhance the model's homogeneity. The final model of the research with 4 factors was confirmed in the form of 26 indicators. In this way, the specified factors were considered as the input of the model. The model boundary and the relationships between the variables were drawn and the dynamic assumptions were developed based on the experts' viewpoints. The dynamic assumptions were also derived by causal loop diagrams and stock and flow diagrams. Causal diagrams are simple plans presenting the causal relationship between the variables. These relationships can be represented by arrows from a cause towards an effect (Sterman, 2000). Here, the cause and effect loops are presented in the form of a model as illustrated in Fig. 2.

In downstream petrochemical industries, a part of the obtained profit is allocated to research, development, and innovation budget. The innovation budget is spent on updating the databases, expanding technological cooperation, developing human resources and education, and developing new products of the industry. The research budget is devoted to developing scientific research papers in the universities which in addition to the development budget may increase the number of patents in the research centers. The patents, besides the development budget, can enhance the number of products in the country. Finally, the profit gained from the sale of the produced products and the patent will raise the total profit of the industry. After drawing the causal loops of the model, the flow diagram was employed for a better analysis of the model. Based on the relationships between the variables and the created causal loop diagrams, the stock-flow diagram was drawn as presented in Fig. 3.

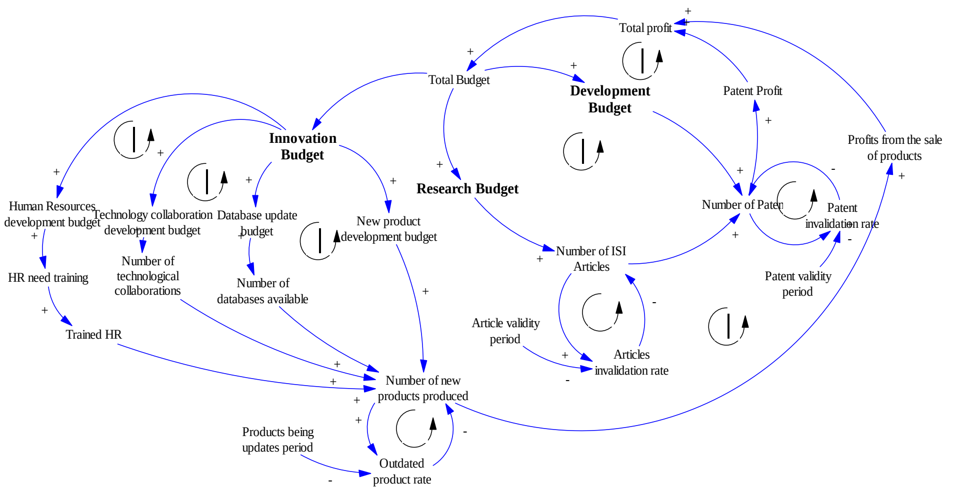

Fig. 2. Cause and effect loops

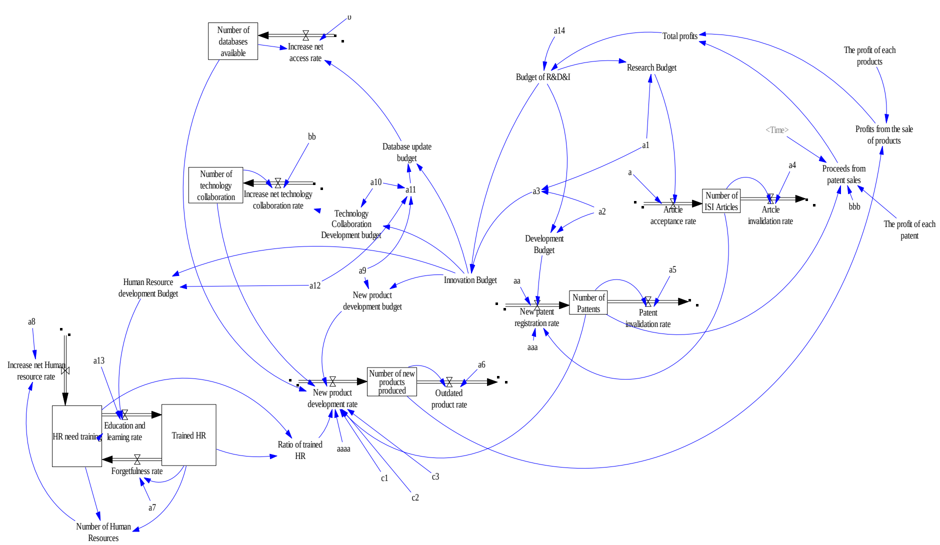

Fig. 3. Stock-flow diagram

5. Conclusions

The simulation results suggest that by the growing increase of using the total profit in R&DI budget, technological products (patent and product) and hence the profit will increase. So, it is recommended to annually increase the ratio of revenue allocated to the R&D budget by 0.0025. It can be concluded that except for some special interactions, there is no effective and serious cooperation between scientific research and manufacturing organizations. This problem can be resolved by more interaction and cooperation with the industry so that the parties become informed and benefit from the needs, expectations, facilities, and capabilities of each other. As a result, scientific works should be focused on solving industry problems and producing technological products. Lack of knowledge about intellectual property rights and its role in industrial production processes have led to unawareness of many researchers about the commercialization value of innovations and technologies developed in the academic environments. It could consequently result in a decrease in technological production in the country. Thus, it is suggested to provide more access to patent information systems in academic centers and research institutes. Regarding the government's policies about the development of downstream petrochemical industries and the creation of handicrafts development office as the responsible authority of this sector, it is recommended to establish specialized technological management and innovation units in this sector. Also, effective interactions between the academic centers, research institutes, and industries can significantly help in recognition of the existing opportunities and threats. Finally, the policymakers are suggested to approve supporting laws in knowledge-based productions of the country to support the sale of these products, prevent the import of products already produced in the country, and encourage their purchasing by internal companies. In this way, this procedure will have an increasing growth in the country.

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