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Openness to External Innovation in Major Oil and Gas Companies

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Abstract

"Open Innovation" has proved to be a successful concept that can facilitate technological development of industries. Though the Open Innovation Model and the challenges of its implementation have been widely researched, there is a lack of studies that deal with the openness to external innovation in major oil and gas companies.

The objective of this research was to study major oil and gas companies' openness to external sources of innovation. The authors focused on the role of R&D investments in the R&D internationalization and the establishment of venture funds, the links between regional specificities, innovation portfolio diversity and the perception of external innovation. To do this, the authors examined the practices of 18 major oil and gas, oil service companies. The data was gathered from open digital sources and analyzed with the use of desk research, qualitative and quantitative methods, including regression and correlation analysis.

The study confirmed that major oil and gas companies with higher R&D investments and diverse innovation portfolios were more likely to be open to external innovation; regional specificities had a great impact on R&D networks as companies in North America and Western Europe had higher R&D internationalization ratio than in Russia and China. It was concluded that venture funding was an inclusive tool for expanding innovation funnel suitable for smaller companies with low R&D expenditures.

Keywords: Open Innovation Model; oil and gas industry; research and development; internationalization; globalization; innovation culture; venture capital funding.

1. Introduction

The digitalization today plays a major role in changing global business environment, becoming the basis for the Fourth Industrial Revolution. New technologies create opportunities for innovative companies and risks for those that cannot catch up with an accelerating pace of changes. The key to success in the new environment is to generate and implement knowledge. Intensification of innovation processes in oil and gas companies has also become more urgent: due to globalization and digitalization knowledge is a more accessible and important resource for creating added value (Salygin et al., 2019).

- Efficient knowledge management is of utmost importance to oil and gas companies as they are on the edge of changes of great magnitude created by environmental and political megatrends. While the Paris Agreement is shaping a new "cleaner" future of energy production, scientific breakthroughs are made in the key consumer market: transportation. Following the global trends, oil and gas companies from developed countries announce the energy transition strategy that requires considerable modifications in their business models.
- In order to increase the efficiency of innovation activities some companies apply the Open Innovation Model that relies on providing open access to innovation, facilitates open discussion, reduces the administrative costs related to protecting intellectual property and encourages the expanded use of external innovation sources (Naqshbandi and Kamel, 2017; Chesbrough and Bogers, 2014). Generally, that model is viewed as a reliable tool for improving the efficiency of innovation processes (Diener and Piller, 2010).

- The Open Innovation concept has been thoroughly researched. First it was introduced by Chesbrough in 2003. According to the list of innovation model generations (Rothwell, 1994) updated by Preez N. D., Louw L., Essmann H. (2009), the Open Innovation Model (OIM) is the latest, sixth generation of innovation models that is based on principles of collaboration between internal and external innovation sources. OIM has incorporated and replaced such models as «Technology Push», «Market Pull», «Network», etc. and it complies with current global Research and Development (R&D) trends and rapidly changing environment. Studies that focused on innovation models' generations did not address the system of relations between external and internal sources of innovation (innovation networks) in detail.
- Networks of internal and external innovation sources constitute the corporate innovation system. The concept of «corporate innovation system», is rather new and was first introduced in the year 2000 by O. Granstrand and later was expanded by E. Hartigh, B. Karlsson and G. O'Connor (2018). According to E. Hartigh, the corporate innovation system includes key elements that interact with each other and result in the implementation of innovation and innovative development. The elements include innovation actors and resources. The actors comprise teams, departments, business units, etc. responsible for the innovative development of a company.
- Growing globalization and internationalization of R&D activities was noted by Gassmann O. and Zedtwitz M. in 'New concepts and trends in international R&D organization' (1999). The article was written in the late 1990s and the results of the research confirmed an increasing role of independent overseas R&D centers in corporate innovative development. These foreign R&D centers facilitate the integration of technologies developed abroad. The authors grouped innovation networks by R&D facilities' location and authority.
- Ethnocentric centralized R&D (centralized research, all R&D activities are concentrated in the home country);
- Geocentric centralized R&D (centralized research, extra investments in R&D personnel in order to increase their international awareness);
- Polycentric decentralized R&D (decentralized federation of R&D sites with no supervising corporate R&D center);
- The R&D hub model (tight central control, the R&D center in the home location is the main laboratory for all internal and external R&D activities);
- Integrated R&D network (Domestic R&D is no longer the center of control for all R&D activities. Central R&D evolves into a competency center among many interdependent internal and external R&D units).
- In 1999 this topic was also brought up by Gerybadze A. and Reger G., who discussed the nature of innovation activities distribution in transnational corporations and developed a framework for analyzing different patterns of internationalization of R&D and innovation.
- The links between external and internal R&D sources of innovation were studied by Berchicci L. (2013). The author suggested that highly efficient innovation processes relied on the balance between internal and external activities in R&D networks. The similar conclusions were drawn by N. E. Hurtado-Torres, J. A. Aragon-Correa (2018) in the research dedicated to the effects of R&D internationalization on the innovative performance of energy companies.
- The connection between the implementation of venture capital and successful expansion of the innovation funnel in OIM was researched by Vrontis D., Rossi M., Thrassou A. (2013), (Rossi, 2015). Vishnevskiy K., Karasev O., Meissner D. (2015) researched the separation of functions between traditional R&D centers and venture funds according to the risk level. A significant number of studies touched upon several issues of venture capital implementation in energy sector, such as venture investments intensity, its positive impact on innovation activity, etc. (Kulanov et al., 2020; Pickl, 2019; Lerner, 2011; Moreva, 2018).
- Though there are numerous studies dedicated to the challenges that major oil and gas companies face when adopting the Open Innovation Model (Pellegrini et al., 2012; Ibrahimov, 2018) and regional factors that influence the internationalization of R&D activities (Gulbrandsen, 2008; Manshadi, 2017), there is a lack of new comparative studies that examine R&D internationalization ratio and the openness of oil and gas corporations from different regions towards external innovation in the current state of the global energy market.
- Moreover, the current research of the impact of venture capital on innovation in the majority of

cases is dedicated to the energy industry level and there is a room for the studies that will focus on the corporate level of the subject matter.

- The aim of this study was to research the openness of major oil and gas companies to external sources of innovation from the perspective of OIM using the data from global oil and gas companies. The hypothesis was that R&D expenditures and regional business culture have an important impact on the R&D model of major oil and gas companies that affect their openness to external innovation.
- "Openness" to external innovation included two aspects:
- Internationalization of R&D Networks. Companies with greater R&D investments were expected to have a greater share of foreign R&D facilities in their R&D networks;
- Implementation of venture funds as the tools to expand the external innovation funnel. Oil and gas companies with greater R&D investments were expected to have a higher chance of establishing venture funds.
- The authors suggested that the companies that were more open to external innovation were more likely to have a diverse innovation portfolio, as OIM was an effective tool to accumulate innovation from different technological fields.
- Furthermore, the authors touched upon the important issue of regional specificities that affected corporate R&D models and significantly impacted the penetration of open innovation in a company.
- Overall, this paper is aimed at presenting the contemporary research on the place of open innovation in research and development of major oil and gas companies in a systemized approach that organizes several aspects of the subject matter (previously discussed in academic literature separately) into one coherent view by answering the following questions:
- What companies are more likely to incorporate open innovation in their R&D models (the impact of regional business culture)?
- Which of approaches are companies more likely to implement according to their business scale (expenditures on overseas labs vs venture funding)?
- When do oil and gas companies implement open innovation model (the links between open innovation and innovation intensity)?

2. Research methodology

- The representative sample for this research was selected on the basis of annual revenue criterion using the cluster method. It included only major oil and gas, oilfield service companies with annual revenues exceeding 15 billion dollars. The revenue criterion was chosen in order to filter companies in accordance with their business scale, as the paper is dedicated to the research of major market players. Then the companies were filtered according to the data availability regarding the number of national and foreign research and development centers. A representative sample of 17 major oil and gas companies[1] from different regions of the world was formed. The inclusion of oilfield service companies (*) together with vertically integrated oil companies was justified by the convergence of their innovation development goals. The data on research facilities and venture funds was primarily found in open sources, including corporate websites and news publications (https://www.rigzone.com/news/oil_gas/a/52886/halliburton_opens_technology_center_in_india/, http://www.sinopec.com/listco/En/about_sinopec/subsidiaries/research_institutions/, https://www.barco.com/ru/customer-stories/2012/q4/2012-11-26%20-%20new%20solutions%20at%20cenpes%20bring%20high%20tech%20to%20petrobras%20research%20centres etc.), annual reports were used to find information on revenues and venture funds (https://corporate.exxonmobil.com/Investors/Annual-Report, https://totalenergies.com/investors/publications-and-regulated-information/regulated-information/annual-financial-reports, https://www.gazprom.com/investors/disclosure/reports/2019/, etc.). The data was analyzed by the means of desk research, qualitative and quantitative methods of research.

[1] The sample did not include such major companies as British Petroleum due to the lack of data on their foreign and national R&D facilities.

- The authors compared the number of national and foreign R&D facilities of oil and gas corporations, the ratio was defined as the "internationalization ratio". It was hypothesized that companies with greater R&D internationalization ratio (more foreign R&D facilities per one national R&D center) had higher R&D expenditures. In order to prove the hypothesis, the authors conducted correlation and regression analysis with the following variables: X = R&D expenditures; Y = internationalization ratio; Y1 = number of foreign R&D facilities.

- To further prove the correlation between R&D internationalization and R&D investments, and to find out whether the share of R&D investments in corporate revenues (%) had any impact on the openness toward external innovation, the authors compared R&D networks and R&D strategies. R&D strategies were defined earlier in the previous study (Lobov, 2020). The companies were divided into nine groups from most active (1) to least active (9) according to two R&D investment metrics: total R&D investments (x) and the share of R&D investments in revenues (y, %) following Sturges' rule (Table 1).

Table 1 Groups of major oil and gas companies according to their R&D investments. Total R&D investments (bln $) and the share of R&D investments in revenues (Lobov, 2020).

Total R&D invest. (bln $) Share in revenues		1 0.96-0.80+	2 0.80-0.64	3 0.64-0.48	4 0.48-0.33	5 0.33-0.17	6 0.17-0
1	1.15%-0.97%+	1. Group CNCP (China)*, Sinopec (China)*		4. Group Suncor Energy (Canada)*,CNOOC (Chine)		7. Group Transneft (Russia), Occidental Petroleum (US) Equinor (Norway), Canadian Natural Resources (Canada)	
2	0.97%-0.78%						
3	0.78%-0.60%	2. Group ExxonMobil (US)*, Total S.A. (France.)*		5. Group Petrobras (Brazil), Rosneft (Russia)		8. Group Syncrude Canada (Canada)	
4	0.60%-0.42%						
5	0.42%-0.23%	3. Group R. D. Shell (Netherlands)		6. Group Chevron (US) Saudi Aramco (Saudi Arabia) BP (UK)		9. Group Gazprom (Russia), Lukoil (Russia), Repsol (Spain) ENI (Italy), ConocoPhillips (US), Indian Oil (India), Phillips 66 (US), Cenovus Energy (Canada), Transcanada (Canada)	
6	0.23%-0%						

- R&D Networks were identified according to the internationalization ratio and the division of competences between them. The authors generalized the list of R&D networks proposed by Gassmann O., von Zedtwitz M. (1999) and divided the companies in accordance with the new two groups (Table 2

Table 2 Types of R&D networks. Source: created by the authors based on (Gassmann and von Zedtwitz, 1999).

Network	Definition	Abbreviation
Geocentric R&D	One or several key R&D centers operate in one country. Low Internationalization ratio.	GRD
Distributed R&D	Several domestic and foreign R&D centers with equal distribution of authority. High Internationalization ratio. The Open Innovation Model.	DRD

- It was also hypothesized that companies with greater R&D investments were more likely to establish venture capital funds in order to expend the innovation funnel. As there was no sufficient quantitative data on oil and gas companies' venture investments, the dichotomous scale was used to assess the "venture capital indicator", 0 = a company did not implement venture funding, 1 = a company implemented venture funding.
- Next, the authors identified the companies' strategic innovation goals in order to assess the level of diversity of their innovation portfolios. It was suggested that companies with more diverse innovation portfolios were more open to external innovation. The authors chose several strategic innovation goals pursued by the major oil and gas companies and using the methods of desk research studied how many technological trends each company followed.
- Finally, drawing on the analysis of R&D networks, corporate experience in implementing venture funds and accelerators, the authors tried to assess the potential level of openness of oil and gas companies to external innovation. The average of Internationalization ratio and Venture capital indicator comprised the "Openness" indicator. Then the companies were divided into 3 clusters according to the openness indicator: "3rd" (high) level of openness, "2nd" (average) level of openness and the "1st" (low) level of openness to external innovation. Spearman correlation was used to confirm a relationship between the "level of innovation diversity" and the "openness to external innovation".

3. Results

- First no correlation was found between variables X = R&D expenditures and Y = internationalization ratio; Y1 = number of foreign R&D facilities. However, after excluding Russian and Chinese companies from the sample, the correlation became statistically significant.
- The correlation analysis validated that R&D internationalization ratio and thus the openness to external innovation in oil and gas companies depended heavily on R&D expenditures primarily in the Western European and North American oil and gas companies (notably, that list also included Saudi Aramco) (Table 3).
- (1. Variables: X = R&D expenditures; Y = internationalization ratio), R^2 = 0.759;
- (2. Variables: X = R&D expenditures; Y1 = number of foreign R&D facilities), R^2 = 0.771; Y1 = 0.007*X-0.852.
- The application of "revenue" variable gave the similar results to "R&D expenditures" variable which proves the direct impact of business scale on R&D intensity and internationalization.

- **Table 3 Number of foreign R&D facilities in oil and gas companies according to R&D investments, Source: created by the authors2.**

Company	Country	R&D expenditures (mln $), X	Internationalization ratio, Y	Foreign R&D facilities, Y1	National R&D facilities	Revenue (mln $) Z
Royal Dutch Shell	Netherlands	962	89%	8	1	352,106
Saudi Aramco	Saudi Arabia	573	75%	9	3	258,772
ExxonMobil	USA	1214	70%	7	3	255,583
Total S.A.	France	968	67%	4	2	176,249
Chevron	USA	500	0%	0	2	139,900
ENI	Italy	213	0%	0	6	79,566
Baker Hughes*	USA	700	80%	4	1	23,838
Equinor	Norway	300	33%	1	2	64,357
Repsol	Spain	88	0%	0	1	55,247

[2] Approx. number of R&D facilities according to open sources.

Halliburton*	USA	404	75%	3	1	22,408
Occidental Petroleum	USA	246	0%	0	2	20,393
Canadian Natural Resources	Canada	190	0%	0	1	18,504
Sinopec	*China*	*3061*	*11%*	*1*	*8*	*444,193*
CNPC	*China*	*3257*	*0%*	*0*	*10*	*415,000*
Gazprom	*Russia*	*197*	*0%*	*0*	*22 (1+)[3]*	*122,554*
Rosneft	*Russia*	*480*	*0%*	*0*	*29 (1+)*	*140,272*
Lukoil	*Russia*	*100*	*0%*	*0*	*5 (1+)*	*124,460*

- If a Western European or North American oil and gas company invested more than 300 mln dollars in R&D chances were high that it would open a research facility in another country in order to expand the innovation funnel. In contrast, while having high R&D expenditures, Sinopec had only 1 R&D facility abroad, CNPC, Gazprom and Rosneft had none.
- Using the regression equation that was acquired from the analysis of European and North American oil and gas companies, the authors calculated a notional number of foreign R&D facilities (Table 4) that could be created by the Russian and Chinese companies if they had internationalized their R&D networks and compared it to the actual number of foreign R&D facilities. According to the calculation, Gazprom, Rosneft, Sinopec and CNPC could open more foreign R&D facilities with their level of R&D investments.

Table 4 Actual and notional number of foreign R&D facilities in major Russian and Chinese oil and gas companies, Source: created by the authors.

Company	Actual № of foreign R&D facilities	Notional № of foreign R&D facilities[4]
Sinopec	1	21
CNPC	0	22
Gazprom	0	1
Rosneft	0	3
Lukoil	0	0

- Total R&D investments played the major role in determining the level of internationalization and openness to external innovation, while the share of R&D investments in corporate revenues did not (Table 5). Of the six companies that have implemented the distributed R&D network with high internationalization ratio, five companies belonged to the 1st – 4th group of total R&D investments (x, y). Previously mentioned companies CNPC and Sinopec did not follow this tendency. At the same time, the share of R&D investments in corporate revenues (%) did not affect neither internationalization nor R&D networks (x, y).

Table 5. Oil and gas companies' R&D networks by investment strategies. Source: created by the authors

Company	R&D network, internationalization ratio	R&D investment strategy
CNPC	*GRD* (0%)	1 (*1.2*) Active
Sinopec	*GRD* (11%)	1 (*1.2*) Active
Gazprom	GRD (0%)	9 (6.6) Passive

[3] National R&D facilities within major R&D centers of Gazprom, Rosneft, Lukoil. For example, 22 R&D facilities within "Gazprom VNIIGAZ"

[4] According to the regression equation Y1 = 0,007*X-0,852

Rosneft	GRD (0%)	5 (4.4)
Royal Dutch Shell	**DRD (89%)**	5 (**1**.5)
Saudi Aramco	**DRD (75%)**	6 (**3**.6)
ExxonMobil	**DRD (70%)**	2 (**1**.4) Active
Lukoil	GRD *(0%)*	9 (6.6) Passive
Total S.A.	**DRD (67%)**	2 (**1**.4) Active
Chevron	GRD *(0%)*	6 (4.5)
ENI	GRD *(0%)*	9 (6.6) Passive
Baker Hughes*	**DRD (80%)**	1 (**2**.2) Active
Equinor	DRD (33%)	7 (5.2)
Repsol	GRD *(0%)*	9 (6.5) Passive
Halliburton*	**DRD (75%)**	5 (**4**.4)
Occidental Petroleum	GRD *(0%)*	7 (5.1)
Canadian Natural Resources	GRD *(0%)*	7 (5.2)

No significant correlation was found between R&D investments and the number of venture funds (Table 6). It was confirmed that the practice of venture funding in oil and gas companies was not defined by the investments in R&D.

Table 6. Oil and gas companies sorted by R&D investments; established venture funds/ accelerators. Source: created by the authors.

Company	R&D Investments	Venture funds/ accelerators[5]
CNPC	3257	0
Sinopec	3061	0
ExxonMobil	1214	1
Total S.A.	968	1
Royal Dutch Shell	962	1
Baker Hughes*	700	1
Saudi Aramco	573	1
Chevron	500	1
Rosneft	480	1
Halliburton*	404	0
Equinor	300	1
Occidental Petroleum	246	1
ENI	213	0
Gazprom	197	1
Canadian Natural Resources	190	0
Lukoil	100	0
Repsol	88	1

- The authors analyzed open digital sources, annual reports, sustainability reports, etc. to identify innovation goals. Almost all companies set strategic goals to implement greener types of fuels, CO2 capture technologies, alternative energy, energy efficiency, digitalization and electric transport (Table 7).
- First, it was assumed that energy transition goals were only pursued by a half of the leading companies. However, due to the recent changing global perception of sustainable development, more companies implement them into long-term strategies. In March 2021 Chinese companies CNPC and Sinopec confirmed their commitment to achieving zero emissions by 2050 and developing hydrogen

1 – Venture funds are established. 0 – No experience in venture funding.

technologies (Evans, 2021, March 3; Xi Yihe, 2021, January 7)6.

Table 7
The number of oil and gas companies pursuing innovation goals. Source: created by the authors.

№	Innovation goals	Number of companies
1	Greener types of fuels	=16/17
2	CO2 Capture technologies	=17/17
3	Alternative energy	=16/17
4	Energy efficiency	=17/17
5	Digitalization	=17/17
6	Quantum computers	=5/17 CNPC. Royal Dutch Shell. ExxonMobil. Total S.A. ENI. Baker Hughes*
7	Electric transport and stations	=17/17
8	**Global energy transition**	=10/17

- Openness to external innovation depended on the level of total R&D investments. Companies with larger R&D investments had higher internationalization ratios, created distributed R&D Networks and had more diverse innovation portfolios; almost all of them established venture funds (Table 8). Companies with less than 500 mln dollars R&D investments were likely to have an "average" or "low" level of openness to external innovation. However, regional factor should also be considered as Chinese oil and gas companies' practice did not comply with the findings.
- Spearman correlation between innovation diversity "X" (corporate innovation goals/8 trends of innovation development) and openness to external innovation "Y" (from 1 (Low) to 3 (High) was found to be statistically significant (R^2 = 0.591) after the exclusion of Chinese oil and gas companies, which proved that overall, the companies that were more open to external innovation were more likely to have a diverse innovation portfolio.

Table 8
Oil and gas companies' openness to external innovation. Source: created by the authors.

№	Company	R&D Investments (mln $)	R&D Internationaliztion	Venture capital indicator	Innovation diversity	Openness to external innovation
1	CNPC	3257	0	0	1	0; Low (1)
2	Sinopec	3061	0.11	0	0.9	0.055; Low (1)
3	ExxonMobil	1214	0.70	1	1	0.85; High (3)
4	Total S.A.	968	0.80	1	1	0.835; High (3)
5	Royal Dutch Shell	962	0.89	1	1	0.945; High (3)
6	Baker Hughes*	700	0.67	1	0.9	0.90; High (3)
7	Saudi Aramco	573	0.75	1	0.8	0.875; High (3)
8	Chevron	500	0	1	0.9	0.5; Average (2)
9	Rosneft	480	0	1	0.8	0.5; Average (2)
10	Halliburton*	404	0.75	0	1	0.375; Average (2)
11	Equinor	300	0.33	1	0.9	0.665; High (3)
12	Occidental Petroleum	246	0	1	0.8	0.5; Average (2)
13	ENI	213	0	1	1	0.5; Average (2)
14	Gazprom	197	0	1	0.8	0.5; Average (2)
15	Canadian Natural Resources	190	0	0	0.7	0; Low (1)
16	Lukoil	100	0	0	0.7	0; Low (1)
17	Repsol	88	0	1	0.9	0.5; Average (2)

[6] It is worth noting that ConocoPhillips' leadership (the company is not included in the research) also confirmed the implementation of a more aggressive energy transition strategy due to the changing environmental policy in the US (Cocklin, 2021, February 2).

Discussion

- Major oil and gas corporations have higher chances of adopting the distributed R&D network and Open Innovation Model (OIM) due to several reasons. Firstly, DRD requires strong financial background and it is an expensive tool of innovation management; secondly, many leading corporations conduct operations across the globe and foreign R&D facilities function as centers for cooperation and representation; thirdly, market leaders might pursue aggressive innovation strategies that require active accumulation of innovative ideas. Smaller companies operate on a national scale, conduct R&D activities within one or several specialized R&D centers. Corporate R&D facilities abroad might serve as important acceptors of external innovation.
- Regional factors play an important role in shaping corporate innovation culture and subsequently the structure of R&D networks. While most major European and American oil and gas companies are open to external innovation, Chinese and Russian companies tend to conduct R&D within national laboratories and have a low internationalization ratio despite large business scale, considerable R&D investments and diversified portfolios.
- These results only partially confirm the conclusions presented by Gerybadze A. and Reger G. (1999), who claimed that national firms in smaller countries with strong innovation activities should develop home-country-based competence centers with less diversified innovation portfolios to gain competitive advantage in selected fields. It should be noted that in case of European and North American companies internationalization ratio and portfolio diversification are affected not only by regional factors, but primarily by the business scale of a company and the composition of R&D networks is based on "corporate-centered" rather than "region-centered" approach: national firms with home-centered R&D centers can be found in such major economies as the US and the internationalization of R&D activities can take place in any company with increasing revenues and R&D expenditures despite its location. Nevertheless, the regional factor does indeed impact the openness to external innovation. The low
- As the world goes through the global Energy transition, it may be hypothesized that the rapid changes in the perception of innovation abroad might produce "innovation culture spillovers" that will affect R&D internationalization level of major Russian and Chinese oil and gas companies confirms the influence of corporate culture on shaping R&D networks (Manshadi, 2017) and complies with the overall internationalization level of business activities (Lavrov and Aleksanyan, 2017).
- With the current Energy transition trend oil and gas companies are more likely to concentrate on sustainable solutions. Developing innovations in the new fields of production requires active knowledge accumulation and sharing as entering new markets and expanding business requires mastering new areas of science and knowledge, which motivates companies to increase the openness of their innovation systems and expand cooperation with external sources.
- There are new approaches to generating innovative ideas using the technological potential of other business organizations, such as venture capital funds and start-up scouting centers. Venture funds, accelerators and scouting groups expand the innovation funnel, helping to incorporate not only ideas, but also proven and ready-to-use solutions; they serve as alternative innovation hubs for external innovation sources.
- Regardless of their size and a region of operations, companies use venture capital funds and start-up accelerators, it might be concluded that those mechanisms of external innovation attraction are more inclusive in contrast to traditional foreign R&D offices. This hypothesis goes in line with the results of J. Lerner's research (2011) that confirmed the exceeding effectiveness of venture capital investments in innovation despite the fact that they accounted for a relatively small share of total research and development (R&D) expenditures.
- Though venture capital funding of oil and gas projects has a long and successful history in Europe and the US, Russian companies today are divided into those market leaders that have recently began to actively participate in venture capital to accelerate innovation (Gazprom 2019, Rosneft 2020) and those majors who has not (Lukoil, Surgutneftegaz, etc.). This time lag in the implementation of the best practices in Russia has been previously noted by Moreva E. in 2018. Russian companies in the long-term and subsequently increase the openness to external innovation, internationalization ratio, diversification of innovation portfolio, etc., yet the current deglobalization processes

(Schwab and Malleret, 2020) might negatively affect this scenario.

- Overall, it may be concluded that the openness to external innovation in oil and gas companies is based upon innovation culture and R&D investments. Companies from the regions that are less open to external innovation do not follow the common linear trend, according to which an increase in R&D investments leads to higher R&D internationalization ratio. Venture funding is the most flexible tool of innovation funnel expansion and a good alternative for the second-tier oil and gas companies to attract external innovation while maintaining low R&D expenditures.

4. Conclusion

- The Open Innovation Model is an effective tool that is used to increase the efficiency of knowledge management by promoting open discussion and access to innovation. Openness to external innovation is one of the aspects of OIM. The authors decided to research major oil and gas companies' openness to external sources of innovation by focusing on the role of R&D investments in the internationalization of R&D networks and the establishment of venture funds; analyzing the links between regional specificities, innovation portfolio diversity and the perception of external innovation.
- The study reveals that the openness to external innovation in major oil and gas companies depends on R&D expenditures. There is a strong correlation between the number of foreign R&D facilities, internationalization ratio and R&D investments. Oil and gas companies with smaller investments have a lower R&D internationalization ratio and they stick to one or several home-based R&D centers. Distributed internationalized R&D networks are an expensive tool for innovation funnel expansion.
- Regional specificities and innovation culture have a considerable impact on the openness to external innovation. North American and Western European oil and gas companies are more likely to have higher internationalization ratio than major Russian and Chinese oil and gas companies despite the comparable R&D investments and scale of operations.
- Oil and gas companies establish venture funds regardless of the volume of R&D investments and their business scale; therefore, it might be concluded that venture funding is a more inclusive tool for expanding innovation funnel than R&D network internationalization and it may be implemented by second-tier oil and gas companies while they maintain low R&D expenditures.
- The correlation between the level of innovation portfolio diversification and openness to external innovation may indicate that diverse innovation goals motivate companies to enter new fields of technology and subsequently expand the cooperation with external sources of innovation.

Declarations

Availability of data and materials: Data available within the article or its supplementary materials.

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