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Measurement of open innovation in the marine biotechnology sector in Oman

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ABSTRACT

National economies are often strengthened by diversification, which is built in turn on a healthy and productive culture of national innovation. Innovation is a complex process, which is difficult to measure in an objective manner. In this work and for the first time, a quantitative measure for open innovation has been developed and validated to determine the performance of a firm within the marine biotechnology sector in Oman. This breakthrough was achieved in four steps. First, the characteristics of the two dimensions of open innovation ('breadth' and 'depth') were identified using a critical review of the literature and a series of pre-tests of a survey design with industrial experts. Second, a quantitative index for open innovation by measuring these two dimensions at firm level was developed. Third, validation of this five-item scale was conducted using the UK Community Innovation Survey (CIS) data set. Fourth, the five-item scale was applied to 22 firms in the marine bio-industry sector in Oman using a case study approach, and was used to rank the firms according to their open innovation index. This analysis shows how Omani marine bio-industry firms could strengthen their open innovation efforts, for example by collaborating more effectively with government organizations and research institutes to thereby boost the quality of their open innovation activities in a measurable way.

1. Introduction

Open innovation is a complex, multi-dimensional process that consists of a set of practices which a firm needs to create to inform its research and which can be used to determine its likely future performance. The concept of open innovation was first introduced by Chesbrough in his book in 2003 about the need for a paradigm shift from a closed to an open model for innovation for industrial R&D firms [28]. He defined open innovation as "the use of both inflows and outflows of knowledge to improve internal innovation and expand the markets for external exploitation of innovation" [31]. Since 2003, the concept of open innovation has gained widespread acceptance [40,122]. Closed innovation occurs internally within a firm's own research and development (R&D) laboratories; open innovation occurs as a result of seeking technologies and knowledge from outside the firm's boundaries [28]. There are some important drivers for the adoption of an open innovation strategy including increased globalization of markets and business activities [21,22,60]. Globalization increases collaboration between many different actors such as universities, government and links in the supply chain [49] and the internationalization of industrial R&D in innovation activities is of the utmost importance.

The literature has described how open innovation can improve the innovation performance of firms [17,87], increasing their sales of new or enhanced products [17,103]. For example, companies can benefit from knowledge networking with different types of actors on the market side [87]. The characteristics of these networks are also supported by Laursen and Salter's [79] work on the dimensions of inbound open innovation, "breadth" and "depth". They argue that breadth and depth dimensions which measure the number and diversity of parties that firms collaborate with, affect relationship dynamics and innovation outcomes [17,79]. This bringing in of new information from outside a company is often referred to as open innovation and its benefits have been widely documented outside the marine biotechnology sector [7,28].

However, although a considerable number of empirical studies have been conducted on innovation, an objective and quantitative measure of inbound open innovation has not yet been developed [40,111,122]. Moreover, although interest in the role of innovation in the development of the marine biotechnology sector has increased [9,42,45,46,58,67,69,108,116], little attention has been paid to the best strategies for marine biotechnology companies to adopt in order to access external ideas for innovation and to overcome industrial barriers

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[23,58,74,80,83]. Companies focus mainly on in-house ideas for improving production and marketing, largely ignoring the opportunities for collaboration with external actors.

This study seeks to address this deficiency by focusing on three gaps in the literature: first, there is need for definitive definitions of the two terms, 'breadth' and 'depth'; second, there is a need to explore the linkage between the two dimensions; and third there is need to develop a more precise (i.e. quantitative) way of measuring breadth and depth. The third gap is the most important to fill, and entails developing an objective and quantitative measure of inbound open innovation values, which has not been attempted before [40,111,122].

The main aim of this study is for the first time, to develop a quantitative measure that has been validated to examine inbound open innovation processes at the firm level. This entails redefining the twin dimensions of innovation breadth and depth and combining them to form a single metric for measuring open innovation. The study then applies this metric rigorously to examine the adoption of inbound open innovation in the marine biotechnology industry in Oman. The paper begins with a literature review of previous research on the concept of open innovation and its application to the maritime sector. It then explains the methods of research used in the study and the results obtained from the conceptual analysis of inbound open innovation and from the fieldwork in Oman and discusses the application of the metric to Omani biotech firms. The implications of the findings for policy makers in Oman are set out in the conclusions.

2. Literature review

2.1. The concept of open innovation

There is a growing literature on the concept of innovation, which shows the evolution of ideas through five stages or generations of development. The first generation was the linear model approach, in which the innovation process in firms uses R&D as a source for innovation (technology push) and the innovation process happens in a sequential way from R&D to new product development [106,109]. The second stage was also linear in approach but differs from the first generation in that the source of innovation comes from the need of the market (market pull) and therefore neglects long term R&D [106,109]. The third generation was the coupling model approach in which the innovation process is a simultaneous integration of both R&D and the market need [106]. The fourth generation of studies addressed the limitations of the previous innovation models which depend on sequential core innovation processes. Here, new product development processes are undertaken with the simultaneous integration of suppliers, R&D, marketing and the manufacturers [95,106]. The fifth generation and the most recent stage of innovation theory is the networking approach which is referred to as 'open innovation' (OI), in which knowledge inflows and outflows occur through the porous boundaries of a firm, improving the efficiency and speed of the development process [17,28]. According to [48], there are two main types of open innovation. The first type is inbound open innovation, which is the acquisition of external ideas, technology and knowledge through, for example, R&D contracts, university collaborations, in-licensing, and acquisitions. The second type is outbound open innovation, which is the transfer of technology, ideas and knowledge to external firms and their commercial exploitation through, for example, out-licensing, joint ventures or venture spin-outs. In this study we focus on inbound open innovation [79,81].

The literature on inbound open innovation concentrates on three issues: its benefits; its requirements; and its measurement. Many studies testify that the benefits of inbound open innovation include increased competitive advantage, risk sharing, access to new knowledge and markets, complementary resources and shorter development times for new products [70,88,99,104,120,121]. On the requirements of inbound open innovation (i.e. how to achieve it), the literature refers to the need to build relationships that are characterized by a high degree of openness which will also allow the firm to search for opportunities to increase not only its current product development portfolio, but also possible future products by networking [22,55]. Writers emphasis the need for collaboration with a variety of individuals (such as scientists) and organizations (such as supplier firms), each with different norms, habits, and rules, which require flexible organisational practices to make the search process successful [28,66,79]. In recent years, the number of theoretical and empirical studies addressing a firm's ability to form such networks and relationships with others, to improve their innovation behaviour and performance, has increased substantially [5,71,79,87].

However, one of the most important issues in the open innovation literature is the problem of measurement of inbound open innovation [27,122]. This involves examining the breadth and depth of inbound open innovation, concepts which were first introduced by Laursen and Salter [79]. The breadth dimension represents the number of different types of external sources of knowledge or partners or collaborators involved in the innovation processes and is the more studied dimension [17,27,111]. The depth dimension is defined as the extent to which these partners are used [72], but is less investigated in the literature. There are many empirical studies in open innovation literature that have focused on the effect of breadth and depth dimensions on a firm's performance. For example, a study by [4] found that the effects of breadth and depth are similar and both correlate with the long term performance of the firm. Belussi et al. [21] studied the regional innovation system (RIS) approach that draws on the view that innovative dynamics are not held within organisational borders or a single firm's search unit. This study used the breadth dimension of open innovation to study innovation in the life sciences sector in the Emilia region of Italy, which consisted of the interactive process with external sources of knowledge. The researchers found that the open innovation model better explained the firms' innovation performances than did a closed system. Another study by [81] showed that breadth in terms of innovation objectives and knowledge sources increases a firm's ability to develop new innovations. Similarly, [103] showed that an increased breadth dimension is positively associated with sales of new or improved products. Another study [32], which divided the effect of breadth and depth dimensions of open innovation into two different types of innovation present in Taiwanese electronics manufacturing firms, discovered that greater breadth increased radical innovation, while greater depth increased incremental innovation.

However, there is considerable controversy over the definitions of both breadth and depth: the literature reveals ambiguity in defining the two dimensions ever since their introduction, and despite their widespread adoption in empirical studies of open innovation [27,47,110,122]. For example, the definition of breadth varies considerably between studies [17,40,98,110]. Some studies define it as the number of external sources of knowledge and information [79,102]. Other studies define it as the number of external partners with the firm, included in innovation processes [59]. Some studies only include partnerships that are involved in cooperation for R&D [84,98,102]. Studies also differ in the types of external collaborator they include under the breadth dimension [17,52,110,125]. For example, [102] defined the breadth dimension as external sourcing with six types of external collaborators, whereas [1,17] included eleven types of external collaborators. In comparison, the definition of the depth dimension is limited to the importance of the sources of information at the firm level [72,79,107].

There is also controversy over the ways of measuring breadth and depth: the literature on open innovation shows many different ways of measuring them. For example, [110] measured inbound open innovation with a total of 16 indicators on a seven point Likert scale, while [20] assessed the degree of openness by rating the importance of 16 potential sources (market-based, institutional, and semi-public) on a top-ten scale. However, the most common method used is the Laursen

Table 1
Studies using proxies to measure the breadth and depth dimensions of inbound open innovation.

Author	Proxies to measure openness	Research topics
Laursen, Salter [79]	Breadth is openness of firms to 16 different sources of knowledge. Depth is the level of collaboration (low, medium and high) with each source	External search strategy or openness
Miotti, Sachwald [86]	Partnership type by classification of partners into (suppliers, customers, rivals and universities) and measuring intensity of collaboration by giving a number to indicate level of intensity	R&D partnership
Belderbos et al., [19]	Cooperation by type of partnership (suppliers, customers, rivals and universities) and importance of partner by asking each firm to rate on a Likert scale (1–5)	R&D cooperation
Faems et al., [52]	Collaboration between firms and 7 different types of collaborators and depth by measuring exploitative variable with customers and suppliers	Inter-organisational collaboration
Amara and Landry [14]	Sum of 7 different sources of information	Information source
Nieto, Santamaría [93]	Four types of collaborating partners customers, suppliers, competitors and research organizations	Technical collaboration
Acha [1]	Breadth is openness of a firm to 11 different sources of knowledge. Depth is the level of collaboration (low, medium and high) with each source	Knowledge source
Tether and Tajar [117]	Type and number of sources of knowledge or information used in a firm's technological innovation activities, and depth measured by the importance of each source to the firm	Sources of information
Leiponen, Helfat [81]	Type and number of the sources of knowledge or information and innovation objectives used in a firm's technological innovation activities, and depth measured by the importance of each source to the firm	Source of knowledge
Oerlemans, Knoben [98]	Breadth is openness of a firm to 8 different sources of knowledge. Depth is the level of collaboration (low, medium and high) with each source	Inter-organisational relationships

and Salter scale which relies on counting the external knowledge sources involved [79,102]. Several studies have followed the Laursen and Salter scale in measuring openness of innovation using the number of varieties of external collaborators [22,64,112].

A quantitative measure is needed to track the successful implementation of open innovation and to study and manage the way a firm searches for and makes use of collaborators to improve its innovation performance. Such a measure would help firms determine the degree of openness they are willing to accept in order to increase their productivity, and to adjust it carefully [40,101,111,123]. Therefore, the development of measurement criteria to quantitatively measure inbound open innovation will help in optimizing the search for innovation activities and thereby contribute to the success of firms [78,79].

2.2. Open innovation in the marine sector

Marine organisms are more diverse, unique and complex in their biological, chemical and genetic characteristics than terrestrial organisms [58]. Scientific and technological development in marine biology during the last four decades has provided countless new discoveries [50], leading to the emergence of new industrial activities in the marine biotechnology sector such as cosmetics, healthcare, functional food and neutraceuticals, all of which depend on open innovation for their successful development [58,67,69,97,108,113]. The biotechnology industry is an early adopter of open innovation [30,33,39,53,76]. Similarly in marine biotechnology, sector collaboration between traditional firms and more advanced biotechnology firms is turning the traditionally low-tech industry (fishing) into a high-tech industry (functional food/nutraceuticals) [7]. One of the success factors for the aquaculture industry is its collaboration with marine biotechnology firms such as vaccine producing firms, fish-feed development firms, marine management firms and fish breeding firms [94,116]. Karlsen et al., [69] showed that in Norway, collaboration between universities and vaccine producing marine biotechnology companies has radically reduced the incidence of disease in fish farming. In New Zealand, effective linkages between fisheries companies and chemical companies led to the extraction of bioactive compounds from marine organisms for commercial use, a good example of which is Lyprinol, an anti-inflammatory extracted from the New Zealand Green-Lipped Mussel (Perna canaliculus) [3,108].

In the case of the marine bio-industry in Oman, the country is characterized by unique marine resources including a diverse fishery [11], unique coral reefs and marine microbes [12,44] that have so far not been intensively investigated for their biotechnological potential.

This study was therefore carried out in order to investigate inbound open innovation as a strategic tool to further develop the marine biotechnology sector in Oman which should, in time, help to diversify Oman's economy [7]. The sector currently consists of over 40 companies, most of which are active in the area of fish processing and exporting [7,8]. Although fisheries exports are considered to be the second most important source of foreign currency in Oman [10], the financial benefits of these exports is low since they consist largely of fresh unprocessed fish with no added value. However, recent advances in biotechnology and the increased role of collaboration strategies such as open innovation at the firm level, offer great opportunities for development from traditional marine bio-industries to marine biotechnological activities by increasing the opportunities for added-value products and to open new markets in seafood, aquaculture, functional food and neutraceuticals, cosmetics and healthcare [97,108]. It has been suggested, therefore, that there are opportunities to increase Oman's exports of added-value products by targeted investment in marine biotechnology [7,8,85].

This paper seeks to extend and develop our earlier work [7], by contributing to a more detailed understanding of open innovation and its adoption by marine biotechnology firms in Oman. The previous paper was introductory in nature, contributing the first baseline study of open innovation in the marine biotechnology sector in Oman. This paper moves the agenda on by developing a quantitative metrics-based index of inbound open innovation and applying it to the marine bio-industry in Oman. Development of this index is both an original contribution to the concept of open innovation, and a practical tool for a much more rigorous examination of the different activities and mechanisms that shape knowledge and innovation dynamics in the marine biotechnology industry in Oman, helping to shape policy decisions related to investment strategies for more effective national economic growth.

3. Method

Several approaches have been used in previous empirical studies to measure inbound open innovation (Table 1). The first approach is measuring the openness of firms to different knowledge sources, and the breadth and depth dimensions are calculated on a nominal scale by assigning the number and extent of the sources of knowledge as binary variables. This approach was first developed by [79] who used the Community Innovation Survey (CIS) with 16 knowledge sources. Here, breadth is measured by the number of external knowledge sources used by a firm, while depth is measured by the level of collaboration (low, medium and high) with each source. Other studies have defined openness in terms of inter-organisational relationships rather than

Table 2
Overlaps and similarities of inbound open innovation dimensions with related research streams.

	Related research streams	Definition of research streams	Domain of overlap and similarities to OI dimension
1	Exploratory learning	Search, experimentation and acquisition of knowledge from external sources [73,82]	Breadth: External search of knowledge, ideas or technology through multiple sources or linkages
2	Information seeking	Active and passive acquisition of facts or advice from others or from others environment [57]	Breadth External search of knowledge, ideas or technology through multiple sources or linkages
3	Environment scanning	The acquisition of information from an organization's external environment [54,57]	Breadth External search of knowledge, ideas or technology through multiple sources or linkages
4	Stakeholder oriented relational	Cooperative relationships that are based on compassion, honesty, integrity, and kindness [26]	Depth The extent to which the relationship between innovating firm and external collaborators is deep and open
5	Network ties	The role of weak versus strong ties in the acquisition of novel Information [24,124,2]	Depth The extent to which the relationship between innovating firm and external collaborators is deep and open
6	Innovation networks	Collaboration with different types of collaborators to give variety of knowledge types [65]	Breadth External search of knowledge, ideas or technology through multiple sources or linkages
7	Spanning boundaries	Bridging relationships embedded in a dense social structure facilitate the formation of common knowledge and shared meanings, reduce frictions due to differences in understanding, and promote the cooperation and coordinated actions that are necessary to integrate and take advantage of diverse sources of knowledge [118]	Depth The extent to which the relationship between innovating firm and external collaborators is deep
8	Collaboration intensity	The ability to coordinate among interdependent actors stems from adequate mutual knowledge that enables individuals to act as if they can predict others' actions (Kotha et al., 2013)	Depth The extent to which the relationship between innovating firm and external collaborators is deep
9	Knowledge identification	The focus is on checking the availability of knowledge in one's mind deemed necessary for effectively coping with the demands of a particular cognitive task, e.g., attaining a particular instructional goal, solving a complex problem, acquiring expert knowledge [115]	Breadth Identification of knowledge out of various sources
10	Knowledge sourcing	The firm's need to access complementary external expertise to help solve novel problems associated with novel strategic opportunities as a main motivation [55,57]	Breadth Identification of knowledge in various external sources Depth The extent that individuals access others' expertise, experience, insights and opinions
11	Knowledge acquisition	Knowledge acquisition is defined as the development of creation of skills, insights and relationships [54]a)	Breadth Identification of knowledge in various external sources
12	Market knowledge acquisition	Collection and assessment of both customer needs/preferences and the forces that influence the development and refinement of those needs [126]	Breadth Identification of knowledge in various external sources
13	Knowledge sharing	The ease with which knowledge is shared, acquired and deployed within the network [65,126]	Depth The extent that individuals access others' expertise, experience, insights and opinions
14	Opportunity recognition	Firms may involve external knowledge sources even after the opportunity recognition stage and draw on such sources to realize opportunities [55]	Breadth Identification of knowledge in various external sources
15	Cross-functional interfaces	Promotion of non-routine and reciprocal information processing and contributing to a unit's ability to overcome differences, interpret issues, and build understanding about new external knowledge [68]	Depth The extent that individuals access others' expertise, experience, insights and opinions

knowledge sources.

For example, some studies examined openness by the use of external knowledge sourcing, R&D partnerships, and cooperation [18,19,84,86]. Other investigations described openness in terms of R&D outsourcing [59], ignoring the variety of the organisational antecedents of these dimensions and their implications for different organisational outcomes [18,93]. We have built on many of these approaches in order to present a new and more reliable method for the quantification of inbound open innovation which we term the open innovation index (OII). In employing a mixed-method approach, we used a sequential research design. First, qualitative methods were used to carry out a literature review and interviews thereafter in order to generate an initial item pool [41,54,92]. Subsequently, quantitative methods were used to test the resulting item pool for reliability and validity [36]. The following sections explain and discuss this sequence.

3.1. Item pool generation

The first step in developing a quantitative metric for measuring inbound open innovation was to search the literature for item pools which represent the meanings of breadth and depth. Item generation is a well-established procedure for developing measures [36,54,92]. A literature review was conducted following a similar approach to [54] in which research streams related to breadth and depth of inbound open innovation were searched and screened from key articles from the top ten management journals during the period 2003–2016 which were: Academy of Management Journal (AMJ), Academy of Management Review (AMR), Administrative Science Quarterly (ASQ), Journal of Management (JOM), Journal of Management Studies (JMS), Management Science (MS), Organization Science (OS), Strategic Management Journal (SMJ), MIS Quarterly (MISQ), and European Management Journal (EMJ). Several criteria were used to select these key journals. First, they had to be in the area of management and organization. Second, journals specialising in topics such as information technology were excluded. Third, the chosen journals had to be prestigious and several rankings were used to check their position as top journals in the management and organization field. For example the 2016 ISI journal citation rankings were used [114,127] as well as the 2015 *Financial Times* Survey of top business schools. Fourth, the time frame of 2003–2016 was chosen because the open innovation research stream

was introduced by Chesbrough in September 2003. Key articles were reviewed and screened for their relevance to open innovation from these journals. This process produced 157 studies from 15 research streams which were divided into two types: (1) studies with an open innovation measurement tool and (2) studies with no open innovation measurement tool.

In order to develop the initial item pool, articles from each journal were screened for their relation to inbound open innovation dimensions and the characteristics of each dimension were analysed and compared.

The next step was to assign items to the breadth and depth dimensions based on the measurement scales that have been used previously in these research streams [63]. On the breadth dimension, the first research stream is opportunity recognition, which overlaps with the breadth dimension by responsiveness to new opportunities through involvement in knowledge sourcing with different types of collaborators [55]. Other research streams are exploratory learning [73,82] and information seeking [57], which share the process of acquisition of external knowledge, facts or advice. Environmental scanning shares with the breadth dimension how an organization obtains and searches for environmental data [54]. The breadth dimension is also related to research on innovation networks; knowledge identification; knowledge sourcing and knowledge acquisition; and market knowledge acquisition. Items generated from these already-used research streams served as starting points for the scale development process. On the depth dimension, knowledge sharing [65] shares with the depth dimension the ease with which knowledge is shared, acquired and deployed within a network. Spanning boundaries [118] shares with depth the bridging of ties which promote the cooperation and coordinated actions that are necessary to integrate and take advantage of diverse sources of knowledge that are conducive to the generation of new ideas. Cross-functional interfaces shares the component of knowledge communication with the organization [68]. As shown in Table 2, based upon prominent definitions of these related research streams, the depth dimension also relates to research on innovation networks, social networks, and collaboration intensity. Following Flatten's approach [54] as Fig. 1 and Table 2 show, the first item pool for the breadth and depth dimensions was generated from the 22 studies that contain measurement. The findings identified 12 items that described the breadth dimension, and 13 items that described the depth dimension.

3.2. Pre-test

Two pre-tests were conducted to assess the quality of the 25 items. In pre-test 1, a brief questionnaire containing the items selected was given face-to-face to five executives who were asked to point out any items that were either ambiguous or difficult to answer. These experts reviewed the items and classified them into three groups: (a) items that could be retained without change, (b) items that needed to be modified, and (c) items that needed to be deleted. Respondents provided detailed comments that led to the modification of some and the elimination of other items, resulting in a scale of 14 items.

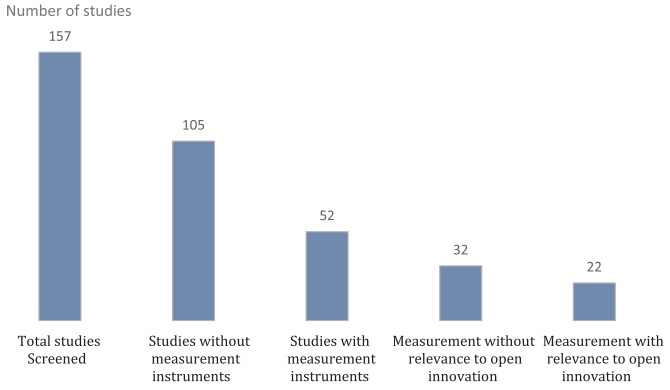

Fig. 1. Studies screened to generate the initial item-pool.

Pre-test 2 was conducted with three executives who were asked to fill out the questionnaire and identify any problems they encountered when completing the scales. This resulted in the identification of eight items to be deleted which gave a final scale of six items as shown in Table 3. Fig. 2 summarizes the steps undertaken in the pretesting phase.

3.3. Developing a single quantitative metric for open innovation

The final step was to convert the six items into a single quantitative metric for assessing open innovation. This step progressed in two stages. In the first stage, content specifications were conducted to eliminate items that did not adequately capture the theoretical components of the inbound open innovation construct. In the second stage, the secondary data of the 2011-UK Community Innovation Survey (CIS) and stochastic measures were used to validate the newly developed measure [41]. The sample used here was readily available data of the 2011-UK (CIS) data set that sampled around 28,000 UK firms. The survey covered the period of three years from 2008 to 2010 and presented data at the sectoral level.

As shown in Table 4, the items generated in this study were matched with the innovation activities measured in the CIS data. We then calculated the openness score by calculating the average of breadth dimensions and depth dimensions and then multiplied them according to the following equation.

$$\text{Openness score} = \left\{\left(\frac{1}{n} * \sum_{i=1}^{n} \alpha_i\right) * \gamma\right\}/100$$

Where α_i is the five proposed new items identified for breadth in Table 4, γ is the item of depth dimension, and n is the total number of new measures that are used to calculate openness. Our model postulates that the openness of any industry must increase when the average of α_i and γ values are high. The result will give us the openness score. The openness score was then calculated for different industrial sectors, and presented with regard to high/low technology sectors, broad sectoral categories and specific sampling sectors.

Finally, the openness measure was tested for reliability and validity. On reliability, the measurement of items were purified by using coefficient α, which is the most commonly used measure of internal consistency [36]. As shown in Table 5, we assessed the reliability of the scale items by assessing their correlations with other items in the same construct. Items weakly correlated with other items in the same construct with correlation $< .20$ should be removed [91]. In fact, all but item one positively correlated with each other, therefore we ran a coefficient alpha test (Cronbach test), and found that when item 1 is included, the Cronbach score is .50, while removing this item increased the reliability of the measure to .79. The total number of items after this refinement step was therefore five, all of which showed good internal reliability [16,96]. On validity, according to Churchill [36], to validate a new measure it must be correlated with previous measures. So the task was to collate the openness score with the number of collaborative projects that have been used to measure openness. Running a Pearson correlation test showed a correlation score for validation of the inbound open innovation scale of .54, which is above the recommended value to show validity [96].

3.4. Applying the metric to the marine bio-industry sector of Oman

The newly developed index was applied to the marine bio-technology industry of Oman given the high importance attached to using open innovation in the development of this sector [7]. Data were collected from firms using our newly developed index to measure both the total openness score for each company, and the scores of the two constituent dimensions – breadth and depth – over the last five years.

Table 3
Item-pool and sources after two rounds of pre-tests.

Item No	Item	Source which the items are based on
B1	The number of new business opportunities that firms had successfully realized in the previous three years. New opportunities means new products and/or services	[55,100]
B2	We have been able to create more value because the new product and services jointly developed by us have opened up new market opportunities and expanded our customer base	[55,100]
B3	We frequently scan the environment for new technologies and information	[54,57,65,82,118]
B4	Our firm has used the new ideas and skills acquired from the partner to create value by improving its products and services	[100]
B5	Our firm has used the knowledge gained about technology from the alliance experience to improve our technology	[100]
D1	Within the alliance boundary, this alliance has led to more efficient deployment and utilization of resources leading to continuous improvement of quality of products	[100,105]

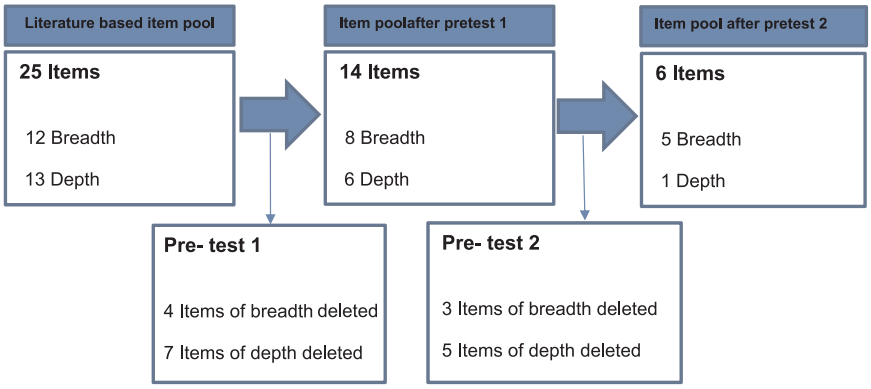

Fig. 2. Different steps of pre-testing.

The data were obtained from 22 companies within the Omani marine bio-industry sector by mailing each of them a survey. Initially, the names and email addresses of potential respondents were collected from a list of Omani marine bio-industry firms [7] received from the Ministry of Agriculture and Fisheries (MAF) (personal contact). Following this, the survey was emailed to those companies which possessed the government's quality assurance certificate. Because executives were considered to be the most knowledgeable about their firm's operations [119], for each company, the CEO was contacted by telephone and asked to participate in the study. It is suggested in the survey literature that pre-notification and pre-contacts increase the response rate [35,43,62], so pre-contact was used. This strategy was effective as it provided us with an opportunity to establish personal contact with the respondents and to explain the research project. Confidentiality was emphasized and it was agreed that a summary of the results would be shared with the respondents.

4. Results

For each company, the open innovation index (OII) was calculated using the collected numeric data, and these scores were compared with the number of collaborative projects that these companies have, as shown in Table 6.

The highest open innovation index (OII) scores were achieved by eight companies, with values ranging from .0550 to .0150. The highest scores were for three companies (Table 6) (Companies A, B and C). The highest breadth dimension score was 2.75, and the highest depth dimension score was 2.0. The first eight companies for breadth values scored between 2.75 and 1.50. The depth values of the top eight companies and the other firms was almost the same (1) except for two companies, A and C. These depth values indicate that inbound OI is practiced by these companies but with a low degree of openness. The group of companies which had lower values of openness had scores ranging from .0125 to .0075: the highest value of their breadth dimensions was 1.25 and their depth dimension score was 1. The purpose of external collaboration for most of these companies is to collaborate with their customers to whom they are exporting and to use the feedback to increase the quality of the product as per their requirements, so products are tailored to customer demand. The results also showed that across the marine bio-industry sector, most external collaboration came from collaboration with customers and consultants. Only two companies (A and F) had external collaboration with R&D institutes. Almost

Table 4
Items and CIS measure.

Items to measure openness	Item generated	Measure from CIS
B1	New opportunities as new products and/or services/ process	Product/process by cooperation partners
B2	We have been able to create more value because the new product and services jointly developed by us have opened up new market opportunities and expanded our customer base	Market introduction of innovation by enterprise
B3	We thoroughly collect industry information and new technologies	Acquisition of machinery by enterprise
B4	Our firm has used the new ideas and skills acquired from the partner to create value by improving its products and services	Improving quality of goods or services
B5	Our firm has used the knowledge gained about technology from the alliance experience to improve our technology	Acquisition of external R&D by enterprise
D1	Within the alliance boundary, this alliance has led to more efficient deployment and utilization of resources leading to continuous improvement of quality of products	New method of organising external relationships introduce by enterprise

Table 5
Correlation coefficient alpha for CIS data.

		Item_1	Item_2	Item_3	Item_4	Item_5	Item_6
Item_1	Pearson Correlation	1	−.577**	−.196	−.345	−.497*	−.566**
	Sig. (2-tailed)		.003	.347	.092	.012	.003
	N	25	25	25	25	25	25
Item_2	Pearson Correlation	−.577**	1	.215	.259	.730**	.683**
	Sig. (2-tailed)	.003		.301	.211	.000	.000
	N	25	25	25	25	25	25
Item_3	Pearson Correlation	−.196	.215	1	.353	.617**	.266
	Sig. (2-tailed)	.347	.301		.083	.001	.199
	N	25	25	25	25	25	25
Item_4	Pearson Correlation	−.345	.259	.353	1	.447*	.349
	Sig. (2-tailed)	.092	.211	.083		.025	.087
	N	25	25	25	25	25	25
Item_5	Pearson Correlation	−.497*	.730**	.617**	.447*	1	.618**
	Sig. (2-tailed)	.012	.000	.001	.025		.001
	N	25	25	25	25	25	25
Item_6	Pearson Correlation	−.566**	.683**	.266	.349	.618**	1
	Sig. (2-tailed)	.003	.000	.199	.087	.001	
	N	25	25	25	25	25	25

* Correlation is significant at the .05 level (2-tailed).
** Correlation is significant at the .01 level (2-tailed).

Table 6
Open Innovation Index scores for 22 Omani marine bio-industry companies. Identities remain confidential.

	Company	Breadth	Depth	Openness score	Number of collaborative projects
1	A	2.75	2.0	.0550	2.0
2	B	2.75	1.0	.0275	1.0
3	C	1.25	2.0	.0250	1.0
4	D	2	1.0	.0200	1.0
5	E	1.75	1.0	.0175	1.0
6	F	1.75	1.0	.0175	1.0
7	G	1.75	1.0	.0175	1.0
8	H	1.50	1.0	.0150	1.0
9	I	1.25	1.0	.0125	.0
10	J	1.25	1.0	.0125	.0
11	K	1.25	1.0	.0125	.0
12	L	1.25	1.0	.0125	.0
13	M	1.25	1.0	.0125	.0
14	N	1.25	1.0	.0125	.0
15	O	1.0	1.0	.0100	.0
16	P	1.0	1.0	.0100	.0
17	Q	1.0	1.0	.0100	.0
18	R	.75	1.0	.0075	.0
19	S	.75	1.0	.0075	.0
20	T	.75	1.0	.0075	.0
21	U	.75	1.0	.0075	.0
22	V	.75	1.0	.0075	.0

all the strategic alliances in these companies were also with customers and/or consultants. In order to explain and analyze the open behaviour of the companies over the openness score, this relationship was compared with the number of the firms' collaborative projects (see Table 6). As expected from this study, the companies that had higher scores of openness also had more collaborative projects. For example, the eight companies which had the highest open innovation index (OII) also had the highest number of collaborative projects, highlighting the validity of this new index.

5. Discussion

A key consideration for countries to develop national strategies for the development of marine biotechnology is that this sector has the potential to address many of the grand global challenges of population health, food and energy security [89]. However, in order to realize this potential, marine biotechnology firms need to innovate, and in a highly turbulent and uncertain environment, innovation is a risky business [31,81]. Firms collaborate with different types of external collaborators during innovation processes to compensate for their internal resource deficiencies and to increase their power relative to competitors [38]. Those external collaborators of firms play major roles in enhancing organisational learning and in helping firms to develop and strengthen their internal competences [61,113]. Therefore public policy is required to strengthen the linkages between different type of actors, such as industry- university linkages through increased dialogue and co-operation. But public policy also needs measurement tools to better monitor and manage the innovation process, which is also necessary for the development of the marine biotechnology sector [90].

Open innovation measurement is still looking for an appropriate metric to calculate the effectiveness of adopting open or closed innovation approaches, in order to help companies to find the right balance. Most studies on open innovation generate results from case studies and surveys [13,34,37,51] that do not employ rigorous criteria for the measurement of open innovation. This highlights the need for a quantitative measure of openness to facilitate the successful implementation of open innovation, by resourcing the right capabilities [48], and strategically monitoring the business model of the company [40]. The proposed measure in this study fulfills this need by providing a numerical quantification metric to assess the degree to which a company engages in open innovation by the breadth and depth of its activities of external collaboration with actors from six traditional partnerships - customers, suppliers, competitors, consultants, research institutes, and governments. We have used the guidelines presented by earlier researchers [36,54,92] in order to construct this new measure. The content specification of the measure was based on the overlaps of antecedents resulting from a search of breadth and depth dimensions from the literature of management and organization [5,70]. The measure is characterized by five items that can be measured numerically and classified into two dimensions, thereby helping the researcher to overcome the charge of subjectivity and making it more acceptable to management [55,56,68]. The proposed measure can provide managers with a more accurate and objective tool with which to assess their firm's strengths and weaknesses in regard to the activities and practices needed for the adoption of an effective open innovation strategy. Most of the previous studies assessing the implementation of open innovation activities were exploratory rather than prescriptive [66,75,101,126].

To test the reliability of the measure we confirmed the internal correlation between the items of the measure. Then we externally validated the index by demonstrating its high correlation with other

proxies used to measure inbound open innovation as found in the literature [6,29]. Our findings confirmed that the measure achieved a high level of validity.

Applying the newly developed index to the marine bio-industry sector in Oman, the results indicated that the Omani marine bio-industry sector has more external collaboration with customers and consultants than with the government and academia. Moreover, this collaboration was exclusively with partners from the fisheries sector. However [77] has found that the innovation performance increases and the new product development process is more successful when there are more combinations of different types of partners. Other studies on open innovation in the life sciences sector [21] have also shown that increased breadth (combination of different types of partners) increases innovation performance. In a similar vein, [25,69,108,116] have shown that collaboration between traditional marine bio-industry companies and more high tech (R&D) companies from different industries will positively affect innovation performance and the success of new product development in marine biotechnology by allowing companies to overcome barriers for innovation by renewing their knowledge base through knowledge creation and learning.

Another important finding is that the role of R&D collaborations in defining the degree of openness is important. A higher openness score was obtained by companies that had effective R&D collaborations in place. A similar finding was reported by [18] who said that R&D co-operation is a crucial instrument for firms to gain and implement external resources efficiently. Similarly, [15] have shown that R&D collaboration is of great importance for large US chemical and pharmaceuticals companies in the biotechnology sector in achieving a high degree of openness. Finally, the results also demonstrated that the highest openness scores are attributed to the firms that have the highest number of collaborative projects and this result is in line with both [6,29] who suggest that operational measurements for open innovation are related to the collaborative projects which companies are involved in. Thus, this study has demonstrated the value of using quantitative measurement of open innovation to assess the potential performance of companies in the marine bio-industry sector. This study also has wider implications internationally, in providing a new method to assist decision –making on whether to collaborate with or invest in, a particular company of interest.

6. Conclusions

In this study, we have developed, validated and applied a newly created measure of inbound open innovation to the marine bio-industry sector of Oman. This is a quantitative measure for inbound open innovation which combines both breadth and depth dimension values for the first time in a single metric, and it provides a valuable tool for managers in industries which rely heavily on innovation. Applying this metric to a new sector (marine biotechnology) and a new country (Oman) makes an original contribution to the literature, and increases the validity of the open innovation model by confirming its practicability as a measurement instrument. The index also makes it possible to compare and rank different firms according to their innovation score values, and it enables managers to build business cases for future innovation investment plans that are based on a systematic approach to collecting evidence for assessing the growth potential of their companies. Marine policy makers in Oman's government can also use this metric to help them formulate policies and investment programmes in the marine bio-industry sector which will contribute to strengthening the national economy.

However, the study has indicated that although there are some companies in the marine bio-industry sector of Oman which practice inbound open innovation, most of them do not involve either the government or academia. Lessons should be learned from other countries about the importance of the role of government in the enhancement of innovation in the marine bio-industry sector. The practice and activities of inbound open innovation could be significantly enhanced by engagement with the government through for example, the Industrial Innovation Centre (IIC), the Omani Authority for Partnership for Development (OAPFD), Tanfeedh and the Research Council of Oman (TRC), which could help strengthen the connection between firms and research institutes through incentive programmes and partnership platforms. Also, if universities both in Oman and abroad were to be encouraged to engage in research collaboration with marine bio-industry companies, the metric we have developed could provide an early diagnosis at the firm level of potential problems, and identification of such problems could lead to the implementation of a suitable recovery strategy. Lessons learned from other countries have also shown the importance of spin-out companies from universities to help enrich innovation in the marine biotechnology sector.

With regard to future research, a fruitful topic would be to identify the processes and conditions that produce and sustain the Omani marine bio-technology firms with the highest scores of inbound open innovation, to enable the other firms to learn lessons of good practice from them. Another promising research avenue would be to examine the application of the OI index to other industries in Oman, such as biotechnology, ICT and oil and gas, and to other countries at different stages of macroeconomic development, in order to detect the differences and similarities between them and formulate good practice guidelines for international application.

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