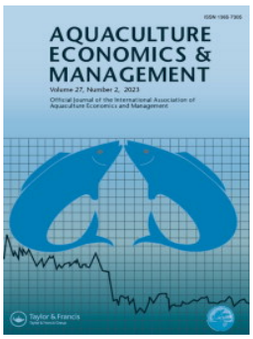

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TECHNICAL REPORT

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High innovation intensity in fish farming: The role of openness in innovation and strategy

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ABSTRACT

The salmon farming industry has since its infancy witnessed immense growth due to innovations increasing productivity. A significant part of the innovations causing the productivity growth has by many observers been attributed to collaborative and open R&D-efforts. Salmon farming in Norway is very research intensive, with a large share of R&D being publicly financed, and with results widely shared and innovations widely adopted. However, in recent years there has been a shift toward an increasing share of R&D becoming privately financed, leading to more closed innovation processes. This paper explores the importance of open innovation in salmon farming and the possible consequences of more closed innovation. The paper shows that openness of the innovations depends on the type of challenge and stakeholder. Innovation is at its most open when common challenges are addressed, like finding solutions for parasites and diseases. Innovation in salmon farming tends to become more closed as the industry consolidates, the larger the firm is and the closer to the market innovation takes place.

KEYWORDS

Productivity; salmon farming; open innovation; R&D

Introduction

Salmon farming constitutes a small part of the world's aquaculture production in volume, but is the second largest species by value after shrimp (Garlock et al., 2020). Salmon farming is a vital part of the world's food supply and is leading in terms of knowledge and technology development (Asche & Smith, 2018; Kumar & Engle, 2016; M. Smith et al., 2010). Globally, all growth in seafood production over the last 30 years has come through increased aquaculture production (Garlock et al., 2020), and aquaculture supplies roughly half of the seafood available. Norway is the largest producer of salmon, with more than 55% of production (Iversen et al.,

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2020). More than 90% of Norwegian salmon production is exported, to around 150 countries (Oglend et al., 2022).

The growth of production to around 1,6 million tonnes a year relies heavily on innovation. In a high-cost country like Norway, productivity needs to be high. This has made salmon aquaculture a research and development (R&D) intensive industry (Bergesen & Tveterås, 2019). The success of salmon farming can be attributed to an increasing degree of control over the production processes that has been facilitated by innovations in biology, technology, organization, products and marketing (Anderson, 2002; Asche, 2008; M. D. Smith et al., 2010). With systematic breeding, salmon grows faster (Aarset & Borgen, 2015; Harvey et al., 2016); with effective vaccines the large disease problems are solved (Ma et al., 2019) and; with better feed and selective breeding, both faster growth and more efficient feed utilization has been obtained (de Verdal et al., 2018). Improved knowledge and equipment have also led to an increased scale at the farm level as well as the company level (Afewerki et al., 2023; Asche et al., 2013). Still, there are several negative environmental externalities, affecting the entire industry (Asche et al., 2022; Hersoug et al., 2021; Osmundsen et al., 2020; Pincinato et al., 2021) that warrants joint efforts from the entire industry to be solved.

Early development in salmon farming was based on trial and error, but also on cooperation and sharing of knowledge (B. Hersoug & Holm, 1992). Cooperative arrangements between companies have been studied, since cooperation is often used for mitigating shared production risks, motivated by reaping the benefits of collective action (Osmundsen et al., 2021). As companies were allowed to grow larger after institutional change in 1991 (Aarset & Jakobsen, 2009), increased consolidation and stock-listing, and with more in-house specialized knowledge (Iversen, 2007; Straume et al., 2022), the aquaculture industry in Norway became the center of extensive innovation with a high R&D intensity. Much of the funding is channeled through public R&D institutions; to obtain funding for innovation projects and gain access to public R&D-spending thus requires a certain degree of openness. On the other hand, privately funded R&D are recently outgrowing publicly funded R&D (Rørstad et al., 2021), allowing for a closing of innovation processes, and perhaps slower diffusion of innovation. While there is consensus in the literature that innovation-driven productivity growth has been vital for the aquaculture industry (Bergesen & Tveterås, 2019), there have been few attempts to study innovation processes in aquaculture (Kumar et al., 2018), apart from studies on adoption of aquaculture technologies (Kumar et al., 2018, 2021) and technology adoption from other industries contributing to innovation and increased scale in aquaculture (Asche et al., 2018). Bergesen and Tveterås (2019) studied patterns of innovation quantitatively, focusing on factors that influence firms' probability of

cooperation with organizations in their innovation processes, and on factors which influence firms' probability of innovation. They call for a deeper understanding of the nature of innovation practices in the industry. We answer this call by studying how openness in various forms of cooperation contributes to innovation in salmon farming. We thus ask: How and why are firms practicing openness in salmon farming? Our focus is hence on openness regarding innovation, in particular cases where innovations might lead to new products or new processes to improve productivity, and on how innovations diffuse to the entire industry through openness.

The literature on open innovation (Hossain, 2013; Natalicchio et al., 2017; Öberg & Alexander, 2018), and open strategy (Hautz et al., 2017; Sunner & Ates, 2019; Tavakoli et al., 2017) sheds light on how openness occurs across firms, which in turn might benefit entire industries. The salmon farming industry is well suited to study the role of openness for an entire industry, since salmon farming is relatively young, globally expansive and innovation intensive, with a history of collaborative development efforts and extensive open public R&D programs. It is also an industry with common challenges calling for joint action (such as parasites and disease), although with strong competition, normally suggesting more closed innovation practices.

The article proceeds with a contextual setting of the industry, presenting the growth, productivity increase and innovation in salmon aquaculture, before theorizing on open innovation and strategy is presented, forming a lens to view openness in the aquaculture industry. Next, we describe the research setting of the Norwegian aquaculture industry, with its high R&D intensity and large share of public funding, where collaboration and openness characterize the industry, by using secondary sources and statistics. Thereafter, we present our industry exploration with 32 different actors in the value chain. Findings related to how openness is practiced is exposed, ending with a framework on closed, inbound, outbound and common innovation and strategy, followed by findings related to why openness is practiced, exposing three important drivers in the industry. Our findings are then discussed in relation to existing theory with our main contributions of common solutions for innovation and strategy in the industry as well as how closed innovation and strategy occur. We conclude with implications for the industry and for politics, as well as needs for future research.

Innovation and productivity in salmon farming

Norwegian salmon farming has experienced a strong and persistent growth from its start in the early seventies until 2012. Since 2012, the volume produced has been relatively stable, with moderate changes from year to year

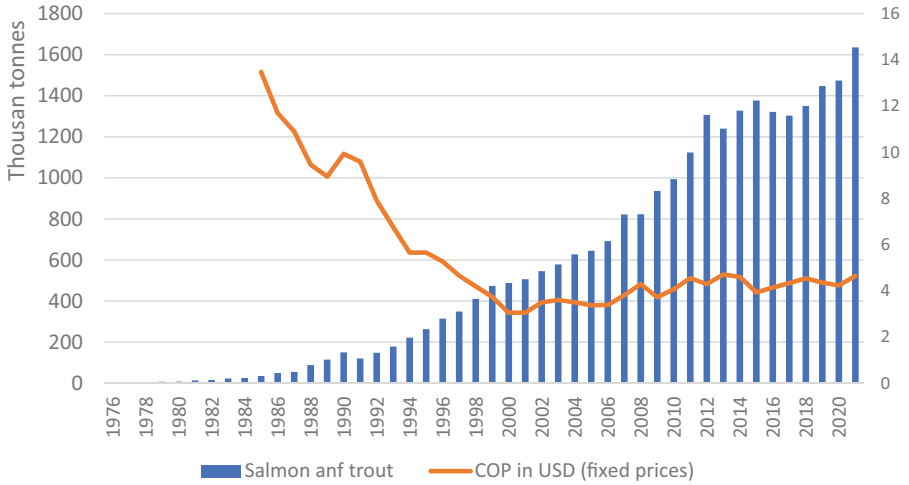

Figure 1. Production of salmon and trout in Norway, thousand tons (WFE, bars, left axis). Production cost (HOG, packed) for salmon in Norway (USD, fixed prices, 2015 = 100, red line, right axis).

but with a certain increase in the last years (Figure 1).[1] Production reached around 1.65 million tons of salmon and trout in 2021, of which just 89,000 tons were trout.[2] Globally, Norway is the largest producer of farmed Atlantic salmon; the production constituting around 50% of the world production of farmed Atlantic salmon (Iversen et al., 2020), and it is a highly profitable industry (Sikveland et al., 2021). Much of the innovation and industrial practices of salmon farming stem from Norway, with global expansion to locations like Chile, Canada, Scotland, the Faroe Islands, Iceland and Tasmania, as well as to other species (Asche & Smith, 2018; Kumar & Engle, 2016; Afewerki et al., 2023).

Until 2005, the industry experienced what seemed quite normal for a new and growing industry, a quite steady reduction in cost as production increased, as shown by the red line in Figure 1. The increase in cost in the early 90s was due to disease challenges, with growth picking up speed again after resolving some of these issues (Asche et al., 1999). Production cost in 2005 was down to 23% of the cost in 1985. With the subsequent stabilization and then increase in cost from 2005 to 2020, the cost in 2020 rose to 42% of the 1985-cost. From 2005 to 2012 much of the cost increase was due to increasing feed prices, while the cost increase since 2012 is found to be heavily affected by measures to prevent and treat for salmon lice (Abolofia et al., 2017; Iversen et al., 2017).

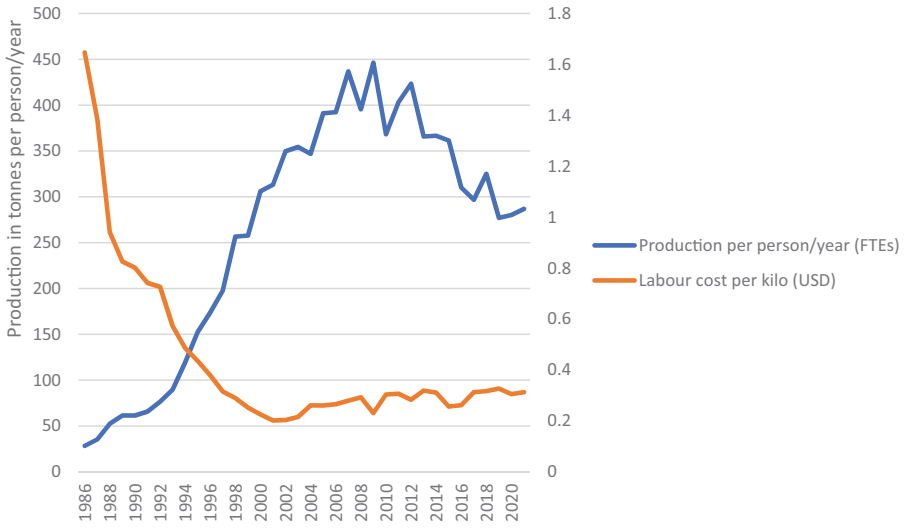

Figure 2. Labor cost per kilo salmon produced (USD, fixed prices, 2015 = 100) and production per person per year (tonnes).

Productivity trends

Most productivity studies are based on data from shorter time periods, but using data from Norwegian Directorate of Fisheries,[3] the long-term development in productivity may be shown by two simple but very illustrative measures of productivity: labor cost per kilo produced and production per person/year (Figure 2). Labor cost per kilo was at its lowest in 2002, at USD 0.2 per kilo, after a long period of growth and increased productivity, which took labor cost down from almost 1.65 USD in 1986 (fixed prices, 2015 as base year). Labor cost rose markedly again in later years, reaching USD 0.32 in 2018, before dropping gently toward 2020. Production per person was at its highest in 2009, after increasing steeply and quite steadily since 1986. Since 2012, production has been quite stable, with some new increase from 2019 to 2020; the reduced production per person is due to an increased use of labor. While the number of employees more than doubled from 2009 to 2020 (an increase of 142%), increase in production was just 57%.

The reduced productivity occurred despite continued efforts to develop technology and production practices, with increased automation (handling of dead fish, for instance), improved control (good underwater cameras lead to less feed waste) and remote feeding (many locations might be fed by a few specialists in an onshore, central location). The increase in productivity from a range of these innovations seems weakened by external factors outside of individual firms' control, such as input prices and environmental conditions related to disease and parasites, leading to reduced biological performance and increased labor input (Iversen et al., 2017; Rocha Aponte & Tveterås, 2019).

The industry's productivity growth shows that innovation has been high in salmon farming, but also that with decreasing productivity in later years, the need for innovation is still high, particularly to solve challenges related to environmental challenges such as lice and disease. These are challenges that the entire industry needs to resolve, through innovation diffusing to all players. Thus, focusing on this high rate of innovation, or its rapid diffusion, we wonder whether this might be explained by the characteristics of the aquaculture industry, and in particular its openness in innovation activity. We turn to literature on open innovation and open strategy to use these insights to view empirically how such innovation diffusion might take place in practice.

Open innovation and strategy

Open innovation might be defined as "a distributed innovation process that relies on purposively managed knowledge flows across organizational boundaries, using pecuniary and nonpecuniary mechanisms in line with the organization's business model to guide and motivate knowledge sharing" (Chesbrough & Bogers, 2014, p. 3). Opening up innovation processes through "the use of purposive inflows and outflows of knowledge" is aimed at enhancing internal innovation processes and accessing markets while reducing innovation costs (Chesbrough, 2003, 2012), where a distinction is made between inbound and outbound innovation (Bianchi et al., 2011; Chesbrough & Crowther, 2006; Dahlander & Gann, 2010).

Inbound open innovation concerns leveraging the technologies and discoveries of others, and refers to how external sources of innovation can be used internally. Outbound open innovation is about establishing relationships with external others to transfer technologies for commercial exploitation; it is about how firms sell or license out inventions, technologies and resources that have been developed in the firm and how internal resources are revealed externally (Dahlander & Gann, 2010). Both inbound and outbound innovation implies opening up to other firms. However, how different combinations of open innovation can affect an entire industry remains unanswered in this literature. Furthermore, innovation stemming from cooperation and collective processes is not considered, neither how actors use such cooperation strategically, to further their own strategy. As this cooperative aspect is important for the Norwegian salmon industry, we turn to theorizing on strategy and open strategy to identify theory shedding light on such cooperation.

The concept of open strategy is related to open innovation, where open strategy has been considered to balance "the tenets of traditional business strategy with the promise of open innovation" (Chesbrough & Appleyard,

2007). It is claimed that "open innovation is a subset of open strategy: innovation is just one of many kinds of strategy processes increasingly subject to openness" (Whittington et al., 2011). Conceptualizing open strategy with the dimensions of transparency and inclusion, transparency refers to internal and external visibility of strategy information, while inclusion refers to internal and external strategic consultation. This form of open strategy is concerned with enhancing participation and formulation during the strategy process.

Another form of open strategy revolves around the economic sustainability of firms using an open approach to innovation (Chesbrough & Appleyard, 2007) and "addresses an organization's open innovation strategy" (Appleyard & Chesbrough, 2017). Focusing on the dynamics of open strategy, (Appleyard & Chesbrough, 2017) consider when organizations choose to maintain open strategy or revert to a more proprietary and closed strategy approach. In traditional strategy literature, a closed strategy is often considered as the "state of nature," whether focusing on a firm's strategic position (Porter, 1980) or it's control over resources (Barney, 1991).

Appleyard and Chesbrough (2017) find that the lifecycle of markets is the main reason for openness. They discuss how firms may choose to stay closed (to secure profits from proprietary products and services) or to stay open (securing profits elsewhere in the value chain), but more importantly, how and why firms may change their strategy from closed to open or from open to closed. They argue that open strategy may foster faster growth or rapid adoption through involving users in development and that a firm might revert to a closed strategy when growths fall off. They illustrate how the rationale behind moving from closed to open is linked to payoffs for users and business models for capturing value for firms, being user-driven, firm-driven, and market-driven forces. They also find hybrid strategies, where firms use both closed and open strategy depending on the interaction between the firm and the users.

The rationale behind moving from open to closed is argued to be mainly firm-driven or market-driven. The firm-driven forces to go from open to closed strategy is for instance when a firm holds enough technological experience inhouse and does not need resources from its innovation system for successful innovation. Market-driven forces to evolve to a closed strategy are found when markets are large, with few new customers, shifting focus from value creation through openness to value capture with a closed strategy.

Firm-level forces for openness or closedness are related to technological and/or organizational competencies (Appleyard & Chesbrough, 2017). Technological competence of a firm, or the level of knowledge and

experience inhouse for developing an innovation initiative, determines whether or to what degree the firm might benefit from the innovation system. Similarly, organizational competencies, like support systems for enabling an open approach with large participation and high transparency, are vital for the practical openness of the firm.

These insights on closed and open strategy are highly valuable to explore in an entire industry. To explore open innovation and strategy, we use the notion of closed, inbound and outbound innovation together with inclusion and transparency between the actors involved. This perspective helps to understand the importance of the competitive situation for development processes and adds understanding to why firms might want to close their innovation processes. There are few other studies, apart from (Appleyard & Chesbrough, 2017), focusing on ICT and software industries, that have investigated open strategy involving entire industries. Werle and Seidl (2015) expose joint exploration of a strategic topic by companies and suppliers from different industries. We explore open innovation and strategy in one industry, covering the whole value chain of salmon farming, including suppliers of technology, to explore their practices, needs and motivations for innovation.

Research setting

The Norwegian aquaculture industry is at the core of an extensive innovation system, consisting of suppliers and producers along the value chain, as well as public universities and research institutes (Iversen et al., 2010). The Norwegian seafood sector has a high R&D intensity, with a ratio of R&D expenditures to value added of around 12–14%, much higher than the average of 2% for the entire Norwegian economy (Bergesen & Tveterås, 2019). In 2020, Norwegian aquaculture R&D employed more than 2000 people: 817 were found in research institutes and 217 in universities (Rørstad et al., 2021), while more than 1,000 researchers were employed in private companies, with more than 50% of the reported R&D now taking place in the private sector.

Initially, salmon farming firms were small, with limited financial and human resources, their role in innovation most often limited to adopting innovations made by suppliers to the industry and often embedded in the input factors used (Bergesen & Tveterås, 2019). Due to a change in ownership regulations in 1991 (Bjørn Hersoug, 2021) the industry has developed into much larger units including multinational companies (Iversen, 2004), with their consolidation also playing a role for their own internal know-how and role in innovation processes (Iversen, 2007). Suppliers play an important role for innovation. Of the R&D-employees in private firms,

around 40% is employed by salmon farmers and 60% by suppliers (Sarpebakken & Ubisch, 2017).

Traditionally, innovations have been clustered at the start (genetics, feed, vaccines, etc.) or the end of the supply chain (processing/retail) (Bergesen & Tveterås, 2019). More recently, technology and equipment have become the most important research area, and also the area with the highest private share of research (Rørstad et al., 2021). This strong focus on new technology relates to control, monitoring and automation of feeding and other operations, as well as new and improved technology for both prevention and treatment for sea lice. There has been a strong increase in R&D among salmon farmers themselves, but an even stronger increase amongst suppliers (Figure 3).

R&D in the salmon industry is concentrated to the larger firms, with 11 firms employing 50% of R&D-personnel in the private sector. Still, a significant share of seafood companies has access to internal R&D resources through dedicated R&D employees, often with education and research training from Norwegian academic institutions (Bergesen & Tveterås, 2019). Many of the smaller firms might have one R&D-coordinator, responsible for connection with public R&D and with other firms doing R&D. With the smallest firms, R&D-coordination might be only a part of the responsibility for an operations manager, technical manager, or the like. Aquaculture firms generally have a low rate of product innovation, since most operate in a bulk market for salmon (Cojocaru et al., 2020). They are also found to have a low rate of radical innovation, since their general technology has not changed much over time and is widespread and well known. Aquaculture firms are

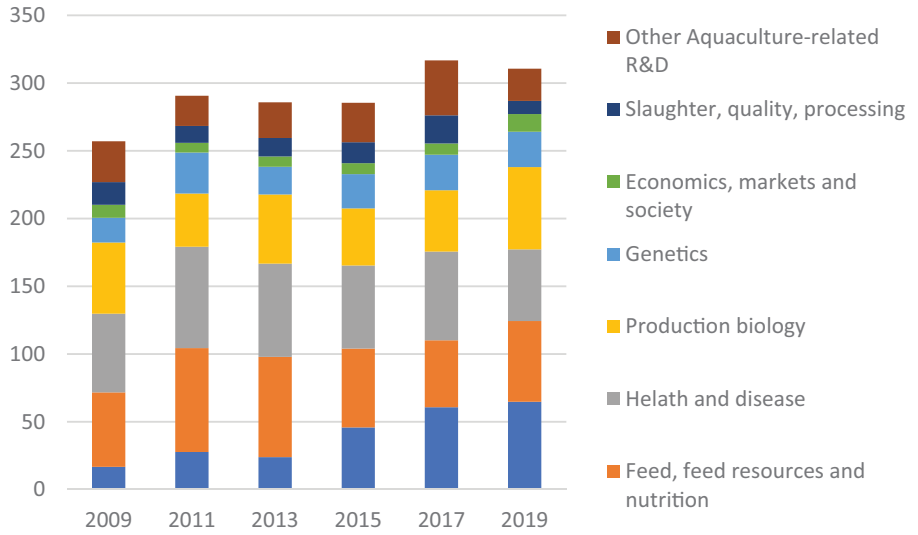

Figure 3. Aquaculture R&D by research area, value in USD. *Source*: Rørstad et al. (2021).

also found to conduct mostly process innovation (Bergesen & Tveterås, 2019), presumably to incorporate innovations from suppliers, or as a result of own improvement efforts. Many producers also have well-organized exchange of advice and best practice between their production units (Iversen et al., 2010).

Public funding, collaboration and openness

The industry is well acquainted with publicly funded and industry-influenced research programs (Iversen et al., 2010). Common development projects, with both public and private funding has been quite common in the Norwegian food industries, with a history of research and innovation openness going back almost a hundred years.[4] In aquaculture, a main motivation for forming the The Norwegian Fishfarmers Union (Norske fiskeoppdretteres forening, NFF, now part of Sjømat Norge/The Norwegian Seafood Federation), was knowledge diffusion, in addition to lobbying toward government (B. Hersoug & Holm, 1992). The Aquaculture Producers Union placed great emphasis on training and information for members. They received financial and professional support from, among others, the Norwegian Directorate of Fisheries and therefore had the opportunity to hold courses and lectures for the members, where the manuscripts were subsequently freely distributed to the fish farmers (NOU, 1977). Sales of salmon was then organized through The Norwegian Fishfarmers Sales Organization (Fiskeoppdretternes salgslag/FOS), a sales monopoly that also funded research and a breeding program (Aarset & Borgen, 2015).

With publicly funded initiatives and projects, most of the results are publicly available. In these publicly funded projects, firms meet in working groups, planning and prioritizing among projects, in reference groups or workshops through the projects, and they often play host to field trials. Access to public financing of R&D thus implies a degree of openness.

Firms do of course vary in their characteristics, and in their propensity for being open in their innovation processes. Firm size is shown to be positively related to cooperation with R&D institutions (Bergesen & Tveterås, 2019). They also found that internal R&D capabilities have a positive contribution to the likelihood of innovation. Firms with internal R&D employees can mobilize external resources in innovation processes to a much greater extent than firms not having internal R&D employees, leading to a much higher rate of collaboration. Collaboration with external academic institutions was found to yield a smaller contribution than collaboration with firms "in the value chain" (Bergesen & Tveterås, 2019).

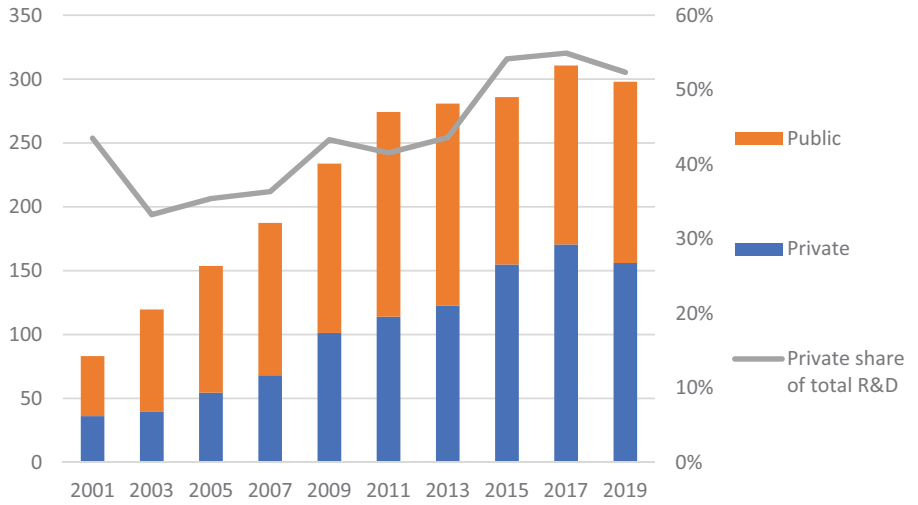

Figure 4. R&D-spending in Norwegian aquaculture (USD, fixed prices, 2015 as base).

Based on data from (Rørstad et al., 2021),[5] we find that by 2015 more than 50% of the R&D-funding is funded by private firms, with the share of private funding reaching 55% in 2017. Public R&D-spending in Norwegian aquaculture is still high, and it is and increasing, but private spending increases even more. With the share of private spending increasing, it is important to explore whether this indicates more closed R&D and innovation. This is partly incentivized by government sponsored innovation schemes such as the so-called development licenses where a designated type of licenses were made available for development projects, but which also allowed increased production (Osmundsen et al., 2022) (Figure 4).

Thus, salmon aquaculture is research intensive, innovation is still to a large extent publicly financed and open, but private R&D increases more than publicly financed R&D, increasing the share of private R&D. We used secondary sources and statistics to expose the innovation in the industry and to demonstrate the characteristics and changes in industry R&D-effort. To explore this shift toward privately financed R&D and other factors that might combine to reduce openness and cooperation in innovation, we conducted in-depth interviews to obtain a deeper understanding of the innovation practices in aquaculture.

Data material and research methods

We conducted semi-structured interviews with 32 different firms within the salmon farming industry in Norway, representing different positions in the value chain, with large variation in size and scope, and with varying R&D

and innovation capabilities. Firms were both producers and processors of salmon, as well as suppliers to the industry.

Interviews were conducted as part of a project examining the role of publicly financed innovation schemes relevant for the seafood industry,[6] including publicly financed industrial research, tax schemes supporting innovation (Skattefunn)[7] and business development (Innovation Norway). The project was financed by FHF (Norwegian Seafood Research Fund). FHF is financed through a tax on seafood exports, implying open results and public dissemination. Openness, open innovation, cooperation or challenges with openness of some form was therefore an important aspect of these interviews. Projects financed through Innovation Norway or Skattefunn are firm-specific, and although publicly funded, firms have no obligation to share these results.

Interview subjects were recruited by us, based on an overview of persons previously or currently involved in FHF-financed projects. Involvement ranged from taking part in reference group once or twice a year to taking active part in shaping the projects and hosting field trials among others.

The on-site visits and interviews first focused on the company, the overall strategy, competence and learning needs as well as their innovation focus. Thereafter, we asked the informants to highlight one innovation project that they found particularly successful and then another project that they perceived as not that successful. The reason for inquiring about successful and unsuccessful projects was to be able to uncover the practices that they themselves found important or detrimental for successful innovation. We asked about sources of knowledge and sources of financing for innovation projects, focusing on public sources of innovation funding (implying openness and cooperation). We also inquired about the optimal conditions for innovation, and what kind of innovation would fit their strategy and innovation needs. Many of the projects discussed was funded by FHF.

We also conducted one workshop involving 10 representatives from the industry to investigate common innovation needs and challenges regarding open innovation, and three group interviews involving a total of 13 actors to delve into the research findings for validation. Results were presented and discussed, and participants were given the opportunity to confirm, reject or elaborate on our findings.

The empirical data gathering followed the ethical guidelines of the Norwegian Center for Research Data. The interviews were recorded and transcribed, and the authors translated the quotes used.

The data analysis was an iterative process with different rounds of coding, contrasting and comparing both expected and emerging themes with existing literature and theoretical concepts. The empirical material was examined in relation to the research question, being both inductive and theoretically driven processes. The coding steps were as follows:

The first step coded according to where in the value chain the different firms were positioned, whether the firm had an innovation strategy, whether innovation projects were radical or incremental, whether the innovation projects came from internal or external initiatives, external collaboration if any and strategic reasons for innovating and collaborating externally. This first step used a large Excel sheet to have an overview of all the firms. This first round enabled us to focus on the relevant data on openness.

Second, concepts of inbound and outbound open innovation and inclusion and transparency were then taken as analytical points of departure and used to uncover the forms and degrees of openness practiced in different parts of the salmon value chain. It became clear from the early interviews that openness differed through the value chain, producers were far more open on issues related to production at sea than processing or marketing. This knowledge enabled us to explore these differences at more depth in the later interviews. These nuances across the value chain were also different from prior work on openness (Appleyard & Chesbrough, 2017). Third, we thus identified a new category of open innovation and strategy that did not fit into inbound/outbound, since the actors found solutions together, often working with public or industry funding. We labeled this category *Common*.

To explore why firms would enter open innovation processes, we went a step further, exploring the drivers behind closeness or openness (in Section "Findings: how openness is practiced in the aquaculture industry"). This interpretive step enabled us to find the three drivers (solving common challenges, shifting focus from production to market and, increasing in size and complexity) explaining the dynamics and tensions involved in the various forms of openness.

Findings: how openness is practiced in the aquaculture industry

Our findings show marked differences in both real and perceived openness between firms, depending on size, position in the value system and attitudes toward openness. Before exposing the different aspects of openness, we describe findings related to closed innovation processes. Thereafter, we expose inbound and outbound innovation, followed by a third category of openness that we found, which we denoted Common challenges.

Closed innovation

Some suppliers to the fish farmers tend to keep their innovation challenges and processes closed, as exemplified by feed companies, pharmaceutical companies providing vaccines and treatment for sea lice and equipment

providers. These suppliers provide alternative solutions, with intense competition as a result.

Feed constitutes more than 50% of the production cost for salmon, and as feed is vital for both the biological and economic performance of salmon production, feed companies have feed with a competitive edge. Informants from feed companies describe their industry as closed, but also one where innovation is quickly picked up and copied.

> The feed industry is relatively closed.
> There are a lot of secrets.
>
> But I have seen that innovation go faster; competitors get the knowledge a lot quicker. In the old days we might be the sole supplier of something for a year, two years, three years. But now the knowledge, not all, but much becomes publicly available, and competitors receive insights much faster than what happened before. (all three quotes from feed companies)

Other suppliers to the fish farmers are also stringent as to what they share. As one manager within a large fish farming company explained:

> Regarding the development of vaccines and treatment methods, the pharmaceutical industry is extremely closed.

In the sea-phase of fish farming, that is generally more open, we identified a few areas that might be closed to competitors, such as certain parameters influencing production and productivity, for instance feed content and feeding practices. An informant explained,

> We have things that we hide; both in terms of production and feed. How do you feed the fish, once or all day? And how do you use the light and what do you have in the fish feed? We do not manufacture [the fish feed] ourselves, but we are big enough to ask for our own recipes. We have no palm oil in our feed for instance … How we feed the fish and what's in the fish feed - that's closed (salmon farmer).

Furthermore, the closer to the consumer product the innovation takes place, the more closed the innovation processes tend to be. One manager explained how generic areas are noncompetitive and open, while competitive areas are closed:

> We have several areas, or many areas, that are defined as generic, or non-competitive. Fish health is typically non-competitive. Competitive areas are mostly when the fish is dead. Then cooperation starts to get a little touchy (fish farmer).

This seems to be a common attitude. Still, there is also a certain degree of cooperation on marketing of salmon, through the Norwegian Seafood Council. For marketing of salmon, we find some of the same ambiguities as regarding R&D. There is a publicly financed generic marketing, making it easy to market your salmon as Norwegian salmon, but which might also make it harder to differentiate from other Norwegian producers (Cojocaru et al., 2020). Likewise, while all producers benefit from more

knowledge on how feed content affects growth or disease resistance, producers might want to use feed content for differentiating their salmon (Cojocaru et al., 2020).

Even though the general notion of the aquaculture industry is of an industry characterized by openness, closer scrutiny reveals important areas of closedness. A range of competitive parameters are decided internally, as for instance production methods (like feeding regimes) are quite well hidden from competitors. Innovation processes are characterized by *exclusion,*[8] and internal practices are not revealed, these we may consider *covered*. Thus, we find that the degree of openness is dependent on the position and the role in the value chain.

Inbound innovation and strategy

Even though several of our informants point to a trend toward closing of the innovation processes, we still found important areas of openness. Inbound innovation and strategy often start by mapping the need for competence, and then combining existing knowledge on one's own competence with an overview of what knowledge is available externally. This would be a driver for starting innovation projects or involving external actors, as one fish farming manager explained:

> Our R&D strategy is laid out based on which subject areas, which knowledge gaps we actually have. And what kind of expertise we need to achieve our goals. Then we start a project alone, or with external partners based on closing those knowledge gaps.

An important driver for fish farming companies to take part in innovation projects with competitors was thus found to be a lack of knowledge internally in the companies:

> Lack of competence internally is an important driver for joining research and innovation projects because then we do not need to build all the knowledge internally.

Much of the needed competence is found in publicly funded research and innovation projects where participants also from competing companies form part of the reference group of a project. One innovation manager from a large fish farming company explained,

> We are there to build competence - in the reference group. I asked to be in the reference group and they [the competitor and the public funding agency] say that you are certainly allowed to do so. Such a project is often about continuing innovation processes and findings from one project to something new.

Although all reports from publicly funded projects are made available, information might be hard to find or overwhelming in its immensity or complexity. Being an active part in a research and innovation project means that one will get access to knowledge before the project has ended.

Thus, taking part in reference groups might give more timely access to results, and it might be an arena for discussing and understanding results:

> The projects often have dialogue meetings, and it works very well, because then we get insight into what happens in the project.
>
> The projects are not fully open until they have reported. Therefore, we must join the project groups or reference groups. And that's another point. With a project lasting for two years and you're not in the reference group, then you get almost no info before it is finalized (both quotes from fish farmers).

Regarding the inbound innovation, we find that salmon farming firms acquire competence from knowledgeable firms, when solutions are commercially available, or they source knowledge through cooperation, *joining* common projects, either as direct partners or in reference groups. Many firms have a good *mapping* of their needs and competences and are using this mapping actively to influence the direction or priorities of common industry projects, to fit the organizations' own needs.

Outbound innovation and strategy

We find that players in the value chain also have different policies for openness. Regarding open strategy, one fish farmer explained that part of their open strategy was to push the boundaries to become world leading in given areas, together with suppliers, using them in external strategic consultation:

> … We also built the world's largest well boat (at that time). It was a hairy strategy. Or the freezer. That was madness. So, this new project is less insane than that. It is bigger, but we have grown bigger. Obviously, that is what drives some development in the industry. And to work with others has been very important because we have met some suppliers in a different way; we sit down, discuss and solve issues in common.

Outbound strategy making was also found as firms were inclusive and worked to solve challenges together, but at the same time, it was evident that openness would have a limit. When the new common knowledge was reached, discussions on how to implement it, or adapt it to the firms' own strategy, would be kept within the firm, closed to the competition.

> So, we have a challenge concerning black spots or areas in the fillet, Melanin. It's such a typical balancing act. For everyone has it and no one understands why they get it. But regarding how much we have and what we do with it, then the blinds are down. But with nutrition, vaccines, viruses it is open. We have been through all tracks, then we run large open projects. To find the cause. But how we handle it, internally and with customers and all, that is something that is closed (fish farmer).

The degree of openness also seems to depend on the role or position in the organization. Different attitudes toward sharing might be found within firms; while top management might emphasize the strategic benefits of possessing information or worry that sharing information might lead to loss of a competitive edge, workers at lowers levels, site managers and operators, are still exchanging information openly with neighboring firms.

> The largest firms are very restrained in exposing and talking about what they do. At lower levels in the organization, they are still interested in talking to others. But at the top it is very restrained. "We will not exchange information; we will not be caught collaborating. In any way." And some are a little scared, after being accused of exposing too much (fish farmer).

Thus, salmon producing firms might share their innovations through selling information or solutions (which does not seem to be very common), or through revealing their solutions to other firms (which seems to happen more often). Even more often, they will be involved in *solving* challenges together, or *showing* possibilities and exhibiting solutions. This way, the entire industry might gain transparency through external information flows.

Common challenges and collaborative solutions

For challenges involving the entire industry, such as lice prevention, disease and knowledge about environmental impact, we found collaboration to be widespread and wide open.

> If the neighbor gets the disease, you can be sure that you get the same disease in 14 days. So, we are together on these issues. Lice is another good example of how we work a lot together (fish farmer).

As one said with wit:

> We live in a common world where we enjoy ourselves with lice. Lice is a huge challenge (fish farmer).

There are many different innovative projects to fight salmon lice, with operational exchange between actors for lice problems, affecting both the health of farmed salmon and wild salmon stocks. As two fish farming production managers explained regarding their views on openness and salmon lice:

> For salmon lice, everything is open, there are no secrets.

> We are as open as we can, and we tell how things work at our sites and get the neighbors [other fish farmers nearby] to collaborate on lice and it gets easier for us. I really feel that there is great openness around these kinds of things.

Learning is also facilitated through open reports, and through publicly available data on lice and disease incidents. This openness works both through R&D, through public online reporting and through exchange of more informal or experience-based knowledge. Our informants identified common innovation projects involving industry, research institutes and governmental actors for R&D projects for environmental monitoring for instance, where fish farmers play an important role in R&D, collecting and sharing data:

> We have a project we started since we had a lot of trouble a few years ago regarding environmental monitoring. And launched a large nutrient salt registration project. And it has been a success and the whole point is to agree on a methodology, and then gather information and methods that the researchers agree on to be the state of the art. And then we gathered information that is available to everyone from here into eternity (fish farmer).

There are also fish health networks involving all or most companies to find innovative solutions together through sharing knowledge and experiences.

> We do have the Fish Health Network, where we meet regularly for a review, where we talk about our own fish and very often how much or how little lice the fish have, and any other diseases, or if something has been discovered or someone has found something (treatment or preventive measures) that does work or not. Then we share.
>
> Veterinarians are also present, all actors are present, and we discuss rules and limits. We are trying to make a system to inform each other and are up to date on what other companies have done, specifically in terms of lice (both quotes from fish farmers).

We also found that veterinarians and fish health experts working with several firms play an important role in building a common pool of knowledge, spreading both formal and experience-based knowledge. They contribute to adoption of new technology and diffusion of innovation. As one informant summed up in relation to collaborative strategy and common open innovative solutions versus individual closed products:

> It is perhaps the most important competitive advantage we have in Norwegian fish farming: It is a collective solution to the problems. The fact that we are open to each other and that we share experiences. We acknowledge that we affect the neighbors' results, and they affect ours. And therefore, we must work together to find solutions (fish farmer).

Thus, we found that salmon farmers are very open on matters regarding common challenges, like mortality, disease and parasites. These common challenges are mostly found in the sea-rearing phase of salmon farming. We find a growing awareness of the role of openness, and of the virtues of cooperation versus competition. Some have even started to denote the early stages of farming the "pre-competitive phase".

Innovation in the salmon farming industry relies heavily on common innovation projects. Firms are searching for commercially available knowledge, like solutions to illness (vaccines, for instance) and they network to find or develop common solutions (in Fish health networks, for instance). They *collaborate* in R&D-projects to solve joint problems, and they *monitor* and share information for the exploitation of common solutions (for instance preventing and solving lice and disease issues).

We thus answer the first part of the research question of how firms are practicing openness in salmon farming, exposing the differences between closed, internal, external and common in relation to inclusion and transparency (table 1).

Why openness is (or is not) practiced in the aquaculture industry

Having exposed *how* firms practice openness, we turn to *why*, and thus the different motivations for keeping innovation processes open or closed. For suppliers to the industry, who in the past have been less open, it seems that the competition between them warrants even stronger efforts to protect their own knowledge, and their own competitive position. They might still share some information but seem generally more closed. Regarding the aquaculture producers, our main finding is that while they have been very open, and still is when trying to *solve common challenges*, they too are increasingly closing, when the situation warrants it. Not only by maturity or by obtained growth, as found by Appleyard and Chesbrough (2017), but also by:

- Shifting focus from production to a more market-driven production
- Increasing in size, complexity and internal competence

These three drivers add understanding to why firms are practicing openness differently, answering the last part of our research question.

Table 1. Forms of openness in an industry, combining concepts from open innovation and open strategy literature.

Innovation and strategy	Closed	Inbound	Outbound	Common
Inclusion *(examples)*	*Excluding* Others, also internally	*Joining* Project	*Solving* Challenges together	*Collaborating* Both private and public actors
Transparency *(examples)*	*Covering* Internal practices are not revealed	*Mapping* Needs and competences	*Showing* Possibilities and exhibiting solutions	*Monitoring* Lice and disease issues

Solving common challenges

While many companies still are very open, even those that are most prone to closing are distinctly open in one situation, namely when focusing on solving common challenges. Salmon aquaculture faces a range of common challenges and problems, some of which benefit from common efforts to solve them, such as vaccination programs, monitoring of environmental parameters and new diseases. One fish farming manager described well how a cooperative effort was initiated:

> The amoeba is called AGD. And … it appeared in Norway. And then within a couple of weeks, we went together to an international meeting in Scotland. For the Scots also had issues with this amoeba. The entire industry went, I think we were about 150 people or something like that, very big meeting, to talk about how the Scots had handled it. What can we learn from them? What questions do they have that they have not found an answer to? Then we sat down from aquaculture companies and took notes of procedures and details around it. These are the challenges we have, and the answers we are missing. And the pharmaceutical companies were there, the breeding companies, public agencies … We were at the airport, and we sat on the bus and discussed what questions we would like to have answers to as soon as possible. Then we agreed on it, so it was, yes where can we get these trials done. All trial capacity was already booked. In this case it was another fish farming company who said: "Well we should start an attempt now at our Lab, we just postpone it we have the fish and the guys available for this project." So, it happened extremely fast, and it was an extreme dynamic and there were never questions about the costs; the money was put on the table, and it was actually the aquaculture companies who guaranteed the amount and then we found financing afterwards.

Other challenges rely on common efforts by all actors to be solved, as noncompliance weakens cooperative effort by those who comply (Osmundsen et al., 2021). Such challenges might for instance be delicing, fallowing of sites and transferring of smolt to sea.

Shifting focus from production to market

Most producers in Norway operate in B2B-markets, producing mostly whole, gutted salmon, or only slightly processed products (fillet). A few producers produce value-added-products, and even develop their own brand. We find that firms openly cooperate on many issues related to primary production (technology, biology, disease, etc.), while they are closing their innovation efforts and strategies as products near market. Processing, including use of differential technology, limits openness, although producers cooperate on specific projects. These projects are focusing on building competence for the project participants. Closer to market,

where customer relations and customer-specific products are involved, openness is very limited as described by the following quote:

> You will find an incredible amount of our products in the stores. But that is a closed room, for competitive reasons. (fish farmer)

As firms grow larger, they are differentiating themselves in the marketplace by building a brand, which in itself calls for closing.

> We sell branded salmon. With special quality, we do things differently during slaughter and in the process that makes the fish become on average better than other fish. So, we sell under a brand called x. As a concept. (fish farmer)

This closedness of innovation effort and strategies at firm level is striking especially since all Norwegian aquaculture firms benefit from worldwide generic marketing performed by the Norwegian Seafood Council. Some producers sell their products just as "Salmon from Norway", while other combine their brand and the focus on origin.

Parallel to the value chain we find suppliers at all stages. A lot of the innovation in salmon farming takes place with suppliers, be it suppliers of technology, vaccines or feed. A general finding regarding suppliers is that they find themselves in a very competitive environment, fearing that sharing might jeopardize their position. We find indications that suppliers follow a similar development of salmon farming in general, since suppliers might be very open as problems are new and common to the industry, while they close as technology mature, and competition increases among suppliers.

> We saw the same thing with cleaner fish, it was full transparency to begin with, but when the technology matures, the information sharing stops. (fish farmer)

Seen from the supplier perspective, large and the small fish farmers may also have different interests in cooperation:

> The largest fish farmers are much more interested in being involved and looking ahead than the small ones are. For the small ones are not willing to take that cost, or even to be the guinea pig. They want to buy a finished product that works, while the big ones have both the resources and the expertise to work with us, they are much more interested in being the first. (supplier)

Innovation for fish farmers stemming from their suppliers expose openness in two dimensions: first, openness in the relations between suppliers and producers, and second, the role suppliers play in diffusion of innovation, bringing knowledge and experience from fish producer to fish producer. For the producer (fish farmers), it is a question of how open they are toward their suppliers. In many cases, it is taken for granted that a supplier should not disclose information from one producer to another; in other cases, there seems to be a common

understanding that a certain knowledge-sharing and information diffusion is necessary for the common good, spreading best practice. We therefore find differences of openness across the value chain, but also across the entire system. The role of the suppliers in the system for innovation and strategy is highly important.

Increasing in size and complexity

Size might be the most important explanatory factor for closedness; not size in and of itself, but rather other characteristics that are associated with size, like complexity, organization, ownership and internal competence. Signs of closing are probably most easily observed from the perspective of smaller firms:

> And there is a danger as the companies grow bigger. They are becoming increasingly closed and do not want to share their knowledge. Best practice, "we will have best practice, but we do not want to share it with the neighbor". And I think you then inhibit yourself, because it's not about competing with the neighbor, it's about competing in the world market to supply the best fish. A good product. Which everyone wants. (fish farmer)

The largest firms are listed on the Oslo stock exchange, which affects their ability to share information that might be stock-price sensitive. There seems to be a cautiousness, a fear of sharing too much, that has increased over the last few years, as some of the major salmon farming companies have been under investigation for price cooperation.

> It has become worse, and it's because of the listed companies. Some are afraid of accusations from the EU about cartels and cooperation and such things and use it as an argument for not participating in projects, and sharing, and so on. (fish farmer)

Through consolidation in the industry, the size of the largest firms has increased, opening for specialization within the organization and giving room for employing competence in-house (Iversen, 2007), thus becoming more self-contained. Increasing size also implies increased probability of finding dedicated R&D personnel within the firm.

> We are organized with a parent company, which I work in. And there are ten employees. The remaining 2000 employees are employed in subsidiaries. We coordinate the projects. We have a fish health officer; there are three of us that work with R&D. We should know about everything, coordinate everything, and then we use a lot of the people from our subsidiaries in reference groups, management groups or project groups, depending on what kind of project it is. (fish farmer)

The largest producers have their own R&D departments. This might explain what seems to be different attitudes toward sharing. Knowledge on technology, biology, diseases, and feed are all found within the different

larger firms. A small fish farmer explained about the large fish farming companies:

> They have a slightly different need. For they have built up a larger organization themselves … The knowledge base is very important. Larger companies may often want to conceal information.

An important effect of the increased knowledge is that larger firms tend to be more conscious about their specific needs, and that they take part in common projects quite selectively. They might not want to participate in projects on some topics, since they have inhouse experts and knowledge. And they are keen on influencing the focus of other projects, regarding topics where they know a lot already, but are in need of specific results or specific tests to be carried out and so forth.

> *The FHF (Norwegian Seafood Research Financing) is an important instrument that we use a lot. And it is a relatively simple approach to promote issues and apply for projects. It is. (Question: Do you do that a lot?) Yes. A lot of projects. These are projects that we do not necessarily need to keep internally. Then we first think of FHF; if our research needs are in line with to the action plan of FHF, we often ask FHF to join and contribute (fish farmer).*

The implication of growing firms and increased inhouse expertise is that even if firms in the industry are interested in the same topic, they might want different projects, as their base knowledge is different. Some of the large firms also seem to be the ones in command, turning the focus of common research project in their direction.

Discussion

In this paper we investigated how and why aquaculture firms practice openness in their innovation processes. We found that openness and sharing of information and knowledge has been common among producers in the industry, while less among suppliers to the industry. Common and publicly financed R&D-projects, along with a need to solve common challenges, keep innovation processes open. Common challenges are characterized by requiring open and collaborative solutions between all the players involved, often between actors from all parts of the value chain or all actors involved in a regional area. This implies some sharing of knowledge and resources, to obtain the common benefits. Our two contributions are related to common solutions and closed innovation and strategy.

In existing literature on openness in innovation, there is little research investigating actors in an industry, although Werle and Seidl (2015) expose joint exploration of a strategic topic by companies and suppliers from different industries. By exploring how openness for innovation occurs among actors in aquaculture industry we found *common* solutions which is our

main contribution to theory. Common solutions are different from closed, inbound and outbound innovation and strategy since it involves collective searching and networking through collaborating and monitoring. Common solutions and openness have been beneficial to the industry. Openness has resulted in the ability to solve problems more efficiently. Common knowledge, and a shared understanding of complex phenomena, has contributed to coordinated action. For the industry, openness is generally acknowledged to be instrumental in solving joint challenges, such as finding methods to handle diseases and parasites. This was confirmed by our findings. There is a general motivation for collectively improving the entire industry, increasing the Norwegian competitiveness, compared to salmon producers globally, but also compared to other sources of protein. The costs for firms partaking in joint projects are their own resources spent for a common cause. Another cost of openness is perceived to be the loss of some competitive advantage; that is, if the notion holds that it is the most efficient producers that are the most active In cooperation and knowledge-sharing activities, and that this openness allows competitors some degree of catch up. It seems that those producers arguing for common development believe that they gain more from this openness than they lose. The gain from solving joint challenges seems to outweigh the potential loss of a competitive edge. Common solutions are an extension of existing research on open innovation and strategy.

The second contribution regards closed innovation processes and strategy. Based on our interviews, combined with the fact that privately financed R&D has increased, we find that openness has been reduced over time. Increased size has also motivated firms to develop their organizations with more internal competence, and to increase R&D-spending, reducing the reliance on publicly funded programs, as seen through the increased share of privately funded R&D. This happens at the same time as larger firms focus more on product development and branding, which shifts the focus from cooperation toward competition. Our finding supports earlier work om ambidexterity in openness, as openness were found beneficial in an early, explorative phase, but where processes were more closed toward an exploitative phase (Hafkesbrink & Schroll, 2016). Part of the increased R&D spending is thus also considered investments that should result in increased profitability for the individual firm to pay back the investment. Closed innovation and strategy through excluding internal or external actors or through covering practices by not revealing these, elaborate existing theorizing on open and closed strategy by (Appleyard & Chesbrough, 2017) by exposing how the innovation and strategy is closed.

Our contributions on common and closed innovation and strategy expose important insights with future implications. Open innovation has been important for the industry, while now we find more closed innovation

processes, which may severely hamper the growth of the industry. Closing of innovation processes will affect the innovation capacity of the aquaculture industry in the long term. Our findings suggest that many challenges that need or will benefit from common effort will be solved more slowly, or not at all. And many issues where one farmer's action, or lack of action, will have effects on other farmers, will not be solved in the most efficient manner. Coordinated efforts are needed to solve issues related to disease and parasites, for instance. Diffusion of innovation will also likely be slower, as innovation might benefit only a few, whereas in the early days of salmon farming the objective for cooperation was the diffusion of best practice and new technology.

Conclusion

This paper examined the role of openness in fish farming innovation using Norwegian salmon aquaculture as the case. Although a number of innovations in salmon farming have materialized, like a marked genetic progress, efficient vaccines against important diseases, more efficient feed and improved technical solutions, there are several common problems that needs to be solved, such as parasites, diseases and escapes. Collaboration requires coordinated activity across different parties to address such jointly defined problems. Our findings suggest that openness in innovation processes will still be vital for the continued progress in the salmon farming industry.

The Norwegian government is heavily invested in the aquaculture sector through public funding of R&D, and public infrastructure for R&D projects. Without industry participation, much of the publicly funded research will be of lower quality and have less relevance and impact. The *policy implications* are firstly that policy makers must make sure that openness is sufficient to ensure relevance and impact of publicly financed R&D, through gaining the necessary knowledge for innovations solving common problems, and through diffusing those innovations to the entire industry. Secondly, that the wide variety of firms, with different positions and resources, require different, maybe tailor-made, instruments, tools and incentive structures to accommodate for different forms of openness in innovation processes.

The managerial implications of these findings may depend on the situation of the firm. For both smaller and larger firms, the benefits of openness should be understood and explored. An increased focus on strategies for differentiation in the industry (Cojocaru et al., 2020), might make more firms prone to close their innovation processes. For smaller firms, with limited unique internal expertise, or with limited differentiation efforts, openness will generally be beneficial. For larger firms, with internal expertise, or focusing on differentiation or branding, partially closing innovation

processes might be beneficial. Higher internal expertise of larger firms also make them more responsive to external changes and shocks (Straume et al., 2022); however, larger firms should be aware of the benefits of openness, increasing their understanding of when and how it might be advantageous to close or to keep innovation open.

In the aquaculture industry, the high public R&D spending represents a huge opportunity, for those most able, to take advantage of the access to public financing. An important future research question then is how firms in the salmon farming industry might be able to employ this R&D infrastructure to their benefit, and what resources or what relations are needed. Future research could examine the effects of public spending on innovation collaboration patterns. We also found that larger firms are closing more of their innovative activity, which raises future research questions regarding how size affect inbound and outbound innovation.

Notes

1. Data for figure 1 is retrieved from Norwegian Directorate of Fisheries, https://www.fiskeridir.no/Akvakultur/Tall-og-analyse.
2. Landazuri-Tveteraas et al (2021) provide a review of the role of trout in relation to salmon in Norwegian aquaculture.
3. Data retrieved from Norwegian Directorate of Fisheries: https://www.fiskeridir.no/Akvakultur/Tall-og-analyse/Loennsomhetsundersoekelse-for-laks-og-regnbueoerret/Matfiskproduksjon-laks-og-regnbueoerret, combining tables for production, labor and labor cost per kilo produced.
4. Nofima (Norwegian Food, Fisheries, and Aquaculture Research Institute) is based on five former institutes serving their specific parts of the food industry, with Norconserv (Norwegian canning industrýs research lab) established as early as 1932, then SSF (Fish oil and meal research institute) in 1948, and with Matforsk (Agrifood research), Akvaforsk (Aquaculture research) and Fiskeriforskning (Fisheries and Aq. technology) established in the seventies).
5. Data used for Figure 5 are not to be found in this form in the report; data was supplied by the authors and converted to fixed prices by using a price index (KPI) from SSB (Statistics Norway).
6. Note that the total number of interviews in the project was 55, of which 32 was considered relevant for aquaculture.
7. «Skattefunn» is a rights-based tax scheme, yielding a tax-refund of 20% of a firms R&D costs. The R&D activity in question must be defined/organized as a project, with given goals, activities and so forth, but as long as these formal requirements are met, a tax redemption might be claimed.
8. The terms in italic at the end of each paragraph is summed up in Table 1.

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