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Firms adaptation to climate change through product innovation

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ABSTRACT

Climate change will impose high costs on different societal actors, including firms and organizations, forcing them to adapt to this new situation. Although the relevance of implementing adaptation strategies is widely recognized, studies on firms' adaptation to climate change are still in their infancy, especially regarding small and medium enterprises. Following a multi-stage approach, we analyze how small and medium enterprises in the marine food industry could adapt to climate-induced ocean acidification through product innovation. First, we use a co-production process with the firms' representatives to gain insights into the industry's adaptation opportunities, in which product innovation arises as the preferred strategy. Second, using a Discrete Choice Experiment, we test if consumers value both the mussels' attributes likely affected by ocean acidification (sensory and nutritional) and the proposed new products developed to adapt to it. We also analyze preferences' heterogeneity through a latent class model. Our results show that consumers value the attributes potentially affected by ocean acidification. We found high heterogeneity in consumer preferences regarding product types, disentangled into two classes (non-innovative consumers and consumers willing to innovate). We suggest that the industry could base its adaptation strategy on two pillars: 1) maintain the traditional format, thus satisfying 21% of the market (non-innovative consumers); 2) direct the innovation efforts towards the canned format, thus satisfying those consumers willing to innovate (79% of the market). Although consumers willing to innovate are prone to try new formats, the preferred alternatives are not radical innovations.

1. Introduction

Climate change is one of the most relevant sources of uncertainty in present times (Kundzewicz et al., 2018), imposing high costs on different societal actors, including firms and organizations (Linnenluecke et al., 2011, 2012; Winn et al., 2011). The increase in global temperature likely crosses the 1.5 °C threshold, triggering unknown changes in precipitation, temperature, and occurrence of extreme events (Masson-Delmotte et al., 2018), forcing firms to adapt to this new situation.

This study analyzes how small and medium enterprises (SMEs) in the marine food industry could adapt to climate-related stressors, specifically ocean acidification (OA). We are interested in innovation, particularly product innovation. Using a bottom-up multi-stage approach, we conducted a comprehensive assessment of product innovation as an adaptation strategy to climate change. Our approach includes three stages: 1) firms' characterization, 2) co-production activities and 3) consumer responses to product innovation. The firms' characterization and the co-production activities aim to gain insights into the industry's adaptation strategies, opportunities, and challenges under OA scenarios. These activities inform a consumer analysis – expected responses to the industry's adaptation strategies – based on a Discrete Choice Experiment (DCE). With our approach, we go beyond merely providing a list of potential adaptation strategies. Instead, we assess whether the selected adaptation strategies will be accepted by the market (or by specific segments within the market). Thus allowing (or not) an effective adaptation process for the industry. This paper uses the Chilean marine-based aquaculture industry, a global player in this market, as a case study. Our results suggest that innovation could decrease the vulnerability of the aquaculture industry to the likely impacts of OA.

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We differentiate from the mainstream literature on firms' adaptation to climate change (Bremer and Meisch, 2017; Meadow et al., 2015), as we conducted our analysis following a bottom-up approach based on co-production activities with the firms within the aquaculture sector. Considering that the magnitude of climate challenges is so vast, some scholars suggest that societal actors could develop broader partnerships to reach solutions through knowledge co-production processes (Kruk et al., 2017). In this sense, adaptation strategies will result from a process of dialog among public, private, and civic entities while ensuring a meaningful collective action among them (Ofoegbu and New, 2021). Thus, firms need support from other societal actors for developing effective adaptation strategies because solutions to climate change could come from multiple sources.

Climate change impacts are a cross-industry phenomenon (Tol, 2018). Yet, some sectors are highly dependent on ecosystem services or sensitive to changes in climate conditions, such as agriculture, aquaculture, and fisheries (Galappaththi et al., 2019; Galbreath, 2010), making them more vulnerable to climate change. As a result, there is a growing concern about the ability of the food industry to cope with and respond to threats and uncertainties that an altered climate system may bring (Hasegawa et al., 2018). In this context, climate change is a severe challenge to the food system, threatening the progress toward food security (Fujimori et al., 2018; Wood et al., 2019) and hindering the fulfillment of the zero hunger goal associated with the Sustainable Development Goals (SDGs, FAO, 2016).

Oceans play a twofold role in sustaining livelihoods. On the one hand, oceans are a vital source of food, income, and development for many industries and countries (Keen et al., 2018), with the potential of producing 25% of edible food by 2050 (Costello et al., 2020). Further, marine-based aquaculture is recognized as one of the leading sectors for addressing food security within the ocean food production sector, mainly because it is an affordable source of protein (Bell et al., 2016; FAO, 2018). Moreover, at national, community, and household levels, aquaculture activities contribute to the diversity of food systems and livelihood portfolios, thus potentially helping to enhance climate resilience (Lebel et al., 2021). On the other hand, oceans constitute a barrier to climate change by absorbing CO_2 emissions helping to balance the carbon cycle (Cole et al., 1993). Unfortunately, increasing anthropogenic CO_2 emissions could challenge this balance, causing widespread changes in seawater pH and carbonate chemistry, producing the so-called OA. In this context, OA has been identified as one of the main threats to the marine food industry. It could affect marine seafood products attributes, change its quality, and ultimately affect consumer choices (Gazeau et al., 2013; Ponce Oliva et al., 2019).

This study is built on the emerging literature strand on firms' adaptation to climate change, focusing on the role of product innovation in facilitating and fostering an efficient adaptation process. We contribute to the empirical literature in two ways: 1) providing new evidence regarding adaptation strategies from the firm's perspective in general, and regarding the SMEs in the primary sector in particular, and 2) despite that innovation has been identified as a critical strategy for addressing climate change challenges, most of the studies have focused on innovations for mitigating greenhouse gases (GHGs) emissions. Further, those few studies addressing climate change adaptation highlight the role of technological and institutional innovation, disregarding the role played by product innovation.

Firms can reduce the uncertainty related to climate change impacts by adopting effective adaptation strategies (Fankhauser, 2016). However, although the relevance of implementing adaptation strategies is widely recognized (Eggers and Park, 2018; Sarta et al., 2021), studies on firms' adaptation to climate change are still in their infancy, especially in the management literature (Daddi et al., 2018). Unfortunately, most of the current literature addressing firms' adaptation is focused on the corporate dimension (Linnenluecke et al., 2013) with scarce attention to how SMEs address climate change (Halkos et al., 2018). This is a significant gap in the literature because due to its characteristics, such as size, limited resources, short term thinking, and lack of formal structures (Ates et al., 2013; Smith and Smith, 2007), SMEs are more vulnerable to climate change than large firms. Moreover, despite the primary sector being one of the most vulnerable sectors to changes in environmental conditions, scholars have paid scant attention to it (Linnenluecke et al., 2013; Daddi et al., 2018). Thus, this paper could shed some light on this regard.

Most studies addressing firms' adaptation behavior are related to changes in conditions due to new competitors, political status, or regulations (Afsah et al., 2019; Eisenhardt and Martin, 2000). Yet, there is scarce evidence about firms' adaptation behavior to changes in environmental or climatic conditions (Daddi et al., 2018; Linnenluecke et al., 2013). Previous evidence in this regard includes ski resorts adaptation to changing temperatures (Hoffmann et al., 2009; J. Rivera and Clement, 2019), water and energy sectors adaptation to changes in water supply (Arnell and Delaney, 2006), and food and wine industries adaptation to changes in temperature patterns (Galbreath, 2014; Galbreath et al., 2016), among others.

Regarding innovation, chapter 20 of the IPCC Fifth Assessment Report claims that "climate resilience will in most cases depend on innovation, developing new ideas and options or adapting robust familiar ideas and options to meet emerging new needs and to respond to surprises" (Fatima et al., 2014, p. 1120). Yet, most studies have examined innovation as a mitigation strategy to reduce GHGs emissions (Su and Moaniba, 2017; Kolk and Pinkse, 2005). Unfortunately, the aggregate commitments for GHGs emissions reductions are unlikely to be sufficient to prevent significant climate change impacts (Kahn, 2016).

There is a need for adaptation in the short term because substantial climate change is already inevitable since mitigation will have only a minor effect on stocks of GHGs in this time frame. This is in line with innovation theories that increasingly emphasize innovation as a key process to effectively and collectively address societal challenges, like climate change (Verburg et al., 2019). In this sense, DiBella (2020) argues that in the context of climate adaptation, business model innovation presents a mechanism for the private sector to leverage its resources for equitable adaptation processes, which can distribute the opportunities and costs associated with climate change proportionally. Furthermore, they suggest that benefits of adaptation for individual firms will emerge as they integrate local knowledge and innovations into their business models. Also, Verburg et al. (2019) offer a framework that includes innovation management as a solution for issues related to the implementation of adaptation strategies. However, the few studies addressing innovation as a strategy for climate change adaptation highlight the role of technological and institutional innovation (Joffre et al., 2017; Galappaththi et al., 2020), disregarding the role that product innovation could play.

2. Conceptual framework

Firms know about the likely climate change impacts, but there is uncertainty on its emergence, extent, intensity, and timeframe (Lewandowsky et al., 2014). Further, disruptions in the natural environment do not emerge continuously and predictably, and they are potentially irreversible (Lenton et al., 2019). According to Winn et al. (2011) climate change differs from other discontinuities in the organizational environment either qualitatively or in magnitude through eight dimensions including severity, temporal scale, predictability, and accelerating trend potential, among others. In this changing context, the concept of uncertainty is ubiquitous, describing a pervasive feature of the environment in which people and organizations must adapt to survive.

According to the IPCC Fifth Assessment Report IPCC (2005, p. 1758), climate change adaptation is defined as "the process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities", whereas, in the management literature, climate change adaptation implies a "process whereby firms improve their ability to manage climate risks and climate fluctuations" (Heltberg et al., 2010; Rodima-Taylor et al., 2012, p. 2). Both definitions imply that firms could reduce the impacts of climate change by implementing adaptation strategies. In this sense, studies on firms' adaptation consider climate change a strategic issue rather than a societal or ethical issue (Linnenluecke et al., 2013; Daddi et al., 2018). Thus, firms can reduce the harmful effects of climate change by preparing through efficient adaptation strategies (Gasbarro and Pinkse, 2016; Gasbarro et al., 2016). In this sense, the implementation of adaptation measures seems to be a firms' inevitable necessity (Ghadge et al., 2019; Pinkse and Gasbarro, 2019) to foster competitive advantage.

Studies on firms' adaptation have assessed a broad set of potential strategies (Daddi et al., 2018; Linnenluecke et al., 2013). For instance, by analyzing the impact of changes in the temperature patterns, Rivera and Clement (2019) suggest that ski resort protective-adaptation option is slope expansion. In contrast, the evidence from the wine industry suggests that climate-induced changes associated with precipitation and drought will drive the implementation of adaptation strategies, including installing or using more effective land drainage and choosing more drought-tolerant rootstocks (Poirier et al., 2021). In addition, agribusiness could face changes in parameters such as temperatures and rainfall that may be dealt with by using drought-tolerant and fast-maturing cultivars, abandonment of marginal land/slopes, change in cultivated land area in line with projected climate change, among other options (Kandji et al., 2006; Nhamo et al., 2019). A recent review on aquaculture identifies coping mechanisms at the local level (biosecurity measures), multilevel adaptive strategies (cultural practices change), and management approaches (co-management) as adaptation strategies for industries in marine and coastal areas (Galappaththi et al., 2020). Further, most of the implemented strategies are associated with changes within the firms' supply chain.

Innovation and climate change adaptation have been analyzed from several perspectives, including technological, institutional, and product innovation, with product innovation receiving scant attention (Galappaththi et al., 2020). For instance, Nyiwul (2021) proposed to develop technological innovation to adapt to one specific impact of climate change, namely water scarcity in Africa. In the same line, several studies addressing innovation and climate change in the aquaculture sector use a technology-driven perspective (Joffre et al., 2017; Galappaththi et al., 2020). Further, Lebel et al. (2021) recognize different types of innovation as adaptation strategies in the aquaculture industry. However, the material and technical aspects of the procedural dimension received the most attention from scholars.

Some authors highlight the role played by institutions for climate change adaptation. For instance, Patterson and Huitema (2018) argue that to adapt to climate change, there must be more attention to the role of institutions. In other studies, researchers have suggested that social and institutional innovation (Lebel et al., 2021; Rodima-Taylor et al., 2012) play an important, often catalytic, role in adaptation to climate change. Regarding product innovation as a way to reduce or manage climate risks, Senyolo et al. (2018), analyzing the agricultural industry in South African, describe two innovation types: process innovation (e.g., expansion of irrigation) and product innovation (e.g., drought-tolerant crops to cope with declining rainfall; planting heat-tolerant crops).

As expected, adaptation strategies to climate change are heterogeneous and highly dependent on firm/industry/sector characteristics, nature of the climate-related stress, and the uncertainty level, among other factors. Previous research indicates that product innovation is a crucial adaptive response to several changes in the firms' environment (Calantone et al., 2006; Eisenhardt and Tabrizi, 1995), including climate change (Madsen et al., 2018). Yet, most of the evidence on product innovation is related to green products, mainly developed in response to changes in environmental regulation or new market demands, but not as an adaptation strategy to climate change (Dangelico, 2016).

Product innovation is the firms' (industries) consistent and planned activities to meet consumers' preferences and values, reflecting the organizations' commitment to developing and marketing products that are new to the firm and/or to the market (Ramirez et al., 2018). However, the effectiveness of the product innovation strategy is not granted, as consumers could accept or reject it based on the response they evoke (Nazzaro et al., 2019). Regarding the food industry, Stolzenbach et al. (2013) pointed out that changes in food characteristics may be perceived as too innovative by consumers who tend to be more inclined toward traditional alternatives (Roselli et al., 2018). A lack of perceived benefits raises doubts about the real advantages of innovation, increasing both concerns and perceived risks (Jacobs et al., 2015; Lusk et al., 2018), which negatively affect consumers' purchasing behavior (Ariffin et al., 2018).

Food innovations have high perceived risks (Albertsen et al., 2020) since they affect major consumer concerns such as food safety and environmental issues (Boccia et al., 2018; Guo et al., 2020). In this sense, trust in the industry, the regulatory bodies, and the information sources mediate between perceived risks and benefits associated with product innovation, reducing the former and increasing the latter (Buskens, 2020). Familiarity with the product also affects consumers' perception about changes involving products' sensory characteristics, such as appearance, taste, texture, or smell (Grahl et al., 2020; Nacef et al., 2019). To this extent, Guiné et al. (2021) found that product acceptance on the food market depends on nutritional value, healthy properties, and a sense of social identity. Further, previous evidence suggests that consumers accept those innovations that increase and preserve product heritage while rejecting those lessening traditional sensory characteristics (Vanhonacker et al., 2013). Food innovations involving products' sensory features can also affect consumer consumption occasions (Głuchowski et al., 2021), playing a central role in assessing the acceptance of food innovation (Mendes et al., 2019).

3. Research design

3.1. Case study

The marine-based aquaculture sector is one of the largest food production sectors globally (FAO, 2018). Among this sector, mussels production has a remarkable presence. It ranks third within the category of shelled mollusks cultivated globally (Gazeau et al., 2013), supporting a global aquaculture industry worth more than US$3.0 billion in 2015 (FAO, 2015). Chile has the highest growth rate in mussel mariculture (FAO, 2018; Salazar et al., 2018). From the early 1990s to 2012, production has increased from 3000 to 257800 tons, with a record year in 2017 exceeding 300000 tons (FAO, 2018).

Mussel aquaculture production includes four stages: i) collection of larvae from the natural environment and fixing and settling larvae in long-line systems ("substrates"); ii) growing individuals in a marine environment until they reach the size necessary for harvesting; iii) industrialization in processing plants; and iv) marketing to national and international markets (Rivera et al., 2017) The most significant exposure of mussel production to climate stressors, such as OA, occurs during the first two stages, but its consequences are found throughout the supply chain.

According to Gonzalez-Poblete et al. (2018), Chilean mussels production is conducted by micro, small, medium, and large firms. Micro and small firms account for the largest number of firms; however, medium and large firms account for the largest production share. Regarding their size, 48% of the firms are small, 47% are medium, whereas 5% are large firms. These differences in size are also related to differences in production, in which small firms yearly production is within the range [400, 1350] ton, medium firms within the range [3500, 4500] ton, and large firms producing around [16250, 23750] ton per year (Figueroa and Dresdner, 2016; Gonzalez-Poblete et al., 2018).

3.2. Assessing adaptation strategies in the marine-based food sector: A three-stage approach

Our approach includes three stages: 1) industry characterization, 2) co-production activities and 3) consumer responses to product innovation. The first stage (industry characterization) starts with 20 semi-structured interviews with key industry representatives between June and August 2014. These interviews aimed at gathering general information regarding cost structure, production level, main perceived threats, future expectations about the industry, and feasible adaptation strategies to climate change, among other topics. This information was key for developing a questionnaire to gather detailed information at the firm level. We got support from the Chinquihue Foundation (a private non-profit organization that promotes artisanal fisheries and small-scale aquaculture sectors) and the Chilean mussel industry association (AmiChile) in applying the questionnaire. The questionnaire targeted firms' representatives with responsibilities in the production and marketing areas. The questionnaire examines firms' specific participation within the value chain, main perceived threats (environmental and productive), and market characteristics. This later section looked into the main markets served and the current product offered. We collected information from 87 firms (out of 148) between November 2014 and January 2015, accounting for nearly 60% of the industry.

The questionnaire results were input for the second stage (co-production activities), composed of two workshops conducted in May 2015 and July 2016. The objective was to provide a broad picture of the industry's current state, the level of climatic/environmental awareness and explore preferable/feasible adaptation strategies to climate stressors, including product innovation. The workshops targeted firms' representatives responsible for the marketing/management and production/processes in their respective organizations. In these activities, we present the main results of the industry characterization stage, with particular attention to those issues related to perceived risks, current products offered, and potential product innovation. In addition, as part of the co-production activities, we provide scientific evidence regarding the expected impacts of climate change for the industry, including the potentially harmful effect of OA.

In the third stage, we use a DCE model to analyze consumers' expected responses to the adaptation strategies. The DCE model is rooted in microeconomic theory, and it is based on the random utility maximization (RUM) model. Through a survey, it quantifies the value placed on specific attributes and estimates its utility (Holmes et al., 2017). In contrast to other valuation methods, which focus on evaluating one good, DCEs are implemented when several product attributes and multiple options are considered (Han et al., 2008).

For developing the DCE survey, we conducted four focus groups and 125 pilot surveys to field-test the instrument's design. Based on this information, we applied the final DCE survey in two Chilean cities: Santiago (Chile's capital) and Concepción (the second-largest city) from October to December 2016. We followed a socioeconomic sampling process, using a probabilistic polietapic sampling design. We interviewed 1278 individuals, each of them facing six decisions, with three alternatives for each choice set, yielding a final sample of 7668 observations.

The DCE survey included four parts. The first part provided general information about mussels' characteristics. The second part explained the relationship between mussels' production and the environmental phenomenon of OA, showing the consequences that OA is likely to have in different mussels' attributes. In the third section, we explain the choice exercise, the attributes of the alternatives, and the levels for each attribute. The last section was devoted to collecting sociodemographic information of the interviewees.

The choice exercise includes three types of attributes:

1. Attributes potentially affected by OA. These attributes and their associated levels come from previous studies (e.g. Cardoso et al., 2013; Sveinsdóttir et al., 2009). We included this information to know whether consumers value the product's attributes likely affected by OA. If consumers value such attributes, then the implementation of adaptation strategies is justified. We consider those attributes affecting the product's sensory characteristics, such as shell size, meat color, shell appearance, texture, and taste (Cruz-Romero et al., 2007; Dupont et al., 2014; Thomsen et al., 2013). We also include the likely effect of OA on the nutritional composition level (Grienke et al., 2014; Pettersen et al., 2010)
2. Feasible/preferred adaptation strategies. These attributes are defined using the information collected within the industry characterization stage, complementing the information generated through the co-production process.
3. Price. We include different prices, which depend on the type of product innovation. Price ranges were identified through the focus groups and pilot surveys.

3.3. The DCE model

A DCE is a flexible methodology to analyze preferences based on RUM, which models consumers' decisions among a set of finite and mutually exclusive alternatives. Formally, a consumer n chooses an alternative i only if the utility provided by this alternative is greater than the utility of all other J alternatives in the choice situation t (Louviere et al., 2000). The utility associated with alternative i for the consumer n can be decomposed in a deterministic and observed component (V_{int}) and a stochastic and non-observable component (ε_{int}):

$$U_{int} = V_{int} + \varepsilon_{int}, n = 1, ..., N, i = 1, ..., I, t = 1, ..., T \tag{1}$$

Assuming that V_{int} is linear and ε_{int} is distributed identically and independently (IID) according to a type I extreme value distribution, we can obtain the most common RUM known as the multinomial logit model. The latter IID assumption imposes that the stochastic terms are not correlated among alternatives or observations, then we cannot capture unobserved heterogeneity (variability in taste and preferences). An alternative to model this heterogeneity is relaxing the IID assumption and estimate a Mixed Logit (ML) model, which gives distributional features to the preference parameters (β). The latter means that β is not necessarily a vector of fixed parameters, it may be a β_n vector of random parameter with a distribution function $f(\beta|b, W)$, where b corresponds to the vector of means, and W indicates the variance-covariance matrix. Therefore, the probability that consumer n choose alternative i in the choice situation t is:

$$P_{int} = \frac{exp(\beta_n{}^* x_{int})}{\sum_{j=1}^{J} exp\left(\beta_n{}^* x_{jnt}\right)}, \quad with\ \beta_n \sim N(b, W)$$

where x_{int} are the different attributes that compose the goods presented in the DCE and consumer's sociodemographic characteristics.

In addition, to capture variability in tastes and preferences, a relevant feature of these models is that we can explore different market segmentations through Latent Classes (LC) models. Now, the β_n distribution can be discrete, which implies that β takes a S finite set of values (each set of values can be labeled as a class or a market segment) with probability π_s. In this case, the choice probability is defined as:

$$P_{int} = \sum_{s=1}^{S} \pi_s{}^* \frac{exp(\beta_s{}^* x_{int})}{\sum_{j=1}^{J} exp\left(\beta_s{}^* x_{jnt}\right)}, \ with\ 0 \le \pi_s \le 1\ and \sum_{s=1}^{S} \pi_s = 1$$

The class allocation probability $\pi_{n,s}$ could be associated with a set of sociodemographic variables which affect the probability of being in specific market segment. The number of market segments to be estimated is chosen by goodness of fit measures such as the Akaike information criterion (AIC) or by the researcher's decision based on their research objectives (Nylund et al., 2007). More detailed information about ML, LC and other DCE estimation methods can be found in (Hess and Daly, 2014; Train, 2001).

4. Results

4.1. Industry characterization

The questionnaire results show a high degree of heterogeneity across firms, which is consistent with previous studies (Gonzalez-Poblete et al., 2018). According to our results, the firms in the industry participate in all the value chain stages, from larvae collection to final product commercialization. Mainly, they produce individual quick-freezing (IQF) meat, 75% produce whole-shell IQF, 63% produce half-shell fresh meat, 50% produce canned meat, and 13% make other formats. All formats are characterized as low value-added. On the other hand, firms' main perceived threats are related to environmental (i.e., red tie) and productive issues (i.e., seed shortage). Firms have a high level of knowledge of different environmental issues, with water pollution from antibiotics ranked first (94% of respondents are familiar with it). This high level of knowledge is explained because the mussel's production "competes" for water with other perceived polluted industries (e.g., salmon farms). Phytoplankton decrease also shows a high level of knowledge (91%), explained because mussels fattening is highly dependent on the phytoplankton level in the water column. Finally, an interesting finding is that global warming ranked third on familiarity (89%). Still, only 50% of respondents perceived it as a threat to the industry, whereas 40% of respondents are familiar with OA, but only 21% think it could harm the industry.

4.2. Co-production activities

As the characterization stage showed a lack of awareness of firms in issues that could directly affect them, we present evidence showing the potential impacts of global warming and OA for mussel's production during the co-production activities. Regarding global warming, we show how the expected changes in precipitation will affect the freshwater flow coming to the sea, with the associated decrease in nutrients that eventually will affect mussels' fattening (González et al., 2013). Regarding OA, we provide evidence on the consequences for several marine products attributes, such as sensory and nutritional (Grienke et al., 2014; Waldbusser et al., 2015; Welladsen, 2010). For instance, OA will affect the shell size and color: moving from large and shiny to small and decolored; it also will affect the meat color: changing from yellow to white; meat texture (from soft to hard), sea-taste (from moderate to intense), and nutritional composition (from high to low).

After this, we discussed the feasible and preferable adaptation strategies. Because of the productive characteristics of the industry -marine-based and not supplementary feed-we learned from the dialog with the firms that moving to an in-land fattening process to avoid OA (e.g., hatchery) is not feasible for its high cost. According to the firms' representatives, most of the viable adaptation options are restricted to innovate in products, moving from the traditional fresh-with-shells format to more elaborated ones (e.g., canned or including sauces). Thus, somehow "hiding" from the consumers the attributes likely affected by OA. From this discussion, the industry representatives suggested five potential products innovation: ***canned in hot sauce, canned in green sauce, bagged with shell in butter and garlic dressing, bagged with shell in white wine dressing, and bagged with shell in tomatoes dressing***. These products complement the current formats offered (5 types): fresh with shell, fresh only meat, frozen with shell, frozen only meat, canned in oil or water. Thus, yielding ten potential products. Details on attributes and their associated levels are shown in Table 1.

4.3. Consumer's responses

As we mentioned, the DCE exercise relied on information from both previous stages (industry characterization and co-production activities), using information about current and proposed new products, expected impacts of OA in mussels' attributes, and prices. Using the attributes and levels presented in Table 1, the interviewees were presented with six choice sets, each with three alternatives: two mussel profiles and one opt-out alternative (non-purchase). An example of a choice set is shown in Fig. 1.

Table 1
Attributes and levels.

Category	Attributes	Levels
Product Types	Current Products	Fresh with shell
		Fresh only meat
		Frozen with shell
		Frozen only meat
		Canned in oil or water
	Product Innovation	Canned in hot sauce
		Canned in green sauce
		Bagged with shell, in butter and garlic dressing
		Bagged with shell, in white wine dressing
		Bagged with shell, in tomatoes dressing
Sensory	Shell size	Small (5 cms)
		Large (7 cm)
	Meat color	Yellow
		White
	Shell appearance	Acidified (decolorated)
		No acidified (shinny)
	Texture	Soft
		Hard
	Taste – sea scent	Intense
		Moderate
Nutritional level	Nutritional composition	High
		Low
Price[a]	Price (250 g)	Six prices per Product assortment ranging from [US$1.3- US$5]

[a] Considering that different product types, include different grams of meat, we normalized the prices to represent the same weight (250 g of meat).

The DCE survey was targeted at individuals older than 18 years. The sample age average is 45 years, with an average household size of 4 individuals. In addition, 38% of the interviewees have post-secondary education. Finally, we assess whether individuals trust in public institutions related to food safety; our results show that – in the face of an environmental shock-such as red tide- 67% of individuals would consume sea products if a public institution certificates them.

First, we will present the results of the ML model, which allows us to identify the presence of heterogeneity in consumers' responses. After that, we will disentangle that heterogeneity, estimating the LC model with two classes (market segments). In both models, we included the sociodemographic variables age and household size to understand their role in the probability of choosing no purchase option in ML and the impact of these variables on the likelihood of belonging to a market segment in LC.

The ML results are shown in Table 2, including the mean and the standard deviation for each attribute parameter. Our results show that consumers value those sensory attributes likely affected by OA (column 3). For instance, meat color and shell appearance are positively valued and statistically significant. The same happened with nutritional composition. On the other hand, other sensory attributes such as shell size, a soft texture, or a moderate sea scent are not statistically significant in this model. Based on these results, consumers likely prefer a product profile including mussels with yellow meat, not-acidified shell, and with high nutritional level. Thus, for the industry to maintain consumers' preferences, it should adopt strategies to cope with the likely impacts of OA. The critical question is which strategy (product innovation) consumers prefer.

Table 2 (column 3) shows consumer preferences for the different product types (current and new) compared to the base category, in this case, fresh-with-shells. Thus, a negative sign on these parameters indicates that consumers would prefer the base category. Our assessment

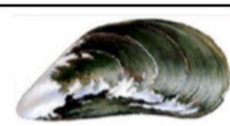
	Option 1	Option 2	Not Buying
Product Type			
Shell Size	Small (5 cm.)	Large (7 cm.)	
Meat Color			
Shell appearance			
Texture	Hard	Soft	
Taste – sea scent	Moderate	Intense	
Nutritional Composition	Low	High	
Price (250 grs.)	$1.490	$1.500	
Your choice			

Fig. 1. Choice set.

Table 2
ML results.

Category		Mean Random Coefficients	Std. Err	SD	Std. Err
Current Products	Format: Fresh - Only Meat	−0.067	0.143	−1.124***	0.332
	Format: Frozen - With Shells	−0.138	0.169	1.673***	0.375
	Format: Frozen - Only Meat	0.492***	0.162	1.720***	0.26
	Format: Canned – Oil or water	0.162	0.177	2.585***	0.344
Product Innovation	Format: Canned - Hot Sauce	−0.542***	0.178	2.247***	0.277
	Format: Canned - Green Sauce	−0.139	0.179	2.272***	0.295
	Format: Bagged with Shell – Butter and garlic	−0.715***	0.159	1.264***	0.379
	Format: Bagged - White Wine	−0.750***	0.168	1.097***	0.348
	Format: Bagged - Tomato	−1.047***	0.159	1.296***	0.266
Sensory	Shell size (large)	0.075	0.06	−0.739***	0.155
	Meat color (yellow)	0.387***	0.08	1.546***	0.114
	Shell Appearance (not acidified)	1.021***	0.093	−1.594***	0.111
	Texture (soft)	0.082	0.059	−0.791***	0.123
	Taste – sea scent (moderate)	0.066	0.063	0.980***	0.112
Nutritional	Nutritional Composition (high)	0.348***	0.068	1.288***	0.105
Fixed Coefficients					
	Price	−0.0004***	0.0001		
	opt-out	−1.020***	0.276		
Opt-out and interactions	opt-out*Age	−0.001	0.003		
	opt-out*Household Size	−0.123***	0.048		

Standard errors in parenthesis. ***$p < 0.001$ **$p < 0.01$ * $p < 0.05$.

of consumers' responses shows that, on average, consumers have strong preferences for the format fresh-with-shells, as most of the parameters associated with alternative products are negative. Moreover, only the current product frozen only-meat is preferred over the base category. Regarding the significance level, the product types frozen only-meat, canned (hot sauce), bagged with shell (butter and garlic), bagged white-wine, and bagged tomato-dressing are statistically significant. As expected, the price parameter is negative (and statistically significant), meaning that consumers prefer products with lower prices. Our results show that the opt-out constant is negative and statistically significant, meaning that consumers prefer any proposed alternatives (in contrast to the no purchasing option). Additionally, we interacted this constant with age and household size, finding only a negative and statistically significant effect for household size (as larger the household size, the less likely to choose the no purchasing option).

Table 2 (column 5) shows that each parameter had a statistically significant standard deviation (of their distribution), suggesting a strong unobserved heterogeneity across consumers' preferences. For instance, consumers prefer (on average) mussels with not-acidified shells (positive mean value of this attribute: 1.021). Despite that, it is possible to find consumers either on the positive or negative side of the distribution. We use two complementary ways to explore preferences' heterogeneity:

1) identifying the share of consumers having positive or negative preferences in the ML for each parameter individually, which is the probability that the coefficient is greater than or less than zero (Fig. 2), and 2) in-depth disentangling of this heterogeneity, by estimating the LC model (Table 3). Unlike the ML, LC models allow us to identify different preference structures in just one step, making both the identification and interpretation of heterogeneity straightforward (Asioli et al., 2018).

Fig. 2 shows that both the mussel's sensory attributes and the nutritional attribute have positive mean values with high heterogeneity across consumers. As shown, for shell appearance, most of the consumers lay within the positive side of the distribution (82%); the same happened with the nutritional level (68%). On the other hand, those parameters not statistically significant (texture and taste) show more evenly distributed preferences between the negative and positive parts of the distribution.

Interestingly, consumer preferences for most of the formats lay in the negative part of the distribution. For instance, despite the mean value for frozen only-meat being positive, most of the preferences lay on the negative side of the distribution (58%). The other existing formats show a more balanced preference structure. On the other hand, new formats like canned in hot sauce/green sauce show some part of the preferences within the positive side (around 38%), whereas preferences for the other new products are almost entirely within the negative side of the distribution (about 95%). Based on this evidence, the firm could take advantage of this heterogeneity by generating products according to different consumers' preferences, with canned in hot sauce/green sauce being the most promising adaptation strategy. To go deeper into this analysis, we estimated the LC model.

LC results show two classes with well-defined preferences for the product attributes: Class 1, accounting for 21% of the sample; and class 2, accounting for 79% of the sample (Table 3).

Consumers in class 1 are generally characterized by positive -and statistically significant-preferences on some of the sensory attributes and positive preferences on the base category. Based on this, we called this group *non-innovative* consumers. On the other hand, consumers in class 2 also have positive preferences on the sensory attributes, but also these consumers value the nutritional composition of the product. Moreover, these consumers have positive preferences for an existing product type (Canned – Oil or water) and a new product type (Canned - Green Sauce). Based on this, we called this group *consumers willing to innovate*. As shown, preferences for product type are the most distinctive difference between both types of consumers. The parameter associated with canned-green sauce is not statistically significant in the ML estimation, with preferences almost evenly distributed between the negative and positive sides. Thus, the LC estimation allows us to uncover consumers with a negative preference for this format (*non-innovative consumers*), and consumers with a favorable preference (*consumers willing to innovate*), unlocking a market segment. Regarding the price attribute, both classes repeat the negative and statistically significant preference, which is expected as a higher price reduces the consumer's welfare. Moreover, note that opt-out is a common parameter for both classes and shows a negative preference for no purchasing option.

Finally, we included age and household size as class allocation variables to understand how these variables can affect the probability of belonging to each consumer group. Both variables are statistically significant and with a positive sign. Considering that the *non-innovative consumers* are the reference group, the higher the consumer's age, the higher the probability of belonging to the *consumers willing to innovate* segment. Similar to the number of people in the house, the higher the household size, the more likely it is to belong to the *consumers who are willing to innovate*. Finally, the *delta* parameter is similar to an alternative specific constant, and it is not statistically significant for the class allocation of *consumers willing to innovate*.

5. Discussion

We are entering the Anthropocene epoch, which is characterized by simultaneous changes in multiple stressors; thus, the challenges faced by firms and organizations are likely to increase (Crutzen, 2006; Gasparin et al., 2020). Like other nature-based sectors (e.g., fishery, forestry, and mining), marine-based aquaculture operates in the natural environment with high exposition to extreme weather events and long-term climatic change. Because of its dependency on the quality of the natural environment, the aquaculture industry cannot 'mobilize' its operations in the face of environmental degradation (Hodgkinson et al., 2014; Martin et al., 2019). Thus, as our multi-stage approach shows, product innovation arises as a feasible strategy to deal with and adapt to climate change when relocating facilities, adopting best management practices, or changing processes is not feasible to address climate risks. This finding is in line with previous studies that found that using

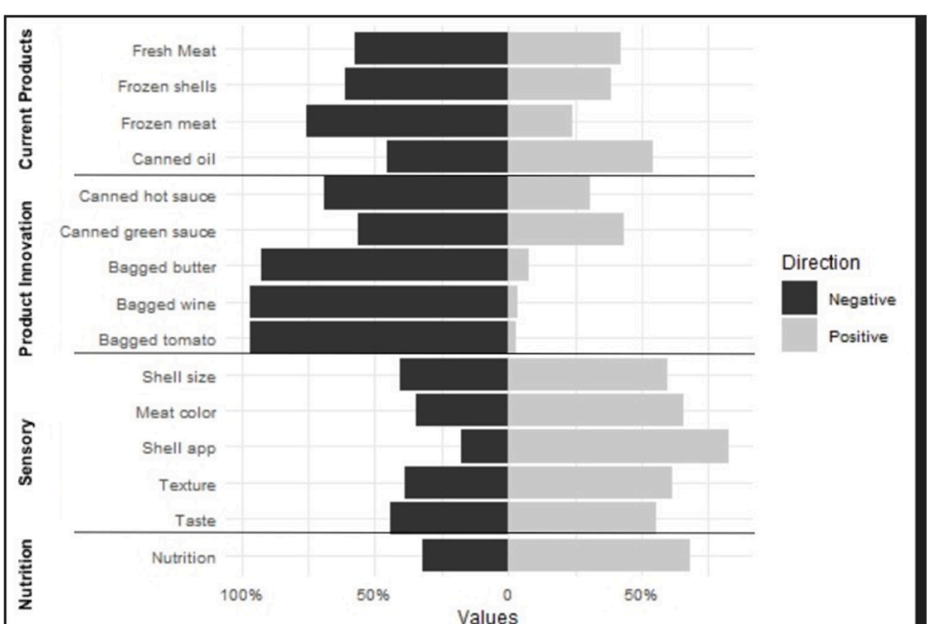


Fig. 2. Attributes preferences.

Table 3
LC results.

Category		Class 1		Class 2	
		Mean	Std. Err	Mean	Std. Err
Current Products	Format: Fresh - Only Meat	−0.877***	0.229	0.112	0.092
	Format: Frozen - With Shells	−1.050***	0.256	0.188^{+}	0.106
	Format: Frozen - Only Meat	−1.438***	0.254	0.07	0.098
	Format: Canned – Oil or water	−0.689***	0.262	0.262***	0.094
Product Innovation	Format: Canned - Hot Sauce	−1.406***	0.352	0.093	0.098
	Format: Canned - Green Sauce	−1.501***	0.428	0.298***	0.102
	Format: Bagged with Shell – Butter and garlic	−1.732***	0.253	0.01	0.107
	Format: Bagged - White Wine	−1.745***	0.28	0.013	0.104
	Format: Bagged - Tomato	−2.327***	0.358	−0.09	0.101
Sensory	Shell size (large)	0.093	0.12	0.046	0.029
	Meat color (yellow)	0.325***	0.159	0.166***	0.04
	Shell Appearance (not acidified)	0.362***	0.151	0.487***	0.041
	Texture (soft)	0.042	0.11	0.039	0.029
	Taste – sea scent (moderate)	0.007	0.112	0.052^{+}	0.03
Nutritional	Nutritional Composition (high)	−0.024	0.113	0.211***	0.033
	Price	−0.0009***	0.0001	−0.0001***	0.00004
	opt-out	−1.774***	0.113	−1.774***	0.113
Class allocation	Age			0.013***	0.013
	Household Size			0.140***	0.053
	Delta			0.24	0.424
Probability of belonging each class		0.2114		0.7886	

***$p < 0.001$ **$p < 0.01$ * $p < 0.05$ $^{+}p<0.10$.

co-production processes serve as a mechanism for learning and lead to adaptation (Armitage et al., 2011; Zarei et al., 2020).

Regarding product attributes, the ML results indicate that customers value mussels' attributes likely affected by OA – meat color, shell appearance, and nutritional composition - with more than half of the market with preferences for these attributes. Regarding the sensory attributes, previous researchers found similar results (Alfnes et al., 2006; Batzios et al., 2002). Further, our findings regarding the relevance of the nutritional status are in line with previous studies in the food sector. For example, Junges et al. (2021) informed that the main motivation for consuming insect-based food is its nutritional quality, making it a protein alternative that is more sustainable than animal protein. Bimbo et al. (2017) developed a systematic review and found a clear pattern of consumer acceptance and preference for healthy-enhancing food products. Additionally, previous studies show that nutrition has been the driver of many innovations in the food industry (Baugreet et al., 2017).

The assessment of consumers' responses to the feasible adaptation strategies shows that product innovation can decrease the vulnerability of the marine aquaculture industry to the likely impacts of OA since we identified market segments that are willing to buy the new products. In this sense, innovation can be used by the industry as a strategy to manage climate-related risks (Damert and Baumgartner, 2018; Weinhofer and Busch, 2013), being also a potential source of competitive advantage in the globalized agri-food scenario (Barcellos et al., 2009; Peiró-Signes and Segarra-Oña, 2018). Our results complement previous literature arguing that climate-induced physical changes represent a stimulus to implement upgrading technology and undertake new technological trajectories that could be a source of competitive advantage.

The ML reveals a high heterogeneity in consumers' preferences. The general results (ML model) show that most current products are preferred by a relevant market share, around 40% on average. However, the opposite happens to the new products that are chosen by only 18% on average. These results are not promising for the industry, as they suggest that consumers do not value the feasible adaptation strategies, hindering the sector's adaptation. However, an in-depth analysis of this heterogeneity could change this conclusion, as the latent class analysis shows the potential of product innovation for decreasing the industry's vulnerability to OA. The heterogeneity analysis reveals that the industry could reach 79% of the market by following a product innovation strategy that targets those *consumers willing to innovate*. This is an interesting result, as previous evidence suggests that innovative consumers are the minority of the market (Huotilainen et al., 2006). Although *consumers willing to innovate* are prone to try new formats, the preferred alternatives are not radical innovations.

Familiarity level could explain the different preferences among existing and new products. But, such differences can also be explained by how rooted the product is in the culture. Previous evidence suggests that familiarity level and tradition are positively related to purchasing behavior. For instance, Guerrero et al. (2009) found that most European consumers associate traditional food with habits. Thus, the authors argued that high consumption of a product implies a high degree of familiarity. Accordingly, relatively small changes in sensory quality are likely to be spotted by regular consumers. For example, a recent study related to patty products discussed the "aversion to new foods" or neophobia, a reluctance to eat, or the avoidance of, new or unknown foods (Kallas et al., 2019). In another study, Conti et al. (2021) talk about "inertia" to describe a disinclination towards change in agri-food. Our results suggest that around 21% of the market has this inertia.

The implementation of product innovation raises several concerns regarding how sustainable are these new formats (e.g., in terms of waste generation). In this sense, the industry should use sustainable practices in the innovation process to reduce its potential environmental impact. For instance, by adopting circular practices (Marrucci et al., 2019, 2020; Testa et al., 2020) In this sense, the industry should communicate its circular efforts effectively, as consumers' propensity to consider additional information regarding the products' environmental impact plays a key role in purchasing (Testa et al., 2020). In this sense, the implementation of environmental management systems and proper waste management systems could help the industy implement these circular processes (Marrucci et al., 2019, 2020).

Our results complement previous studies on innovation as an adaptation strategy for SMEs and the food industry, particularly aquaculture. Currently, the study of innovation as an adaptation strategy to climate change has been focused on management (Galappaththi et al., 2020), technological innovations (IPCC, 2018), and innovation in procedures (Lebel et al., 2021). Although extensive previous literature assesses the benefits of innovation, the present study shows this approach's limitation. Thus, it represents a warning for the nature-based food industry regarding the scope of the innovation used in product types. Our results suggest cautiousness about newness (Finkel, 2019).

6. Conclusions

Our results show that adaptation as a business strategy becomes necessary for the marine aquaculture industry survival, with product innovation playing a promising role in developing such strategy. Further, the approach used in this study highlights the relevance of utilizing a co-production process for developing adaptation strategies. As firms' managers know their barriers and drivers, they can provide valuable information for designing a more accurate and effective adaptation strategy.

Taking advantage of product innovation as an adaptation strategy to climate change is not granted because it requires a smooth and trustful dialog across different stakeholders, including the academia. The firms' perspective implies identifying what kinds of business risks are emerging due to climate change and transforming these risks into opportunities to innovate. From academia's perspective, it means aligning its research questions towards meaningful topics for the private sector.

Based on our results, we suggest that the industry adaptation strategy could be built into two pillars. On the one hand, maintain the traditional format (fresh-with shells), thus satisfying 21% of the market, composed of the *non-innovative consumers*. On the other hand, the industry could direct the innovation efforts towards the canned format (with green sauce), while maintaining the current canned with the water-oil format, thus satisfying those *consumers willing to innovate* (79% of the market). Furthermore, considering that OA will modify sensory attributes, such as meat color and shell appearance, prioritizing canned formats (existing and new) could sustain consumers' purchase intention because these formats tend to hide the affected attributes by OA. Further, our findings also highlight the relevance of a proper treatment of consumers' preferences heterogeneity. We found that depending on the method used, the innovation strategy moves from not recommended (using the ML results) to a suggested strategy (using the LC results).

This study is subject to several limitations, with implications for future research. First, the analysis was made with data from one specific country. Although this paper covers detailed information about the Chilean mariculture food sector, it could be useful to know whether our conclusions remain in other contexts. Second, our analysis is based on hypothetical scenarios of mussels' attributes changes, thus moving towards "taste -test experiments" could be an interesting avenue of research for confronting our findings. Third, despite that our three-stage approach provides valuable information for assessing product innovation as an adaptation strategy, we need to know whether the firms have the internal capabilities for implementing such strategies. Thus, more studies with a strategic perspective of climate change adaptation are needed to improve our understanding of key elements shaping firms' adaptation.

CRediT authorship contribution statement

Roberto D. Ponce Oliva: Conceptualization, Methodology, Validation, Writing – review & editing, Supervision. **Joana Huaman:** Conceptualization, Methodology, Validation, Investigation, Writing – original draft, Writing – review & editing, Project administration. **Felipe Vásquez-Lavin:** Methodology, Software, Validation, Resources, Writing – review & editing. **Manuel Barrientos:** Software, Formal analysis, Data curation, Visualization. **Stefan Gelcich:** Investigation, Writing – review & editing, Funding acquisition, All authors have read and agreed to the published version of the manuscript, Please turn to the CRediT taxonomy for the term explanation, Authorship must be limited to those who have contributed substantially to the work reported.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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