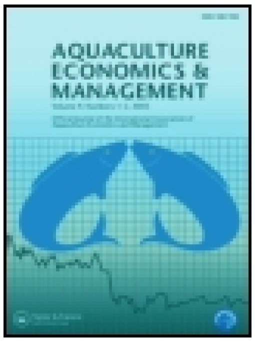

Aquaculture Economics & Management

ISSN: 1365-7305 (Print) 1551-8663 (Online) Journal homepage: http://www.tandfonline.com/loi/uaqm20

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To cite this article: César Salazar, Marcela Jaime, Yanina Figueroa & Rodrigo Fuentes (2018): Innovation in small-scale aquaculture in Chile, Aquaculture Economics & Management, DOI: 10.1080/13657305.2017.1409293

To link to this article: https://doi.org/10.1080/13657305.2017.1409293

Published online: 01 Mar 2018.

AQUACULTURE ECONOMICS & MANAGEMENT
https://doi.org/10.1080/13657305.2017.1409293

Innovation in small-scale aquaculture in Chile

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ABSTRACT

In light of the current depletion of extractive marine resources and the sustainability issues that have arisen in the aquaculture industry, the small-scale aquaculture sector has emerged as a viable and sustainable alternative for generating income. To integrate the small-scale aquaculture sector into the food value chain, understanding the decision-making process to innovate becomes essential. This paper explores the factors underlying both innovation choices and intensity among small-scale aquaculture producers by utilizing exclusive census data from the small-scale aquaculture sector in Chile. The results indicate that education, secure property rights, internet access, participation in organizations, commercialization methods, government instruments, understanding of credit, and social learning promote innovation decisions. We also find that largest producers innovate in more areas, suggesting a role of size for both technological and non-technological innovations.

KEYWORDS

Innovation; microeconomic analysis; small-scale aquaculture

Introduction

Chile has become one of the leading exporting countries in the fishery and aquaculture sectors. However, this achievement has not been without its problems in the face of extractive marine resource depletion and sustainability issues in the aquaculture industry. In this context, the small-scale aquaculture sector emerges as a viable and sustainable alternative as an income-generating activity, with an important role in achieving food security and poverty alleviation (Ahmed & Belton, 2010; Ahmed & Lorica, 2002; Burbridge, Hendrick, Roth, & Rosenthal, 2001; Edwards, 2000). The Chilean government recognizes the importance of small-scale aquaculture in terms of its contribution to the production, employment and development of coastal fishing communities by distinguishing it from the industrial aquaculture sector in the National Aquaculture Policy (PNA, 2003). A definition of small-scale aquaculture in Chile can be found in FIP (2005). After a diagnosis of the sector, the study concludes that small-scale aquaculture producers are micro-entrepreneurs,

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hold less than 10 ha in concessions, use less than five workers and operate with low levels of investment and technology.

The fast growth of this sector implies new challenges in terms of integrating small-scale aquacultures as productive, active agents in the food value chain. Therefore, promoting innovations is essential for understanding the potential capacities for the development of the sector. This paper explores the factors underlying innovation decisions among small-scale aquaculture producers in Chile.

There is an increasing interest in the innovation activities of small and medium-sized enterprises (SMEs) and their potential to be competitive in a globalizing knowledge economy (e.g., Rogers, 2004; Almus & Czarnitzki, 2003; Bhattacharya & Bloch, 2004; Doloreux, Isaksen, Aslesen, & Melançon, 2009; Frenz & Ietto-Gillies, 2007; Lund Vinding, 2006; Moreno, Paci, & Usai, 2005; Quagrainie, Ngugi, & Amisah, 2010). Most of the empirical literature on the decision to innovate has attempted to test the "neo-Schumpeterian" theory. This theory states that the market structure might affect the incentives and capacities of firms to innovate, suggesting that firm size, market concentration and industry characteristics are important to explain innovation decisions (Cohen, 2010).

In the aquaculture sector, concerns have been focused on the conditions and institutional arrangements that stimulate the building and development of a more mature aquaculture innovation support system (Berkhout et al., 2010; Lebel, Mungkung, Gheewala, & Lebel, 2010; Sankaran & Suchitra Mouly, 2006). We study both innovation choices and intensity by taking advantage of the richness of a unique census data from the small-scale aquaculture sector in Chile (INE, 2009).

In a small-scale aquaculture, there are no related studies designed to explain innovation decisions. However, the literature is extensive in exploring other production-related decisions such as participation in aquaculture, technology adoption, supply and location decisions and factors explaining technical and productive efficiency (Asamoah, Ewusie Nunoo, Osei-Asare, Addo, & Sumaila, 2012; Asche & Roll, 2013; Bimbao, Paraguas, Dey, & Eknath, 2000; Ifejika, Ayanda, & Sule, 2007; Iliyasu et al., 2014; Kareem, Aromolaran, & Dipeolu, 2009; Pomeroy, Dey, & Plesha, 2014; Wetengere, 2009). From this literature, it is possible to distinguish that variables such as gender, age, education, financial constraints and participation in agricultural activities are key determinants of production-related decisions, and they can play an important role in innovative activities as well. Furthermore, financial constraints and public incentives have been found to be more important for enhancing innovation among smaller and younger firms (Brown, Martinsson, & Petersen, 2012; Guariglia & Liu, 2014; Sasidharan, Lukose, & Komera, 2015).

Our study attempts to contribute to the literature by providing more general knowledge about the small-scale aquaculture sector which is currently limited (in particular, knowledge about innovation decisions among small-scale aquaculture producers, which is almost non-existent), and to shed light on the behavior aspects of a sector that, by operating in non-subsistence economies, cannot be defined either as a subsistence economy or rural activity (as is the case in some Asian and Latin American countries), or as characteristics of SMEs (FAO, 2010).

Small-scale aquaculture and innovation in Chile

While salmon is the dominant industry in the Chilean economy, the emerging small-scale aquaculture sector has a high social and economic importance in terms of its capacity to create jobs and generate incomes, especially in locations with a declining fishing sector. The main species are Chilean mussels (*choritos*) and *Gracilaria chilensis* (a red seaweed named *pelillo* in Spanish) which comprise 96% of the total fish farms in the sector.[1] In terms of farming methods, these species are produced extensively using labor-intensive methods. In particular, mussel cultivation starts with seeds being uptaken by collectors built with gill nets and installed in long-line systems. This process lasts for 4–6 months (Díaz, Figueroa, & Sobenes, 2011). Then, when the seed reaches a size of approximately 5 mm, it is detached from the collectors and seeded at a lower density to be fattened for about 12 to 18 months. *G. chilensis* producers generally extract the plants from natural grasslands, by pruning or collecting them from the coasts. Then, they are grown in suspended rope systems for 3–4 months. For both species, employees are hired hands and family workers. Farms are mainly run by their owners, who exhibit low educational levels. Other potential issues in the sector are problems related to informality, as centers often operate without concessions or authorization, lack access to market information and capital and have low bargaining power with respect to transformation and commercialization sectors (FIP, 2005). The orientation of the sector toward exporting, in spite of its disadvantageous conditions, implies the fulfillment of international standards. This alone requires special efforts to promote innovation.

In Chile, innovation policy is mainly handled by the "*Corporación de Fomento de la Producción*" (CORFO). CORFO has devoted around 60% of its resources to fund technological innovation projects under the Technological Innovation Business Program. In the small-scale aquaculture sector, innovations are mainly observed in the seaweed and mussel sectors. In the case of seaweed species, innovation has focused on developing and adapting inexpensive technology to enable the development of seaweed aquaculture in areas with different environmental characteristics (Parada, 2009). The sector has also promoted innovations in new products from seaweed and technologies to produce biofuels from native macroalgae, mainly brown seaweed (*Macrocystis pyrifera*). In the mussel sector, innovation involves the development and implementation of new environmental management practices (i.e., georeferenced environmental monitoring systems in the seed collection stage to reduce dependence on environmental factors). In commercialization and products, some innovations have also emerged in new products derived from mussel shells, which serve as substitute for marble material used in construction and new food supplement products to feed other aquaculture species (CORFO, 2016).

Data

We use data from the first Fishing and Aquaculture Census performed in Chile between the years 2008–2009, with questions designed to cover the period of 2006–2007 as a reference. The Census was designed to quantify information about social, economic and cultural characteristics of the people involved in the fishery and aquaculture sectors. Furthermore, the questions were intended to gather information regarding physical infrastructure, equipment, and technology used in fisheries and aquaculture, so as to supplement the lack of statistics on production and costs (INE, 2009). The census was conducted using 14 questionnaires covering various sectors: artisanal, industrial, aquaculture and fishing services. We use the data on small-scale aquaculture producers surveyed in the Census. There are 507 individual producers, distributed across the entire national territory.

Aquaculture producers report whether or not they have introduced innovations during the last 3 years. Furthermore, they provided information about the main area in which innovations were implemented: products, services, process and organization. Finally, questions regarding the size of investment in innovation in monetary terms were also asked. First, we measured innovation decisions. We constructed our innovation proxy as a bivariate variable taking the value of 1 if the producer innovates and zero otherwise. In addition, we utilized details on the type of innovation to construct a multivariate variable taking the value of 1 if the producer adopts innovations in either product or production (technological innovations), and zero otherwise, and if the producer implements innovations in either services or organization (non-technological innovations), and zero otherwise. We here followed OECD (2005) and modified slightly the definition suggested by the Oslo's Manual due to limitations in information.

Next, we measured innovation intensity. We focused on two aspects: the number and size of innovations. Thus, we created a countable variable by adding the number of innovations that a producer reports. Additionally, we proxied the size of innovations by the amount of money that a producer reports having invested in innovation activities in 2007.

Descriptive statistics for our different proxies of innovation are shown in Table 1. Results indicate that innovation in the small-scale aquaculture sector

Table 1. Descriptive statistics of dependent variables for non-technological and technological innovation.

Category	Total		Non-technological		Technological	
	Mean	Std	Mean	Std	Mean	Std
Innovation variables						
Innovation (dummy = 1)	0.197	0.398	0.14	0.34	0.93	0.256
# innovations	1.17	0.513	1.85	1.02	1.18	.530
Innovation investment ($ miles)	2,990	3,843	3,102	3,934	3,807	4,308
Observations	507		14		93	

Source: Own elaboration based on Census data (2009).

is somewhat low, as only 19.7% of producers adopted at least one type of innovation, compared to the 24.8% observed for the whole economy. However, this is higher than the fishery sector, including both aquaculture and extractive activities (7%) in a similar period. The fraction of firms innovating in the small-scale aquaculture sector seems to be relatively close to that observed in the agriculture sector (19.3%) (Ministry of Economics, 2010). Among innovators, the majority of producers are more likely to introduce technological innovations (e.g., innovation in products and processes) than non-technological innovations (e.g., organization and services); adoption rates reached 93 and 14%, respectively.[2] Results also suggest that producers do not innovate intensively, as innovators engage, on average, in only one innovation activity. Surprisingly, producers who adopt non-technological innovations appear to innovate more intensively than those involved in technological innovations. In contrast, producers who are involved in technological innovations appear to invest higher amounts of money than those involved in non-technological innovations.

Empirical specifications

Small-scale aquaculture producers report whether or not they have introduced innovations. We use this question to investigate aquaculture producer innovation decisions. In order to do so, we first analyzed the probability of innovation in the aquaculture sector. The probability that the producer i has adopted an innovation is given by:

$$P(y_i = 1|\boldsymbol{x}_i) = \Phi(\boldsymbol{x}_i\beta) \tag{1}$$

where y_i is a dummy variable indicating the innovation status of producer i in the year of the study (1 innovate, 0 otherwise), $\boldsymbol{x}_i$ is a vector of observed covariates, β is a vector of parameters to be estimated, and Φ is the normal cumulative density function. This equation is estimated by univariate probit models.

We then analyzed producer decisions further by examining producer choices of innovation types. We utilized details on whether the producer adopted innovations in either product or production (technological innovations), or services or organization (non-technological innovations). It is assumed that innovation alternatives are mutually exclusive, which is to say that producer decisions regarding whether or not to innovate, or to adopt a given innovation, exclude the other alternatives. Based on this understanding, choices faced by producers can be characterized as follows:

$$P(Y=j)=\frac{e^{\beta_j' x_i}}{1+\sum_{k=1}^{J} e^{\beta_k' x_i}},\ j=1,2,\ldots,J$$

$$P(Y=0)=\frac{e^{\beta_j' x_i}}{1+\sum_{k=1}^{J} e^{\beta_k' x_i}} \tag{2}$$

where $P(Y=j)$ and $P(Y=0)$ denote the probability that producer i chooses the alternative j (e.g., technological and non-technological innovations) or the baseline alternative (e.g., not innovating), respectively. Moreover, x_i denotes a vector of characteristics (i.e., attributes) that vary among producers, but not necessarily among alternatives. β_j is the estimated parameter associated with alternative j, and β_k is the vector of estimated parameters associated with the set of alternatives, k. It is also assumed that the error terms are iid with an extreme value distribution (i.e., log-Weibull), and, therefore, this model can be estimated econometrically by multinomial logit models.

In the second stage, we investigated the intensity of innovation by producers. Our approach is twofold: first, we modeled the number of innovations adopted by a producer using Poisson models (Cameron & Trivedi, 2005). We here created a countable variable by adding the number of innovations that a producer reports. Based on this model, the decision faced by a representative producer is presented as follows:

$$\mu_i \equiv E[y_i|x_i]=\lambda_i=\exp\left[x_i'\beta\right],\ i=1,\ldots,n \tag{3}$$

where μ_i denotes the expected number of innovation types adopted by producer i during the study period (i.e., the mean), and y_i is the actual number of innovations adopted by producer i. The latter vector includes innovation in the four main areas: products, process, marketing and organizational; thus, producers who innovate would exhibit a positive value, whereas non-innovators would exhibit a value of zero. Moreover, x_i is a vector of characteristics λ_i denoting the estimated mean, and exp[.] is the exponential functional form.

Second, aquaculture producers reported the amount of money invested in innovation activities. We then investigated the monetary investment in innovation by producers. As the investment variable is censored at the zero level, we analyzed aquaculture producer investment decisions by Tobit models as follows:

$$y_i^* = x_i'\beta + \varepsilon_i$$

$$y_i^* = \begin{cases} y_i^* if\ y_i^* > 1 \\ -if\ y_i^* \leq 0 \end{cases} \tag{4}$$

where y_i^* represents the amount invested in innovation by producer i, x_i is a vector of producer characteristics, and ε_i is the error term, which is assumed to be normally distributed and homoscedastic.

The literature suggests that variables related to technological and firm characteristics, socioeconomics features of producers, market characteristics and financial constraints are key determinants of innovation decisions (e.g., Blundell, Griffith, & Van Reenen, 1999; Cohen & Klepper, 1996; Farrell & Klemperer, 2007; Hall, 2002; Lee, 2009). To explain innovation decisions among small-scale aquaculture producers, then we consider a common set of covariates x_i for all of the models characterizing the producer, fish-fattening centers, organization and management activities as well as access to financial instruments, government support and location variables. We use the fishing census data to find proxies for these variables.

To control for producer characteristics, we add the variables gender, age, education and aquaculture dependence. *Age* corresponds to age in years of the producer; *education* represents the producer's education level. It is divided into five categories: 0—no formal education, 1—elementary school education, 2—high school education, 3—post-secondary education in technical or professional institutes, 4—undergraduate education in universities, and 5—postgraduate education. *Agriculture* and *fisheries* are dummy variables that capture aquaculture dependence by taking the value of 1 if the producer reports to have complementary activities in one or the other sector.

To control for center characteristics, we introduced variables that related to production scale, tenure status and main species. In relation to production scale variables, we used two proxies of size: *land size,* measured in squared meters of land devoted to production activities, and *sea size,* measured in hectares of sea area devoted to production activities. In a similar way, we controlled for tenure status in land and sea water. The variable *land own* takes the value of 1 if the center is located on a land surface that is owned by the producer and zero if otherwise. The variable *concession* takes the value of 1 if the center operates under a concession or authorization and zero if otherwise. Finally, we distinguished the producer's main species including the dummy variables *fish* and *mollusk* species, leaving the category *seaweed* as baseline.

In relation to management and organization characteristics, we include variables which give information about the adoption of information technologies, production organization, marketing methods and social capital. The variable *Internet* is a dummy variable that takes the value of 1 if the producer has internet connection and zero otherwise. Additionally, we include three dummy variables to distinguish the destination of products: *wholesale,* *intermediaries,* and *direct sale*. We assume the category *processing plants* as baseline. Finally, we add the dummy variable *participation* that takes the value of 1 if the producer participates in any organization and zero otherwise.

In addition, we include a set of covariates to control for access to financial instruments, government support and fulfillment of technical standards. *Credit* is a variable that takes the value of 1 if the producer reports having access to formal credit instruments and zero otherwise. *Government instrument* is a dummy variable receiving a value of 1 if the producer receives any support from governmental agencies and zero otherwise. Furthermore, we include a dummy variable called *technical standards* which takes the value of 1 if the producer has any certification following technical standards and

Table 2. Mean and standard deviation of determinants for innovation, technological, and non-technological innovation.

	Innovation		No innovation		Technological		Non-technological	
Category	Mean	Sd	Mean	Sd	Mean	Std	Mean	Std
Producer characteristics								
Age (years)	49.2	11.9	48.3	11.3	49.1	12.2	48.0	11.9
Gender (Male = 1)	0.78	0.41	0.81	0.39	0.78	0.41	0.64	0.49
Education								
No education	0.06	0.23	0.03	0.18	0.06	0.24	0.07	0.26
Elementary school education	0.47	0.50	0.52	0.50	0.47	0.50	0.35	0.49
High school education	0.25	0.43	0.29	0.45	0.23	0.42	0.21	0.42
Higher education (technical)	0.07	0.25	0.05	0.23	0.07	0.26	0.00	0.00
Higher education (university)	0.20	0.40	0.11	0.31	0.20	0.40	0.21	0.42
Postgraduate	0.00	0.00	0.01	0.11	0.00	0.00	0.00	0.00
Agriculture	0.11	0.31	0.09	0.29	0.11	0.32	0.00	0.00
Fisheries	0.20	0.40	0.20	0.40	0.14	0.36	0.19	0.39
Center's characteristics								
Land size (square meters)	952	4,511	372	2,465	1,014	4,673	3,069	10,639
Sea size (hectares)	4.21	3.04	2.44	4.59	4.31	3.06	4.07	2.80
Own land	0.24	0.42	0.09	0.29	0.23	0.24	0.14	0.36
Concession	0.04	0.19	0.02	0.14	0.032	0.17	0.21	0.42
Mollusks	0.77	0.42	0.38	0.48	0.76	0.42	0.85	0.36
Fish	0.03	0.17	0.03	0.17	0.03	0.17	0.00	0.00
Seaweed	0.20	0.40	0.57	0.49	0.20	0.40	0.14	0.36
Management and organization characteristics								
Internet	0.48	0.50	0.16	0.36	0.49	0.50	0.64	0.49
Processing plant	0.67	0.47	0.37	0.48	0.85	0.37	0.71	0.46
Wholesale	0.10	0.30	0.05	0.13	0.10	0.31	0.21	0.42
Intermediaries	0.18	0.38	0.47	0.49	0.19	0.39	0.14	0.36
Direct sale	0.16	0.36	0.11	0.31	0.16	0.36	0.35	0.49
Participation	0.65	0.47	0.51	0.50	0.63	0.49	0.78	0.43
Financial and government support								
Credit	0.41	0.49	0.16	0.36	0.40	0.49	0.64	0.49
Technical standards	0.35	0.47	0.10	0.30	0.35	0.48	0.50	0.51
Government instruments	0.12	0.32	0.01	0.13	0.11	0.32	0.14	0.36
Location variables								
Los Lagos Region	0.10	0.34	0.86	0.33	0.86	0.34	0.71	0.46
Number of innovators	12.24	7.91	7.96	6.42	11.8	7.88	15.4	7.99
Observations	100		407		93		14	

Source: Own elaboration based on Censual data (2009).

zero otherwise. Finally, we control for some locational variables, including a dummy variable which takes the value of 1 for Los Lagos Region, the main aquaculture area of the country, and the number of innovators at the commune level. Table 2 displays descriptive statistics on the covariates explaining producer innovation decisions and propensity.

Results and discussion

Results of the binary and multinomial logit estimations, Equations (1) and (2) for innovation decisions, are shown in Table 3. We focus on the covariates that were significant in explaining the likelihood of innovating. In terms of producer characteristics, the probability of innovating is higher when centers are managed by personnel with a higher level of formal education. This result is in line with that of Njankoua, Pouomogne, Nyemeck, and Yossa (2012) and seems to be more important for technological innovations. Furthermore, the probability of innovating in non-technological innovation is lower for aquaculture producers involved in agriculture as secondary activity. However, it is not significant for the total sample or when explaining technological innovation decisions.

The characteristics of the aquaculture centers also play a role in determining innovation decisions. We find that the larger the farm size is, the more probable innovation activity is. This result is in line with that found by Bhattacharya and Bloch (2004). However, it is only significant in explaining non-technological innovations. Furthermore, farmers that own land are more likely to innovate in general and adopt technological innovation, in particular. This fact confirms the importance of designing tenancy arrangements that guarantee rights to long-term benefits from investments, as suggested by Olaoye and Oloruntoba (2010). Having as baseline seaweed species, aquaculture centers producing mainly mollusks are more likely to be involved in technological innovations. Those producing fish are less likely to engage in non-technological innovation.

There is also evidence on the management and organization characteristics underlying innovation decisions. Estimations suggest that aquaculture centers with internet connection are more likely to innovate. Having internet access in distant and remote areas can ease diffusion of information of new technology. The commercialization method of production also influences innovation and type of innovation. We find that centers selling directly in markets are more likely to innovate in non-technological innovations while those that use intermediaries have a lower probability of adopting this type of innovations, having as baseline destination *processing plants*. The latter is expected since selling production directly to the public requires effort in terms of promotion, pricing and positioning of products, all concepts related to non-technological innovations. Moreover, results show that aquaculture

Table 3. Estimates of the logit binary and multinomial models for innovation decisions.

		Multinomial	
Variables	Logit	Technological	Non-technological
Producer characteristics			
Age (years)	0.0156	0.0140	0.0393
	(0.0135)	(0.0138)	(0.0347)
Gender (Male = 1)	−0.241	−0.170	−0.669
	(0.346)	(0.363)	(0.800)
Education	0.231*	0.222*	0.393
	(0.130)	(0.133)	(0.325)
Agriculture	0.123	0.240	−13.55***
	(0.492)	(0.480)	(0.875)
Fisheries	0.160	0.182	0.297
	(0.366)	(0.369)	(1.032)
Center characteristics			
Land size (square meters)	5.62e−05	1.54e−05	0.000114***
	(3.56e−05)	(3.51e−05)	(3.71e−05)
Sea size (hectares)	0.0195	0.0237	−0.00273
	(0.0236)	(0.0234)	(0.0741)
Own land	0.713*	0.790**	0.159
	(0.378)	(0.376)	(1.039)
Concession	−0.638	−0.584	−1.225
	(0.469)	(0.481)	(1.090)
Mollusks	1.059**	1.132**	0.258
	(0.436)	(0.451)	(1.208)
Fish	−0.183	0.509	−13.58***
	(1.062)	(1.112)	(2.152)
Management and organization characteristics			
Internet	1.022***	0.967***	1.012
	(0.338)	(0.346)	(0.746)
Wholesale	0.391	0.343	1.091
	(0.503)	(0.541)	(0.690)
Intermediaries	−0.471	−0.399	−1.562**
	(0.409)	(0.426)	(0.771)
Direct sale	0.358	0.280	1.239*
	(0.442)	(0.485)	(0.681)
Participation	0.608**	0.522	1.784**
	(0.307)	(0.317)	(0.758)
Financial and government support			
Credit	0.958***	0.840**	2.415***
	(0.321)	(0.337)	(0.789)
Technical standards	0.348	0.251	1.284
	(0.360)	(0.370)	(0.817)
Government instruments	1.732***	1.892***	1.581
	(0.624)	(0.672)	(1.073)
Location variables			
Los Lagos Region	0.749	1.122	−2.074
	(0.614)	(0.718)	(1.293)
Number of innovators	0.0575***	0.0472**	0.202***
	(0.0207)	(0.0210)	(0.0602)
Constant	−4.966***	−5.275***	−8.673***
	(1.102)	(1.213)	(2.425)
Log pseudo-likelihood	−181.43	−207.098	
Pseudo R^2	0.28	0.29	
Observations	507	507	

Robust standard errors in parentheses.
$^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

producers participating in organizations are more likely to implement innovations in general and to get involved in non-technological innovations, in particular. Participation in organizations can be considered a proxy of the extent of an individual's social connectedness, and, thus, it may serve as a vehicle for the adaptation, transmission and diffusion of knowledge of new technologies. Similarly, the networking effect in innovation has been found to be stronger in the smallest firm size group (Rogers, 2004). This finding is also in line with Pinto, Cruz, and Combe (2015), who highlight the importance of social and human capital in the consolidation of marine clusters. Participation in organizations can also help small-scale aquaculture producers in the acquisition of management and organizational skills, which may explain the higher likelihood of innovating in non-technological innovations that was observed.

Financial and government support also seem to be important in the decision-making process of innovation. Aquaculture producers who have access to credit should have fewer difficulties in acquiring resources and covering investments needed to undergo innovations. Our results support these predictions, finding that the producers who report borrowing from a formal financial system are more likely to adopt innovations as suggested by Olaoye and Oloruntoba (2010). In addition, we find that support from government agencies matters in explaining innovation decisions. Thus, aquaculture producers who report using government instruments are the ones who show higher probabilities of innovating. The effect is also significant when studying technological innovations. Finally, the number of innovators at the local level is also significant in explaining innovation decisions. The latter intends to capture potential learning effects among aquaculture producers that belong to related networks or adjacent geographical areas.

Table 4 summarizes the estimation results of the Poisson and Tobit models in Equations (3) and (4). Once again, we focus on the covariates that were significant in explaining the propensity of innovation. Estimated coefficients of the Poisson model suggest that producers with higher formal education are more likely to adopt a larger number of innovations, compared with less educated producers. Moreover, results suggest that producers with larger farms tend to innovate more intensively. The size of the farm is a proxy for its potential production. Then, the larger the farm is, the larger the benefits from innovating are. Thus, for this type of producer, innovations not only in products and processes but also in management and services are more likely to serve as instruments to increase both economic benefits and market participation. It is also worth mentioning that non-innovators operate, on average, in smaller centers; therefore, for these producers, the benefits of being involved in a number of innovations may not surpass the cost of innovating. Furthermore, results show a positive and statistically significant relationship between access

Table 4. Estimates of the Poisson and Tobit models for the number of innovations and investment, respectively.

Variables	Poisson number	Tobit log (innovation investment)
Producer characteristics		
Age (years)	0.0115	0.0290
	(0.00791)	(0.0616)
Gender (male = 1)	−0.210	−1.048
	(0.192)	(1.706)
Education	0.163**	0.977
	(0.0742)	(0.641)
Agriculture	0.00377	2.805
	(0.302)	(2.159)
Fisheries	0.126	2.003
	(0.257)	(1.703)
Center characteristics		
Land size (square meters)	5.09e−05***	0.000244
	(1.92e−05)	(0.000185)
Sea size (hectares)	0.0166	0.0838
	(0.0159)	(0.120)
Own land	0.416**	4.019**
	(0.211)	(1.766)
Concession	−0.705**	−2.579
	(0.280)	(2.363)
Mollusks	0.599**	4.006**
	(0.291)	(2.030)
Fish	−0.634	−1.707
	(0.590)	(4.802)
Management and organization characteristics		
Internet	0.735***	6.335***
	(0.201)	(1.608)
Wholesale	0.306	1.552
	(0.236)	(2.215)
Intermediaries	−0.545**	−3.352*
	(0.239)	(1.834)
Direct sale	0.312	2.185
	(0.224)	(2.137)
Participation	0.231	2.149
	(0.189)	(1.485)
Financial and government support		
Credit	0.750***	3.714**
	(0.173)	(1.541)
Technical standards	0.302	1.358
	(0.207)	(1.857)
Government instruments	0.924***	6.921***
	(0.246)	(2.285)
Location variables		
Los Lagos Region	0.233	3.160
	(0.365)	(3.043)
Number of innovators	0.0333**	0.249**
	(0.0130)	(0.105)
Constant	−3.400***	−22.47***
	(0.578)	(5.202)
Log pseudo-likelihood	−229.35	−238.65
Pseudo R^2	0.24	0.26
Observations	507	507

Robust standard errors in parentheses.
$^*p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

to credit and innovation propensity. This highlights the importance of promoting microcredit markets in small-scale aquaculture.

Results from the Poisson model also indicate that producers who own their land and whose production is specialized in mollusks, compared to seaweed, are more likely to adopt a larger number of innovations. While the former can be associated with the economic stability of the production activity, the latter indicates the relative importance the mollusk subsector has in Chilean small-scale aquaculture. Moreover, in line with the binomial and multinomial models above, because there is lack of direct contact with customers, centers selling directly to intermediaries—with respect to processing plants—are less likely to be involved in a number of innovation activities. In other words, selling through processing plants encourages innovation, possibly because of the opportunity it presents to indirectly penetrate foreign markets, increasing competition, and requiring higher standards in the whole value chain (Bhattacharya & Bloch, 2004).

Results also show the importance that having access to information has on innovation propensity. In addition, producers that use internet and those that are surrounded by innovators are more likely to innovate more intensively, compared with producers that are more isolated.

Results explaining the amount of investment in innovation resonate with main findings from previous models. In particular, estimations from the Tobit model suggest that investments in innovation are larger among aquaculture producers who own their land and operate in the mollusk sector. Furthermore, we find that having access to internet and trading through processing plants rather than intermediaries boosts innovation investments. Finally, results also highlight the role of credit and government support in promoting innovation investment.

Conclusion

The objective of this research was to gain a greater understanding of the factors that affect small-scale aquaculture producers´ likelihood to innovate. It looks not only at whether producers innovate or not, but what areas of innovations they participate in, how many innovations they engage in, and how much money they put into those innovations. Poisson and Tobit models were used to analyze the various factors which could have an effect on the innovation decision.

The results indicate that more educated aquaculturists are more likely to innovate and participate in more areas of innovation. This supports arguments based on human capital in explaining innovation decisions. Furthermore, aquaculture producers owning their land and operating in the mollusk sector are more likely to innovate. We also found that larger aquaculture producers innovate in more areas, suggesting that for this type of producer, innovations not only occur in products and processes but also in organization and services.

This evidence reinforces arguments based on land tenure security and economies of scale. Moreover, aquaculture producers who have access to the internet, participate in organizations, and sell their production to processing plants are more willing to undertake innovations. It is worth mentioning that internet access not only promotes the decision to innovate but also the magnitude of it. While the internet and participation variables support the importance of access to information and diffusion of new technology, a high probability of innovating among aquaculturists selling their production to processing plants may be in line with more rigorous technical standards imposed by the transformation industry. In addition, aquaculture producers benefiting from government instruments and with access to formal credit are more likely to innovate. Having access to credit also promotes innovations in more than one area. The latter reiterates the importance of government extension and financial restrictions in the decision process of innovation. Finally, we found evidence that the number of innovators in a determined locality affects the individual probability of innovating. This points out the role of *learning-by-others* to reduce uncertainty about new technologies.

However, a couple of caveats deserve attention. First, we are not able to distinguish investment in technological from non-technological innovations, which constrains the analysis to the study to only a total investment. Second, the small number of innovators in our data does not allow us to explore patterns of innovation across species. Despite these limitations, our findings have important implications for the success of government interventions to address the concerns about the low innovation rate that is observed in the small-scale aquaculture sector. For a policy instrument aimed at increasing innovation investment, it is necessary to understand the factors underlying this decision. Our results suggest that government support through credit and promoting instruments are key for boosting innovation investment. Furthermore, we found that the transformation industry may play an important role in encouraging innovation among their suppliers. The latter suggests that innovation policies must be designed in such a way that they must consider key aspects of the entire value chain.

Notes

1. Others species of minor relevance such as shrimp and trout are produced intensively, representing around 4% of the total production (FIP, 2005).
2. The type of innovations may be respond to the industry life cycles, with young industry associated with strong product innovation and more mature industries caring more on productivity through process innovations (Tether, Mina, Consoli, & Gagliardi, 2005).

Acknowledgments

The authors would like to thank the participants at the IX Meeting of the Chilean Society of Regional Studies, the editor and two anonymous reviewers for helpful comments. Any remaining mistakes are the authors' responsibility.

Funding

César Salazar acknowledges financial support for the Research Support Fund, University of Bio-Bio, Project DIUBB 1567172/RS and Project GI 160317/EF. Marcela Jaime acknowledges funding for the Research Nucleus on Environmental and Natural Resource Economics (NENRE). Yanina Figueroa also acknowledges gratefully financial support from project FONDAP, No. 15110027.

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