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Estimating the biomitigation benefits of Integrated Multi-Trophic Aquaculture: A contingent behavior analysis

R. Martínez-Espiñeira [a,*], T. Chopin [b], S. Robinson [b,c], A. Noce [b,d], D. Knowler [b,e], W. Yip [b,e]

[a] Department of Economics, Memorial University of Newfoundland, St. John's NL, A1C 5S7, Canada
[b] Canadian Integrated Multi-Trophic Aquaculture Network, University of New Brunswick, St. John, NB, Canada
[c] Fisheries and Oceans Canada, St. Andrews Biological Station, St. Andrews, NB, Canada
[d] State University of New York at Plattsburgh, School of Business and Economics, Department of Economics, Plattsburgh, NY, United States
[e] School of Resource and Environmental Management, Simon Fraser University, Burnaby, BC, Canada

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ABSTRACT

Using the contingent behavior method, we estimate the benefits derived from the biomitigative effects of Integrated Multi-Trophic Aquaculture (IMTA) in the farming of Atlantic salmon. We asked a sample of Canadians how their farmed Atlantic salmon consumption choices would be affected by the availability of IMTA products in response to the decreased external costs they would impose on the surrounding marine environment. We used a random-effects negative binomial model to estimate their different demand functions and, from them, measures of increases in consumer surplus arising from the availability of IMTA products. We estimated a lower bound for the aggregate benefit that current salmon consumers in Canada would derive from the introduction of IMTA salmon of about CAD 280 million/year, while less restrictive assumptions about the representativeness of our sample would lead to an aggregate figure of about CAD 1.5 billion/year. We also found that consumers would benefit from proper labeling of farmed salmon, since conventionally farmed salmon and IMTA salmon are considered non-substitutes, the latter being a normal good and the former an inferior good for the typical consumer. We find that there is room for improving welfare by disseminating information to enhance consumer understanding of IMTA production techniques.

1. Introduction

In the face of rising demand for seafood and declining availability of wild species and stocks, the world is increasingly turning to aquaculture as the key source of seafood supply. However, concerns have also been expressed about the environmental impacts of aquaculture (Naylor et al., 2000; Olesen et al., 2011). These environmental impacts vary extensively and depend on the type of aquaculture activity and the type of species raised. Aquaculture farming activities can range from semi-intensive to hyper-intensive, where intensification suggests increasing stock density and generation of waste products, and a greater potential for the spread of pathogens. Likewise, the type of species farmed also varies widely. There are hundreds of species of finfish, invertebrates, and seaweeds that are farmed and the farming of some species can further burden or contribute to the collapse of fishery stocks worldwide. For example, shrimp and salmon farming have the potential to further deplete wild fishery stocks as a result of damage to ocean and coastal resources through habitat destruction, waste disposal, and large fishmeal and fish oil requirements (Naylor et al., 2000). By contrast, herbivorous or filter feeders aquaculture species, such as carp and molluscs, can be net contributors to global fish stocks (Naylor et al., 2000).

The development of intensive fed aquaculture such as finfish and shrimp activities that are highly geographically concentrated or located in suboptimal sites whose assimilative capacity is poorly understood can result in environmental impacts (Chopin et al., 2001; Diana, 2009; Naylor et al., 1998). Salmon farming in particular, the focus of our study, is believed to be one of the anthropogenic sources of eutrophication in coastal areas. Other environmental effects of salmon aquaculture production include increased water turbidity from effluent discharges, escaped farmed species, diseases (e.g. sea lice), and the increasing presence in waters of various drugs (e.g. antibiotics) used in the rearing or feeding of the farmed fish (Naylor et al., 2000). Minimizing the environmental damage associated with aquaculture requires the internalization of environmental costs through the adoption of new,

* Corresponding author. Tel.: +1 709 864 3676; fax: +1 709 864 2094.
E-mail addresses: rmartinezesp@mun.ca (R. Martínez-Espiñeira), tchopin@unb.ca (T. Chopin), Shawn.Robinson@dfo-mpo.gc.ca (S. Robinson), anoce003@plattsburgh.edu (A. Noce), djk@sfu.ca (D. Knowler), wyip116@gmail.com (W. Yip).

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cleaner production technologies. Integrated Multi-Trophic Aquaculture (IMTA)[1] is one approach that can be adopted to mitigate ecological effects of fish monoculture. IMTA, unlike polyculture, where more than one species can be farmed together but share the same biological and chemical processes (e.g. three species of finfish — salmon–cod–halibut), combines the culture of fed organisms (e.g. finfish or shrimp) with that of extractive species (seaweeds and invertebrates), so that the biological and chemical processes at work are balancing each other (Chopin, 2006). Adoption will occur, however, only if economic circumstances, particularly price trends, are favorable (Whitmarsh et al., 2006).

If environmental damages affect the production environment and economic performance locally, they should be internalized by farmers themselves. However, small-scale independent farms have little incentive to take into account regional or coastal-wide environmental impacts in their decision making process (Asche et al., 1999; Johnston et al., 2008). With no effect on individual profitability, the internalizing of externalities is unlikely, so regulation becomes necessary (Asche and Tveteras, 2005). However, as pointed out by Tisdell (2001), the costs of meeting government regulations should not be underestimated as a barrier to the successful economic development of new types of aquaculture products.

For example, Liu and Sumaila (2007) described how experience suggests that, although enclosed systems for salmon aquaculture (helpful to prevent or minimize environmental impacts of salmon farming) are technically feasible and environmentally promising, they can be financially profitable only when they produce fish that achieve a price premium. In fact, their sensitivity analyses show market price as the most important determinant of the profitability of salmon production with sea-bag systems requiring a price premium of at least 20% relative to the market price for net-cage systems to be profitable.

Similarly, Whitmarsh et al. (2006) analyzed the financial profitability of an integrated salmon–mussel production system in Scottish aquaculture farms, considering, over a 20-year time horizon salmon monoculture, mussel monoculture, and integrated salmon–mussel culture systems. The latter resulted in the highest level of profitability but their sensitivity analysis showed that the 'economies of integration' afforded by the integrated system are highly sensitive to market price changes. Just a 2% per annum decrease in salmon prices would make an investment in the integrated system unattractive, confirming that market conditions and future price forecasts will play an important role in affecting decisions about the adoption of more environmentally friendly technologies.

In light of these concerns and in order to estimate not only the effect of adopting IMTA techniques on the demand for farmed salmon but also the total social economic value of IMTA strategies, we use a stated preference method to value the benefits from the use of IMTA to farm Atlantic salmon, where these benefits result from decreased external costs imposed on the marine environment (bio-remediation).

A Canada-wide hybrid phone/Internet survey[2] was used to collect the data. Recruiting participants randomly over the phone afforded the advantage of providing the usual degree of representativeness. Allowing the respondents to complete the survey online allowed them extra time to consider the description of the environmental issues involved and their reading (as usual, rather than hearing) about the different prices of salmon that would inform their hypothetical purchasing choices. A split-sample approach was used whereby different respondents received different types of questionnaire, depending on whether or not they were consumers of farmed seafood. The first type of questionnaire asked current consumers about how their farmed salmon consumption choices would be affected by the availability of IMTA Atlantic salmon under a variety of price conditions. The second type targeted respondents who had not consumed farmed salmon within the previous twelve months and asked respondents about their willingness to support, through increased annual taxes, a hypothetical policy that would subsidize the adoption of IMTA production techniques.

This paper focuses on the analysis of the data from the first type of questionnaire, based on the contingent behavior approach, which asked respondents about how their farmed Atlantic salmon consumption choices would be affected by the availability of IMTA products.[3] This non-market valuation technique can help in the derivation of the full social economic value of IMTA, even if currently there is no substantial market for IMTA salmon with sufficient observations of combinations of price and quantity demanded needed for conventional demand analysis. Our econometric analysis, based on pseudo-panel data analysis techniques that take into account that several responses were obtained from each respondent, makes it possible to derive measures of the increase in consumer surplus enjoyed by consumers due to the availability of IMTA salmon.

We estimate the benefits that salmon consumers in Canada would derive from the introduction of IMTA salmon, under certain assumptions about its effect on the proportion of effluent emissions. We also investigate the effects of different socio-demographic characteristics and how these might cause consumers to shift towards IMTA salmon and/or away from conventionally farmed salmon once the former became available as proposed in the survey.

2. Background on Integrated Multi-Trophic Aquaculture

Integrated Multi-Trophic Aquaculture (IMTA) promises to help the industry evolve towards more ecosystem responsible systems (Chopin, 2013). IMTA is the farming, in proximity, of aquaculture species from different trophic levels and with complementary ecosystem functions, so one species' uneaten feed and wastes, nutrients and by-products can be recaptured and converted into fertilizer, feed, and energy for the other crops, and synergistic interactions between species can be exploited (Chopin, 2006; Chopin et al., 2012). IMTA combines fed aquaculture (e.g. finfish or shrimps) with extractive aquaculture, which utilizes the excess inorganic and organic nutrients from fed aquaculture for growth. The objective of IMTA is to ecologically engineer systems for environmental sustainability (biomitigative services for improved ecosystem health), economic stability (improved output, lower costs, product diversification, risk reduction and job creation in rural and coastal communities) and societal acceptability (better management practices, improved regulatory governance and appreciation of differentiated and safe products).

Several previous studies have examined the economics of more sustainable aquaculture. For example, Whitmarsh and Wattage (2006) found consumers willing to pay a price premium for salmon produced in a more environmentally friendly manner and Whitmarsh and Palmieri (2011) showed increased concern over the environmental performance of the salmon farming industry associated with a lower propensity to purchase salmon.

Results from Canada are based on attitudinal studies towards salmon farming in general and IMTA in particular (Barrington et al., 2009, 2010; Ridler et al., 2006, 2007a). These studies, all centered on the development of IMTA on the Canadian East Coast, found that the general public is more negative towards current monoculture practices and feels positive about the adoption of IMTA (Ridler et al., 2007b). To our knowledge, however, no study to date has estimated measures of increased consumer surplus due to the introduction of IMTA seafood in Canada.

[1] Abbreviations: IMTA: Integrated Multi-Trophic Aquaculture, WTP: Willingness to pay.
[2] See Section 5 for further details.

[3] The second questionnaire, targeted at those members of the general public who do not consume farmed salmon, used the contingent valuation method instead, asking about willingness to support a policy that would subsidize IMTA production. Further details on the distinction between the two valuation methods are provided in Section 4.1.

3. An economic model of the consumption of IMTA salmon

Food products can be seen as endowed with a set of attributes, which can be classified into *search attributes*, *experience attributes*, and *credence attributes* (Wessells, 2002; Wirth et al., 2007). Consumers cannot observe a product's credence attributes either at the point of sale or after consumption. Credence attributes can affect purchasing behavior in unpredicted ways (Frank, 2006), particularly if they do not directly affect a consumer's individual utility, as in the case of attributes associated with the environmental impact of aquaculture products. They are often impossible or impractical to determine or can only be revealed at high costs to the consumer (Dulleck et al., 2011; Wessells, 2002). Consequently, consumers must generally rely on identifiers (e.g. certificates, eco-labels) that assure that unobservable product attributes are bundled within the good. Product attributes, such as environmentally friendly production, have value to the consumer. This leads to a demand for and a supply of credence attributes, with demand curves being expected to shift upwards for products endowed with these attributes.

In general, *green*, eco-labeled, and organic products are impure public goods, because they have both a private good characteristic and an environmental public good characteristic (Cornes, 1984; Kotchen and Moore, 2007). IMTA salmon would be an impure public good and its labeling as such could signal that IMTA can reduce the environmental consequences of salmon production. If the utility from salmon consumption is separable from consumption of other goods and represented by a concave function, it can be represented as:

$$U(s, s_{IMTA}, C) = U(s, s_{IMTA}) + B(s_{IMTA}|C) \quad (1)$$

where s is the quantity consumed of non-labeled Atlantic salmon, s_{IMTA} is the quantity consumed of IMTA-labeled salmon, $U(s, s_{IMTA})$ is the utility function that describes the consumer's preferences for salmon consumption, and $B(s_{IMTA}|C)$ represents the additional utility from knowing that the salmon being consumed comes from IMTA. The vector C represents the criteria under which the IMTA-label can be legally attached to the salmon product. Expression (1) assumes that the utility derived from salmon consumption and the utility derived from knowing about its IMTA origin are additively separable. Under that assumption, the consumers' marginal willingness to pay (WTP) for knowing that, by purchasing the IMTA product, they contribute less to environmental degradation represents the added utility from consuming IMTA-labeled salmon. The unlabeled salmon carries no information, so B is not specified as a function of s. There are two prices for seafood products, one for the unlabeled salmon, p, and another for the labeled salmon, p_{IMTA}. Crucially, it must be assumed that, in all other respects perceivable by the consumer, the two types of salmon are assumed to be identical.

Maximizing (1) subject to the salmon budget constraint

$$M = p \cdot s + p_{IMTA} \cdot s_{IMTA} \quad (2)$$

and assuming that the marginal utility from both types of salmon is the same at every level of consumption ($U_s = U_{s_{IMTA}}$), since IMTA salmon and conventionally farmed salmon are undistinguishable except for the IMTA-based attributes, and that the second-order conditions hold, direct Marshallian demand functions for non-labeled and labeled salmon (L) can be derived as functions of p, p_{IMTA}, M,and C:

$$s^M(p, p_{IMTA}, M, C) \quad (3)$$

$$s_L^M(p, p_{IMTA}, M, C). \quad (4)$$

The estimation of both these curves would be straightforward if currently there were a functioning market for IMTA salmon, so observations of different combinations of price and quantity demanded could be used for regression analysis. This would make it possible to also estimate the increase in consumer surplus, that is, the extra economic welfare enjoyed by consumers, due to the availability of IMTA salmon. However, since there is no market yet for IMTA salmon,[4] one must resort to non-market valuation techniques to approximate both curves. Not only there are no actually observable transactions of IMTA salmon available; the demand for conventionally farmed salmon in the presence of IMTA salmon must also be estimated with non-market techniques, because both products are substitutes, so their prices would enter each other's demand function as an explanatory variable.

We estimate and compare the demand curves for conventional and IMTA salmon, in order to estimate the value that consumers place on the public good characteristic of IMTA salmon, arising from the biomitigative effects of this aquaculture production technique.

4. Material and methods

4.1. The contingent behavior method

When dealing with the WTP for a new product or a newly available attribute, one must consider whether consumers will be able to choose among the new and existing products. However, valuation studies usually propose a take-it-or-leave-it situation, whereby consumers can only choose the existing version of the good or its new quantity or quality, but not some of both (Corsi and Novelli, 2003). The prevalent practice fails to identify prospective consumers' behavior when they can adjust the quantity purchased (Corsi, 2007) and implicitly assumes that respondents will buy the same quantity of the new good as they did of the existing one. Instead, the contingent behavior method (CBM) makes it possible to estimate the demand curves for salmon consumption with and without IMTA adoption (Huang et al., 2004; Whitehead et al., 2003) and mimic real market choices by allowing respondents to express a choice between IMTA products and conventional farmed seafood, and even some combinations of both. This method directly elicits information about hypothetical behaviors in conventional markets by first presenting the current state of some environmental problem and a hypothetical policy aimed at mitigating it at a specified aggregate cost and then asking about planned changes in respondent behavior if the environmental quality is enhanced at an increased cost (Whitehead et al., 2008).

The CBM is thus a stated preference approach, because it is based on asking individuals questions about future behavior under hypothetical circumstances, such as how often they would visit a recreational site under altered levels of environmental quality or cost conditions. These questions may be asked in isolation or in combination with data on observed behavior (for example, actual visiting choices within the travel cost method, or actual purchases within the averting behavior method or in the case of valuation of private goods).

An advantage of the CBM over revealed preference methods of valuation (which rely on actual observed behavior) is the flexibility given by the fact that hypothetical choices make it possible to gain policy relevant information when historic variability in environmental conditions is limited. Its weakness is also due to its hypothetical nature (Whitehead et al., 2010).

The Contingent Valuation Method (CVM) is a very commonly used alternative stated-preference method of valuation that asks instead about willingness to pay for a hypothetical policy. CVM enjoys the same flexibility and suffers from the same shortcomings as the CBM. However, it is more suitable to value non-use values, since it does not rely on behavioral choices made by the potential users of the good or service valued. On the other hand, CBM has the advantage that respondents, as current or potential users, are usually very familiar with the context of the valuation scenario.

[4] IMTA-labeled salmon has recently been introduced in the East Coast of Canada but the amounts are at this time too small relative to the total market size to constitute a functioning market for the purposes of this study.

In our example, we expect that the demand for farmed salmon by current consumers (that is the functional relationship between the quantity they demand and the level of price they face) would change after the market introduction of IMTA salmon, either because they would substitute, totally or partially, their current farmed salmon demand with IMTA salmon, or because the availability of IMTA salmon would increase the total quantity of farmed salmon they would demand at a given price. We do not take into consideration the gain in surplus for those consumers who, although currently not buying any farmed Atlantic salmon, would start purchasing IMTA salmon once available.[5]

It should be noted that our analysis does not consider changes in supply (the relationship between the quantity supplied and the price) but rather focuses on estimating how the introduction in the market of a salmon variety with a new credence attribute would affect the consumer demand for the different types of farmed salmon. In particular, there is no assumption that the availability of salmon would change or that the (hypothetical) changes in the price proposed to the respondents would be linked to changes in supply. We simply consider hypothetical changes in prices, so that the demand schedule can be traced.

4.2. Econometric analysis

We asked survey respondents a set of between one and five questions about their frequency of home consumption of fresh farmed Atlantic salmon meals at several recalled or proposed prices, in order to estimate demand curves for salmon under different scenarios. These scenarios initially included both stated preference and revealed preference responses.[6] However, in the remainder of the paper we concentrate on the stated-preference responses only.[7]

The responses to questions about purchase frequency ($meals_0$ and $meals_1$) at hypothetical prices (P_0 and P_1) allowed us to estimate the stated demand for farmed Atlantic salmon before the availability of IMTA salmon, $X_{BEFORE}(\bullet)$, as a demand relationship whose main arguments are the price of the salmon and the identifier (variable *BEFORE*) of the *policy scenario* indicating that at that stage of the interview there had been no mention of the availability of IMTA salmon. Other covariates (e.g. age, income, household size) were included in the demand functions.

Then respondents were presented with the possibility of IMTA salmon becoming available either at a price premium, at the same price, or at a discount, and easily identifiable by a label, while P_{NOW} would remain the benchmark price for conventionally farmed salmon. Respondents were asked whether they would buy any IMTA salmon at P_{IMTA0} and whether, in that case, they would completely switch to IMTA salmon and, if so, how often they would now purchase farmed salmon. We obtained with this information a point on the IMTA demand curve $X_{IMTA}(IMTA, \bullet)$. Those respondents stating that they would not switch completely to IMTA salmon were asked how often they would purchase each type of salmon given their respective prices (P_{NOW} and the randomly assigned one for IMTA). The responses to these questions allowed us to trace out the demand curve for IMTA farmed salmon and the revised demand curve for conventionally farmed salmon $X_{CONV}(IMTA, \bullet)$, where the subscript CONV refers to conventionally farmed Atlantic salmon. Note that we assumed that these changes occurred without any adjusting of the quantity bought *per meal*, which, following similar studies (Johnston and Roheim, 2006; Johnston et al., 2001), we assumed given in the short run.

The construction and estimation of the set of salmon demand curves described above and summarized in Table 1, make it possible to estimate the size of the change in consumer surplus associated with the introduction of IMTA salmon. This change in consumer surplus could originate from one or more of three sources. First, those who decided to completely switch to IMTA salmon could increase their purchase frequency at a given price because of the introduction of the IMTA variety (an increase in their demand at the extensive margin). Second, those same consumers choosing to switch completely could be willing to pay more at the margin for each meal now that the salmon bought would be IMTA. Third, there could be some increase in consumer surplus for those consumers who decided to only partially switch to IMTA salmon while still enjoying some conventional salmon.

When estimating the salmon demand functions, since it was based on several responses about salmon consumption patterns from each respondent, we used panel data techniques that account not only for the count data features of the dependent variable but also for the potential correlation of responses within cases (Englin and Cameron, 1996).

We labeled the number of meals of farmed Atlantic salmon purchased per month as *M* and assumed this variable to be a function of a vector of variables *X*. These variables include the relevant own-price per salmon meal (*Pmeal*) and the cross-price ($P_{subs}meal$) per salmon meal if applicable, along with income, other socio-demographic variables capturing respondent characteristics, variable *scope* (which represents the magnitude of the biomitigative effects resulting from the adoption of IMTA salmon farming suggested within the description of the proposed policy scenario), and indicators of the type of demand in question. Note that, although we use *M* to denote both types of purchased meals (conventionally farmed salmon and IMTA salmon), by using binary indicators and their interactions, we can identify separate demand functions for each type of product.

We first considered a random-effects Poisson model (Haab et al., 2010; Huang et al., 2004) but ended up using a random-effects negative binomial model (Haab et al., 2010) to account for the overdispersion of the dependent variable (Greene, 2011; Hausman et al., 1984). We used indicator variables (dummies) to identify which demand curve we were considering and under which hypothetical circumstances the pairs of meals and prices (per typical meal) were being observed, as well as interactions of these indicators with the price variable and, in the most flexible model, with the *income* variable (Beaumais and Appéré, 2010; Englin and Cameron, 1996; Whitehead et al., 2000). In our case, the demand shift variables are given by the policy indicator that indicates whether IMTA salmon is available or not. These different indicators allow us to consider differences between the situation before and after the availability of IMTA salmon, so we can trace the salmon demand curves under both scenarios. Geometrically, the demand curves can change because of a change in the intercept of the linear predictor, because of a change in its slope (implying a change in price-elasticity), or both.

The final model specification (Model 3) is given by:

$$\begin{aligned} M = {} & \beta_0 + \beta_1 BEFORE + \beta_2 Pmeal + \beta_3 BEFORE \times Pmeal + \beta_4 IMTA \\ & + \beta_5 IMTA \times Pmeal + \beta_6 income + \beta_7 IMTA \times income \\ & + \beta_8 BEFORE \times income + \beta_9 P_{subs}meal + \beta_k (S_k \times IMTA) \\ & + \beta_{k'} (S_k \times CONV) + e_{it} \end{aligned} \tag{5}$$

where *M* is the number of monthly meals of farmed Atlantic salmon, and β_k is the coefficient vector for the additional *k* covariates S_k interacted with the indicators *IMTA* and *CONV*. Using these interactions helps us determine what type of consumer would gravitate towards the *IMTA* version of the product and away from the conventional version once *IMTA* salmon becomes available. These interactions help us determine how much stronger the demand for IMTA salmon relative to

[5] We ignore this component of consumer surplus, both because we adopt a conservative approach to the calculation of welfare benefits of IMTA and because it would have been complex to sample non-consumers who would start buying IMTA-salmon (for now barely known by any consumer). They would also find it more difficult to answer questions about salmon shopping habits, leading to more measurement error biases.

[6] The literature contains several examples of this approach that deal with the analysis of food consumption in general and of seafood consumption in particular (Haab et al., 2002, 2010; Morgan et al., 2013; Parsons et al., 2006; Whitehead et al., 2003).

[7] We chose to discard the information about revealed demand, since consumers appeared to have an inconsistent interpretation of the size of a fillet and a hard time recalling the amount of fish they purchased per meal as well as the price per pound, per kilogram or per fillet.

Table 1
Guide to demand scenarios before and after IMTA salmon becomes available and data sources for estimation under the CBM.

Scenario	Salmon type	Quantity demanded	Price		Demand function
			(conventional)	(IMTA)	
$BEFORE = 1$	$CONV = 1$	$meals_0$	P_0	NA	$X_{BEFORE}(\bullet)$
	$CONV = 1$	$meals_1$	P_1	NA	$X_{BEFORE}(\bullet)$
$BEFORE = 0$	$CONV = 0$	$meals_{IMTA0}$	p_{NOW}	P_{IMTA0}	$X_{IMTA}(IMTA, \bullet)$
	$CONV = 0$	$meals_{IMTA1}$	p_{NOW}	P_{IMTA1}	$X_{IMTA}(IMTA, \bullet)$
	$CONV = 1$	$meals_{CONV}$	p_{NOW}	P_{IMTA1}	$X_{CONV}(IMTA, \bullet)$

Scenario identifiers: BEFORE = 1 for current situation; BEFORE = 0 when IMTA salmon available; NOW = indicator of current consumption scenario (revealed demand data).
Salmon type identifiers: CONV = 1 for conventionally farmed salmon, CONV = 0 for IMTA salmon; Prices: p_{IMTA0} = first proposed IMTA price in \$/lb; p_{IMTA1} = second proposed IMTA price in \$/lb to those who would switch completely to IMTA; P_0 = first proposed price in \$/lb; P_1 = first proposed price in \$/lb P_{NOW} = estimated current price in \$/lb.
Demand functions: $X_{BEFORE}(\bullet)$ = stated demand for (conventionally) farmed salmon before IMTA is available; $X_{IMTA}(IMTA, \bullet)$ = stated demand for IMTA salmon; $X_{CONV}(IMTA, \bullet)$ = stated demand for (conventionally) farmed salmon before IMTA is available.

conventionally farmed salmon (both once IMTA salmon is available and when it was not available yet) is for, say, someone with college education. They do not tell us, however, how much stronger the demand for farmed conventional salmon is, in the same example, for someone with a college education when no IMTA salmon is available. That is, in this flexible model, we relegate the effect of covariates on general salmon demand to the general intercept. This helps us keep the model relatively parsimonious (so we can identify several significant relationships), while focusing on the issue we are more concerned with, namely the effect of introducing IMTA salmon, rather than explaining farmed salmon consumption in general. It is only in the case of income that we also estimate an effect on the demand for farmed salmon in general, apart from the difference in income elasticities of demand between farming techniques.

We also report the results of two models that are more restrictive when it comes to the coefficients on the covariates. First, Model 2 is given by:

$$M = \beta_0{}' + \beta_1{}'BEFORE + \beta_2{}'Pmeal + \beta_3{}'BEFORE \times Pmeal + \beta_4{}'IMTA + \beta_5{}'IMTA \times Pmeal + \beta_6{}'income + \beta_9 P_{subs}meal + \beta_k{}'S_k + u_{it} \quad (6)$$

where we estimate the general effect of socio-demographic covariates, including *income*, on the demand for farmed Atlantic salmon (regardless of its variety and regardless of whether that demand was measured assuming availability of IMTA or not).

The most restrictive model is Model 1:

$$M = \beta_0'' + \beta_1''BEFORE + \beta_2''Pmeal + \beta_3''BEFORE \times Pmeal + \beta_4''IMTA + \beta_5''IMTA \times Pmeal + \beta_6''income + \beta_9 P_{subs}meal + v_{it} \quad (7)$$

where income is the only covariate other than price and scenario identifiers whose coefficient we allow to differ from zero.

5. Data collection

Data were collected through a hybrid phone/Internet survey administered to a sample of adult Canadians which included a CVM version and a CBM version. In this paper we deal only with the latter; that is, households that had purchased farmed Atlantic salmon in the past twelve months. A total of 1197 usable responses (out of a total of 1246 responses) were obtained between the two subsamples,[8] with a response rate of 18% after up to three reminders. [9]

Our survey (whose full text is available upon request to the authors) asked about consumer shopping habits (e.g. habitual shopping locations and quantities usually bought), prices currently paid for farmed Atlantic salmon, preferences for salmon (wild versus farmed), demographic characteristics, and attitudes towards eco-labels and knowledge of IMTA. The key questions for the valuation exercise, shown in Fig. 1, were about the altered purchasing patterns of farmed Atlantic salmon once IMTA salmon become available and the questions of WTP for a policy that promoted the production of IMTA salmon. In order to motivate these questions, a policy scenario was included briefly describing the basics of IMTA and the hypothetical effect on the marine environment of the adoption of this new technology. In particular, we asked respondents to assume that this adoption would reduce waste from aquaculture farms adopting IMTA relative to conventional aquaculture farms by a proportion given by the variable *scope*. This value was randomized among respondents, so that we could test for scope sensitivity. The variable *scope* took five discrete values between 10% and 50%.

Since our focus was on the study of farmed salmon, we asked respondents whether they knew that only farmed, rather than wild, Atlantic salmon was available in shops. This question was also used to eliminate respondents from the CBM version of the questionnaire, reducing the working subsample used in this paper, after all the filtering, to 525 cases.

Table 2 includes a definition of the variables used in the analysis. The revealed number of typical farmed Atlantic salmon meals per month was coded as the variable $meals_{NOW}$. We assumed that those who said that they had purchased farmed Atlantic salmon less than once per month had no consumption in a given month in order to facilitate the construction of a count data variable measuring typical current levels of consumption.[10]

We then asked respondents to provide an estimate of the typical quantity of farmed Atlantic salmon they bought to feed their family. As suggested by Johnston et al. (2001), this quantity could be stated in pounds (lb), kilograms (kg), or fillets, which we converted into pound equivalents as the variable *mealsizeinlbs*.

Next, we asked about the price currently paid for salmon at the respondents' usual shopping location and respondents could express this price in dollars per pound (\$/lb), dollars per kilogram (\$/kg), or dollars per fillet. However, about a third of respondents failed to provide an estimate. This suggests that the results obtained by exploiting this information are likely subject to measurement error. One key problem with the elicitation of the current price variable is that it is not obvious how to translate the prices per fillet, which does not have a standard weight. We assumed that a fillet weighed 300 g. Additionally, the stated values 'more than \$18/kg' and 'more than \$16/fillet' were conservatively recoded as \$19/kg and \$17/fillet. With these assumptions, we constructed a common price variable expressed in \$/lb (P_{NOW}).

[8] The data were collected with *EKOS Research Associates*' panel Probit, as a dual mode hybrid methodology (Internet collection for online Canadians, telephone collection for off-line Canadians). Approximately 80% of the interviews were conducted online, while the balance was collected off-line by telephone.

[9] Although low, this rate compares relatively well to those obtained by other web-based surveys (Canavari et al., 2005, 6%; Marta-Pedroso et al., 2007, 5%; Petchenik and Watermolen, 2011, 2%); other surveys that dealt with similar goods regardless of the survey mode (Burton et al., 2001, 11%; Kaneko and Chern, 2005, 28%); and by studies closer in topic and format to ours (Morgan et al., 2009, 17.8% base response rate and 23.8% final response; Whitmarsh and Palmieri, 2011, 14.9%).

[10] Although in principle this variable was censored by the value 'more than eight times a month', no respondents chose that option, so there was no need to consider the censoring.

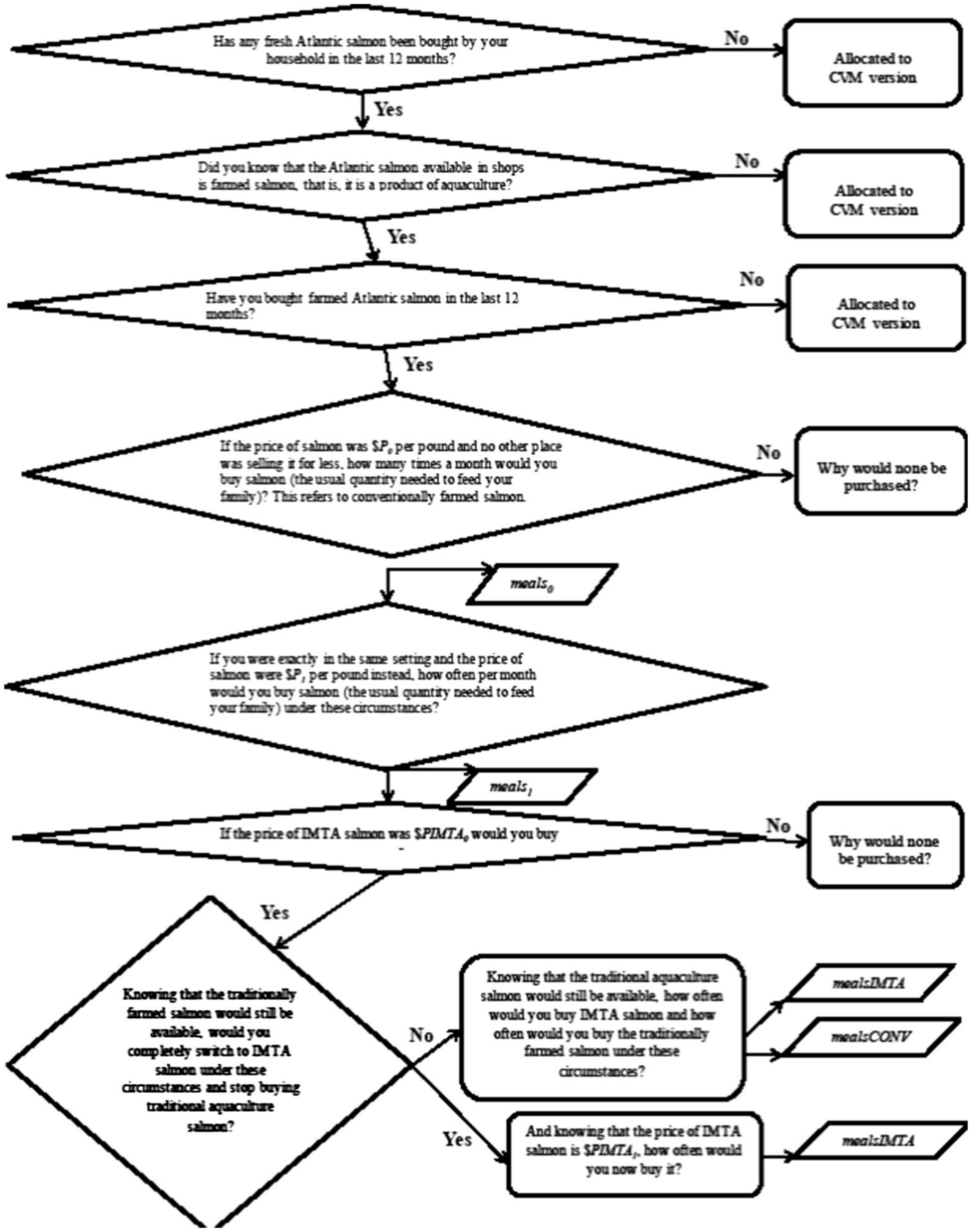

Fig. 1. Flow chart of main survey questions.

Variable $meals_0$ indicates the number of conventionally farmed Atlantic salmon meals (of the usual size purchased for their families) that respondents said they would buy monthly at a hypothetical price (variable P_0), randomized across respondents from the set ($3, $4, $5, $6, $7 per lb). We replaced the response 'less than one meal a month' by a value of zero and 'more than eight' by a value of nine. Next, respondents were asked how many salmon meals (labeled $meals_1$) they would purchase if prices changed into P_1 ($3, $4, $5, $6, or $7 per lb), while all other food prices remained the same. Note that the change from P_0 to P_1 could be positive or negative.

After that, we presented respondents with the possibility of having IMTA salmon available either at a price premium, at the same price, or at a discount.[11] This price differential per pound took the (randomly assigned values): −$2.00, −$1.50, −$1.00, −$0.50, $0, +$0.50, +$1.00, +$1.50, and +$2.00. The actual question posed to the respondents after a brief reminder of their budget constraint was:

> *Imagine that some aquaculture farms adopted this new technology and their IMTA fish were labeled as such by a reliable third party. This would reduce waste from those aquaculture farms relative to conventional aquaculture farms by [randomly assigned values 10% 20% 30% 40% 50%, coded into variable scope]. Imagine now, again where you normally buy salmon, that it is available in the size and quality you prefer and that there are no special sales on any other salmon. However, now IMTA salmon becomes available at a discount price/at the same price/at a price premium and it is easily identifiable by a label. The quality, flavor, freshness, color, and appearance would be the same as the equivalent salmon farmed with traditional techniques. Salmon farmed with traditional techniques would remain available at the price at which you normally buy it. If the price of IMTA salmon was [p_{IMTA0}] would you buy any?*

[11] These three different possibilities were randomized across respondents.

Respondents were also asked about their awareness of IMTA and their categorical responses were coded as ordinal variable *heard2*.[12] Because IMTA is a relatively new technology, most respondents were not familiar with it.

Since the description of the hypothetical shopping scenario mentioned that conventionally farmed salmon would remain available at the price at which the respondent normally bought it, we used P_{NOW} as the basis on which to apply the premium, or discount, if any, to construct P_{IMTA0}. However, since, as explained above, many respondents failed to supply a price for their current purchases and those who did provide inconsistent price levels, we had to impute P_{NOW} in 195 cases (identified by the indicator IMP_{NOW}) based on province of origin and shopping venue.

First, we asked respondents whether they would plan to buy any IMTA salmon at P_{IMTA0}. We lost 50 observations for the next demand estimation step, because 49 respondents answered 'don't know' and one respondent provided no answer.

Using their responses to whether they would purchase the IMTA version of Atlantic salmon once it became available, we could sort respondents into three categories. The first question identified those consumers who would not buy any IMTA salmon. For these consumers, we would know the price of conventional salmon (assumed to remain equal to P_{NOW}), the price of the newly introduced impure public good substitute (P_{IMTA0}), the stated quantity demanded of conventional salmon (labeled $meals_{CONV}$ and given by their value of $meals_{NOW}$), and the stated quantity demanded of IMTA salmon (since it would simply be zero), labeled $meals_{IMTA}$.

That same question allowed us to divert the rest of consumers to a second question that asked whether they would completely switch to IMTA salmon or not at a new proposed price P_{IMTA1}. In the first case, we would not know yet the new quantity demanded of IMTA salmon or the price. However, we would know about the price of conventional salmon (P_{NOW}) and the quantity demanded (which would be simply zero). On the other hand, if respondents declared that they were not planning to completely switch to IMTA salmon once available, we went on to ask them further questions in order to obtain information on $meals_{IMTA}$ and $meals_{CONV}$ under prices P_{IMTA1} for IMTA salmon and P_{NOW} for conventional salmon. With all this information combined about own-prices and price of the substitute salmon type, we could estimate two demand curves under IMTA salmon availability: one for IMTA salmon and one for conventional salmon.[13]

Most (200 or about 77%) of the respondents who said they would buy at least some IMTA once available and who provided an answer declared that they would switch completely to IMTA salmon once it became available at the initially suggested price P_{IMTA0}, revealing that they would demand zero conventionally farmed salmon at price P_{NOW}.[14] However, we did not know how much their farmed salmon consumption would change once they switched to IMTA salmon. They might increase consumption at a given price, since they would know that the negative externalities caused by their consumption would now be less, but could also keep their same purchase frequency.[15] In any event, since we proposed a price change (which, depending on the respondent could be null, a discount, or a premium) the quantity demanded could have been adjusted simply in response to the price differential, regardless of the change due to the different utility provided by the IMTA versus the conventional salmon. Therefore, we needed to further question them. We took the opportunity to also suggest a new price (P_{IMTA1}), so we would be able to more efficiently estimate the demand for IMTA salmon.

Table 2
Variable definition.

Variable	Label description
age	respondent's age with imputed missing values
anyimta	if the price of IMTA salmon was P_{IMTA0}, would you buy any?
BC	= 1 if respondent lives in British Columbia
BEFORE	= 1 if IMTA salmon was not yet commercially available
children	= 1 if there household members under 18 in the household
college	= 1 if respondent has at least some university education
CONV	= 1 if information is about conventional salmon when IMTA variety is available
firsttrier	= 1 if among the first to try new food products
fisher	= 1 if fished for sport within the last five years
heard	how much have you seen, heard, or read about IMTA?
hunter	= 1 if hunted within the last five years
IMTA	= 1 if information is about IMTA salmon
income	annual household income from all sources before taxes (with imputed missing values)
IMP_{NOW}	= 1 if imputed value was needed for P_{NOW}
labels	= 1 if usually reads labels on food products
male	= 1 if respondent is male
$meals_0$	number of farmed Atlantic salmon meals demanded when *BEFORE* = 1 at P_0
$meals_1$	number of farmed Atlantic salmon meals demanded when *BEFORE* = 1 at P_1
$meals_{CONV}$	number of conventionally farmed Atlantic salmon meals demanded when *BEFORE* = 0
$meals_{IMTA}$	number of IMTA Atlantic salmon meals demanded when *BEFORE* = 0
mealsizeinlbs	size of typical meal size to feed family in pound equivalents
member	= 1 if member of any national or international environmental organization
NOW	indicator of current consumption scenario (revealed demand data)
p_{IMTA0}	first proposed IMTA price in $/lb
p_{IMTA1}	second proposed IMTA price in $/lb to those who would switch completely to IMTA
P_0	first proposed price in $/lb
P_1	first proposed price in $/lb
P_{NOW}	estimated current price in $/lb
POP	estimated number of households in Canada
Pmeal	price per typical salmon meal in dollars per pound
P_{subs}meal	price per typical meal of substitute type of salmon in dollars per pound
scope	policy scope: % reduction of waste by IMTA farms relative to conventional aquaculture
wgt1	sampling weight
wild	= 1 if respondent prefers wild salmon

Finally, we asked respondents about their socio-demographic status (including question about age, education, and income).[16] In the end we stacked the original 525 observations into a pseudo-panel. Some of these observations had missing values for some of the meal frequency variables ($meals_0$, $meals_1$, $meals_{IMTA}$, $meals_{CONV}$), so the pseudo-panel we used contained 1429 observations, rather than the maximum possible of 2100 (525 cases times four data points), with the average number of data points being thus only 3.4 (ranging from 1 to 4).

The values of the variables used in the analysis are summarized in Table 3. Further details about the data and the data transformations can be found in a full unpublished report of the project (Martínez-Espiñeira et al., 2012).

The scope of the survey was national. However, since we wanted to ensure that we could find out about the preferences of consumers located in relative proximity to the coastal areas in Eastern Canada where ocean aquaculture is practiced, the sampling design was aimed at obtaining a 50–50 split between respondents from Atlantic Canada

[12] Original 'don't know' and 'no response' responses were deemed equivalent to category 1 "nothing".

[13] Note that our survey ignored the possibility that IMTA salmon turned non-buyers of salmon into buyers unless they went from stating 0 or "1 meal or less" under P_0 or P_1 to later stating at least "1 meal" under P_{IMTA0}.

[14] We again faced a serious issue of item non-response, since 32% of the 379 respondents did not come up with an informative response.

[15] Note how the converse would not be true for those who would choose not to take advantage of the availability of IMTA salmon at all. The axiom of revealed preference suggests that there would be no reason to expect that they would alter their consumption of conventionally farmed salmon just because a substitute became available.

[16] Some respondents did not volunteer their age and/or income, so missing values were imputed through a multiple imputation process based on their answers to other survey questions.

Table 3
Summary statistics.

Variable	Mean	Std. dev.	Min.	Max.	N
age	51.418	14.145	21	98	1429
BEFORE	0.58	0.494	0	1	1429
BC	0.024	0.152	0	1	1429
children	0.341	0.474	0	1	1429
college	0.758	0.429	0	1	1429
CONV	0.21	0.407	0	1	1429
firsttrier	0.199	0.4	0	1	1429
fisher	0.372	0.483	0	1	1429
heard	2.223	1.614	1	7	1429
hunter	0.143	0.35	0	1	1429
IMTA	0.21	0.407	0	1	1429
income	6.887	2.548	1	10	1429
IMPage	0.071	0.258	0	1	1429
IMPincome	0.136	0.343	0	1	1429
IMPpnow	0.354	0.478	0	1	1429
M	1.711	1.718	0	9	1429
male	0.5	0.5	0	1	1429
meals0	1.856	1.589	0	9	416
meals1	1.91	1.694	0	9	413
$meals_{IMTA}$	2.14	1.816	0	9	300
$meals_{CONV}$	0.807	1.502	0	8	300
$meals_{NOW}$	1.322	1.477	0	8	525
mealsizeinlbs	2.205	1.619	0.662	10	1429
member	0.114	0.318	0	1	1429
P_0	5.019	1.454	3	7	416
P_1	5.034	1.383	3	7	413
pIMTA	5.273	1.945	1	9	300
Pmeal	13.875	7.138	2.31	59.316	1429
Pnow	9.358	4.649	1.814	25.678	525
P_{subs}meal	13.875	7.138	2.31	59.316	1429
readslabels	0.945	0.227	0	1	1429
scope	30.7	14.145	10	50	1429
wgt1	0.689	0.793	0.081	3.143	1429
wild	0.498	0.5	0	1	1429

Table 4
Results of the random-effects negative binomial regressions on CBM demand data. Dependent variable is *M*, weight is *wgt1*, N = 1429.

	Model 1	Model 2	Model 3	
BEFORE	1.4449***	1.3775***	BEFORE	0.8361
Pmeal	−0.0166*	−0.0157**	Pmeal	−0.0324***
BEFORExPmeal	−0.0409***	−0.0402***	BEFORExPmeal	−0.0246
IMTA	1.1178***	1.0806***	IMTA	0.0746
IMTAxPmeal	−0.0015	−0.0023	IMTAxPmeal	0.0127
P_{subs}meal	0.0013	0.0006	P_{subs}meal	−0.0001
income	0.0207	0.0232	income	−0.0835**
			IMTAxincome	0.1084**
			BEFORExincome	0.0999**
scope			scopeIMTA	−0.0022
		−0.0048	scopeCONV	−0.0054
age			ageIMTA	−0.003
		0.0170***	ageCONV	0.0341***
wild			wildIMTA	0.0114
		−0.0224	wildCONV	−0.9985***
college			collegeIMTA	0.1476
		0.1975	collegeCONV	−0.2699
firsttrier			firsttrIMTA	0.0943
		0.2152*	firsttrCONV	−0.0148
heard			heardIMTA	−0.0288
		−0.0662**	heardCONV	0.029
fisher			fisherIMTA	0.0567
		0.0921	fisherCONV	0.2261
hunter			hunterIMTA	−0.5581**
		−0.0428	hunterCONV	−0.6383*
member			memberIMTA	0.0527
		0.2131	memberCONV	−0.7850*
labels			labelsIMTA	0.5407*
		−0.2396	labelsCONV	−0.8287***
BC			BCIMTA	0.2408
		−0.5018**	BCCONV	0.1693
children			childrenIMTA	−0.0587
		0.1675	childrenCONV	0.7348***
male			maleIMTA	0.1197
		0.1234	maleCONV	0.1789
IMPpnow	−0.2362**	−0.1791*	IMPpnow	−0.2259**
constant	2.4090***	2.4161*	constant	16.0619
ln(r)	3.5644***	4.4635***		16.471
ln(s)	0.9565***	1.1604***		0.8736***
Statistics				
χ^2	156	210		226
AIC	3161	3148		3106

Significance levels *: 10%, **: 5%, and ***: 1%.

and from the rest of the country, including the Canadian territories. Therefore, sampling weights (variable *wgt1*) were used during the econometric analysis to correct for the over-sampling of the former.

6. Results and discussion

6.1. Estimated demand models for IMTA salmon

As explained in Section 4.2, since our dependent variable (farmed salmon meals per month *M*) is a count, several versions of an econometric demand regression model suitable for count data were considered. The models based on the Poisson version were discarded in favor of those based on the negative binomial distribution, in order to account for the overdispersion in the dependent variable. Assuming that all the data could be pooled, and thereby ignoring the intra-respondent correlation among the values of *M*, a pooled-data negative binomial regression would ignore the pseudo-panel structure of the stacked data. This would result in underestimated standard errors of the coefficients, since the observations from a given respondent are not actually independent. On the other hand, the random-effects negative binomial regressions that we finally report in Table 4 (labeled as Models 1, 2, and 3, corresponding to the specifications given by Eqs. (7), (6), and (5) in Section 4.2) do take the pseudo-panel structure of the dataset into account. The relevant likelihood-ratio tests rejected the null hypothesis that the pooled model was valid in all three cases of Models 1, 2, and 3.

While restricting coefficients β_7, β_8, and $\beta_{k'}$ in Eq. (5) to take the value of zero, so no interactions with income of any other socio-demographic covariates were considered, Models 1 and 2 in Table 4 allow for a different intercept and a different slope between the stated current demand for farmed salmon (the equation that jointly explains $meals_0$ and $meals_1$) and the ones driving the purchasing choices once IMTA salmon becomes available in shops (when *BEFORE* is 0). Model 2 also introduces in the model covariates other than *income*, variables whose effect had been left to build the intercept coefficient in Model 1.

In the relatively restrictive Models 1 and 2, both the indicator *BEFORE* and its interaction with the price are significant, suggesting that respondents respond differently to hypothetical questions about their conventional salmon purchases depending on the policy scenario presented to them (given by the availability of IMTA salmon). The positive sign of *BEFORE* shows that the intercept of the linear component of the demand curve for conventionally farmed salmon would decrease once IMTA salmon became available, while the negative sign on the interaction of *BEFORE* with the price per meal suggests that the price-elasticity of the demand for conventional salmon would decrease and the consumer surplus per meal would increase once IMTA salmon became available.

The other fixed effect is the indicator of whether we were referring to conventional salmon or IMTA salmon once available (again allowing for additional slope and intercept differences between farming techniques in the demand curve). The coefficient of *IMTA* is positive and significant in both Models 1 and 2. This means that the IMTA demand curve would have a higher intercept than the one for conventional salmon with both salmon types available. However, since the coefficient of *BEFORE* is larger than the one on *IMTA*, the intercept of the original demand curve would be estimated as higher than its counterparts for both new curves (*IMTA* and *CONV*).

The non-significant estimated interaction term between *IMTA* and *Pmeal* suggests no significant differences in price-elasticity of demand depending on farming technique either. The coefficient of $P_{subs}meal$[17] is not significant either, which indicates that the two varieties of salmon products would not be considered close substitutes by consumers.

We would normally expect *income* to positively affect farmed salmon demand (confirming it as a normal good) but our results suggest that it would not significantly affect demand in Models 1 and 2, suggesting that farmed salmon is income-inelastic. It is likely that, although seafood products in general, and salmon in particular, are normal goods, farmed seafood in particular, including farmed Atlantic salmon, could be income-inelastic because of the existence of superior close substitutes, namely their wild counterparts. Model 3, however, adds interactions between *income* and both indicators *BEFORE*, and *IMTA* to test whether the income effects could be different across demand scenarios. Not only is the coefficient of the interaction between *IMTA* and *income* significantly positive, suggesting that richer households would be willing to buy IMTA salmon at a higher premium but also, when both types of farmed salmon become available, IMTA salmon would be a normal good and the conventionally farmed salmon would become inferior, as revealed by the negative and significant coefficient of income. Interestingly, the estimated cross-price elasticity remains statistically non-significant, suggesting that these two varieties of salmon products would not be considered close substitutes.

Furthermore, in Model 3 the indicator *IMTA* is no longer significant, which suggests that most of the premium for IMTA salmon estimated under Model 1 was due to the fact that it would become a normal good, as opposed to its conventional counterpart, and also due to the other effects considered through the inclusion of the interactions between *IMTA* and *CONV* and the additional covariates in Model 3. That is, most of the premium that consumers would be willing to pay for IMTA salmon would be explained by the differences between income elasticities across demand scenarios, and differences in elasticities with respect to education, age, and so on. Similarly, the differences in intercept and slope between the demand curves for conventional salmon before and after the availability of IMTA salmon become non-significant once we control for the differential effect of socio-demographics between *IMTA* demand and *CONV* demand. In particular, we see that the fact that conventionally farmed salmon would become an inferior good once *IMTA* surfaced as an alternative contributes to the initially detected (under Models 1 and 2) difference between demand curves *BEFORE* and *CONV*. This applies to a few other covariates as well, as explained below.

When it comes to the effects of covariates other than own prices, substitute prices, and income, we find that variable *scope* is not significant, suggesting that consumers would just concern themselves with choosing the more environmentally-friendly option when shopping for salmon, without worrying about *how much more* environmentally friendly that option were to be.[18]

[17] Note that in the case of demand functions other than those for *IMTA* salmon or its substitute, $P_{subs}meal$ simply took an artificial value equal to the own price *Pmeal*. This could certainly lead to a loss of significance of the estimate coefficient of $P_{subs}meal$. However, we also checked that its interaction with indicator variable *IMTA* was clearly not significant.

[18] Scope insensitivity is a recurrent issue in this type of valuation studies and indeed a key criticism of stated preference valuation methods (Desvousges et al., 2012; Hausman, 2012). It has been argued (Heberlein et al., 2005), however, that the inability to pass conventional scope sensitivity tests does not necessarily imply that the WTP estimate is invalid, since it may be due to reasons consistent with economic and psychological theories. Respondents may, for example, see the "part" and the "whole" as two different goods, preventing a meaningful direct comparison of mean benefit estimates between the "part" and the "whole" (Boman and Bostedt, 1999). In our case, respondents failed to understand the policy scope in a quantitative fashion, since it is difficult for them to know how much environmental damage salmon farming might be causing in the first place. They responded instead to *scope* in a qualitative fashion, stating that they would alter their farmed salmon purchasing patterns in response to the fact that the farming would become cleaner, not being sensitive to how much cleaner. Therefore, we cannot rely on the validity test implied by the estimated coefficient of scope to add support to the validity of our valuation exercise.

Model 2 indicates that older respondents tend to purchase significantly more farmed Atlantic salmon than younger people in general. However, once we abstract from the effect of *age* on consumption of farmed Atlantic salmon in general (by lumping it together with the effects of all covariates other than *income* in the intercept of Model 3) and try to differentiate instead between the effect of covariates on the consumption of IMTA salmon versus its conventional counterpart, an interesting split in the direction of the effect arises. We see that *age* positively affects the purchase frequency of conventionally farmed salmon only, while having a negative effect, if non-significant, on IMTA salmon.

Consumers who prefer wild salmon to farmed salmon, not surprisingly, purchase farmed salmon less frequently in general than other consumers. Interestingly, however, we see from the coefficients of the interaction terms *wildIMTA* and *wildCONV* in Model 3 that the significant and negative effect of variable *wild* would apply only to the demand for conventional salmon. The interaction between *wild* and IMTA, although positive, is not significant. This suggests that, although those who prefer wild salmon would clearly appreciate the difference between IMTA salmon and conventionally farmed salmon, this translates only into a strong negative effect on the demand for the latter, while the use of IMTA techniques does not seem enough to convince them that farmed salmon is a better choice than wild salmon. Basically, knowing that a cleaner IMTA option for farmed salmon was available would turn these consumers farther away from conventionally farmed salmon in particular but would not be enough to significantly attract them to farmed salmon in general.

Having a university education (measured by the binary variable *college*) does not have a significant effect on salmon consumption, perhaps because, although seafood consumption may be positively associated with education attainment levels, the effect is not significant for the farmed variety.

Those who describe themselves as the usual first triers of new products would consume farmed salmon in general more frequently. However, although we see in Model 3 a split in sign into the expected positive effect on IMTA salmon demand and the negative one on demand for conventionally farmed salmon, these effects are both non-significant.

Those who had already *heard* about IMTA salmon when completing our survey tend to purchase farmed salmon significantly less frequently than the average consumer. This suggests that perhaps most of the information received before the survey about IMTA had made consumers wary of farmed salmon. It might be particularly important, as a policy recommendation, to assuage concerns based on wrongly perceived similarities between IMTA and mad cow disease, for example. Fears relating to this disease and genetically modified foods (or "Frankenfish") had, for instance, been raised by participants in a study conducted by the Canadian Department of Fisheries and Oceans (DFO, 2005), contributing to negative perceptions of aquaculture in general. Although recycling of food in an IMTA system was not directly addressed by that study, improving information about how IMTA works might result in an increased demand for its products. Our results are far from conclusive in this regard, not least because most of our respondents knew very little about IMTA (as shown by the low sample mean value of the variable *heard*).

Being a *fisher* does not seem to be a significant driver of any type of demand for farmed salmon. On the other hand, *hunters* would consume less of both types of farmed salmon once IMTA becomes available. Not surprisingly, *members* of environmental organizations would demand significantly less conventionally farmed salmon if able to purchase IMTA salmon.

From the interpretation of the estimated coefficients of the interaction terms *labelsIMTA* and *labelsCONV* in Model 3, we see too that there is a negative significant effect of variable *labels* on conventional salmon demand but a significant positive effect on IMTA. This is good news for IMTA: those who read food labels would be less keen on conventionally farmed salmon but feel attracted to the so-called *process attributes* of IMTA salmon.

We also observe that, perhaps due to the long-standing controversies about aquaculture in that province, British Columbia (*BC*) consumers tend to demand significantly less farmed salmon in general. This is particularly interesting, since the availability of farmed salmon in BC would lead one to expect the reverse. Despite this finding, there are no significant effects on the differential between IMTA and CONV demands due to the effect of the binary indicator variable *BC*.

Although households with children do not consume farmed salmon with a significantly different frequency, they would stick to conventionally farmed salmon when IMTA became an option. We suspect that this effect might be related to the misperceived fears described above equating IMTA to a form of genetic manipulation whose effects might only be observed in the very long run. Further research is needed to uncover the role that this perception might play in consumer behavior.

Finally, we tested the hypothesis that having imputed values of P_{NOW}, *income*, and *age* did not significantly affect results by introducing indicators flagging those observations for which these variables had originally missing values. Only the indicator for p_{NOW} was significant suggesting, not surprisingly, that those who did not come up with an estimate of the price of farmed salmon were those who bought it less frequently. We report the results of regressions for which the coefficients on the indicator variables that identify cases for which *age* and *income* had to be imputed, are constrained to be equal to zero, since they showed no statistical significance in the corresponding unrestricted regressions.

6.2. Estimating consumer surplus for IMTA salmon

Economists measure the welfare effects on individuals associated with different policies and changes in economic conditions mainly by analyzing changes in consumer surplus (CS). Geometrically, the CS can be found as an area bounded by the inverse demand curve and a horizontal line at the height given by the current price. When a policy involves a shift in the relevant demand curve, as in our case, the associated welfare change (the change in CS) can be measured as the area between the two demand curves corresponding to the situation before and after the policy and bounded by current and choke prices.

Mathematically, the formula to calculate consumer surplus depends on the functional form of the demand curve. In our case the CS per meal can be calculated as the inverse of the coefficient of the own price coefficient, since we use a negative binomial regression with a semilogarithmic functional form.[19] Further details on the calculation of consumer surplus and its theoretical background can be found elsewhere (Beaumais and Appéré, 2010; Bockstael et al., 1987; Creel and Loomis, 1991; Haab and McConnell, 2002; Whitehead et al., 2000).

The estimation of the expected change in CS generated by the adoption of IMTA was measured as the difference between the sum of areas under the two new demand curves (conventional salmon under IMTA and IMTA salmon) and the area under the original one (conventionally farmed salmon only) all bounded by current and choke prices. More simply, for those who would switch completely to IMTA salmon only a change from their original demand curve to their new one would have to be considered. For those who would not buy any IMTA salmon, no gain in CS would have to be considered. The change in CS per meal would be obtained in each case, since the price was measured per meal. By multiplying these predicted changes in CS per meal by the predicted number of salmon meals of each salmon type consumed per month by the average consumer, we would obtain equivalent measures of monthly CS. The differences in the estimated size of CS *per meal* would depend only on slope differences across the different demand curves. However, the differences in the predicted value of meals *per month* would depend both on differences in intercepts and in slopes.

[19] This specification guarantees that the expected number of meals be positive. An individual's expected demand asymptotically approaches zero as the price increases.

There are three demand equations to consider (as shown in the last column of Table 1), one for current stated demand of conventional salmon at hypothetical prices (labeled *BEFORE*); one for IMTA salmon (labeled *IMTA*); and one for conventional salmon with IMTA available (labeled *CONV*). Therefore, we can denote the change in CS per month (Huang et al., 2004; Kragt et al., 2009; Whitehead et al., 2000) across the two demand scenarios as:

$$\Delta CS = \left(\frac{\hat{M}^{IMTA}}{-\hat{\beta}^{IMTA}_{Pmeal}} + \frac{\hat{M}^{CONV}}{-\hat{\beta}^{CONV}_{Pmeal}}\right) - \frac{\hat{M}^{BEFORE}}{-\hat{\beta}^{BEFORE}_{Pmeal}} \quad (8)$$

where $\hat{M}^{IMTA}$ is the predicted number of IMTA salmon meals, $\hat{M}^{CONV}$ is the predicted number of conventionally salmon meals (when IMTA salmon is also an option), $\hat{M}^{IMTA}$ is the predicted number of farmed salmon meals before IMTA is available as an option, and the estimates $\hat{\beta}$ in the denominator correspond to the relevant *Pmeal* in each of the demand functions (each in principle constructed as a combination of the estimates of β_2, β_3, and β_5 from Eq. (5)).

Using the set of estimates from Model 3, reported in Table 4, and setting all the independent variables other than the price at their average values when calculating the predicted number of meals,[20] we could obtain the change in consumer surplus following Eq. (8).

However, since Model 3 yields estimates of the own price coefficient $\hat{\beta}_{Pmeal}$ that are not significantly different across demand scenarios, Eq. (8) simplifies to:

$$\Delta CS = \left(\frac{\hat{M}^{IMTA}}{-\hat{\beta}_{Pmeal}} + \frac{\hat{M}^{CONV}}{-\hat{\beta}_{Pmeal}}\right) - \frac{\hat{M}^{BEFORE}}{-\hat{\beta}_{Pmeal}} = \frac{\hat{M}^{IMTA} + \hat{M}^{CONV} - \hat{M}^{BEFORE}}{-\hat{\beta}_{Pmeal}}. \quad (9)$$

The predicted level of CS per meal before IMTA salmon became available would be $\frac{-1}{-0.0324} =$ CAD 31 (given by the inverse of the highly significant[21] estimated price coefficient $\hat{\beta}_{Pmeal}$ from Model 3). We can check, before proceeding further, that this value falls within the ballpark of other estimates found in the literature. For example, Alfnes et al. (2006), using data for Norway for 2004 found that the willingness to pay for salmon ranged between NOK/Kg 33.87 and NOK/Kg 154.14, which translates into around CAD 5.75/meal and CAD 26.17/meal. These figures are comparable to the CAD 31/meal estimated in our study, most of all once we take into account the fact that we surveyed different countries and almost 10 years apart. Similarly, Chern et al. (2002) estimated the willingness to pay for non-genetically modified salmon in the US and Norway at the equivalent of between $15.41 and $18.63 per meal of the typical size used in our sample. No values are available for the equivalent type of comparison for the two hypothetical scenarios, since this is, to our knowledge, the first time that the willingness to pay for IMTA versus conventionally farmed salmon has been investigated.

We proceed to calculate the change in average monthly CS afforded by the hypothetical introduction of IMTA salmon by considering that the predicted number of monthly IMTA salmon meals would be 2.2 and the predicted number of conventionally farmed salmon meals would be 0.93 (their difference being highly significant with a standard error of 0.056), while the original number of meals per month would be predicted at 1.73.[22] Following from Eq. (9), our estimations would

[20] Following Whitehead et al.(2008), we used predicted values of farmed salmon meals in each case to estimate the predicted level of consumer surplus per month. This choice assumes that the dependent variable was measured with error (Bockstael et al., 1987).

[21] The 95% confidence interval obtained with Krinsky–Robb's method (Krinsky and Robb, 1986; Krinsky and Robb, 1990) using 10,000 replications is $18.74 to $86.17. In simple terms, this procedure generates 10,000 random draws from the distribution of the estimated parameters and from them generates 10,000 consumer surplus estimates. The estimates are sorted in ascending order and the 95% confidence interval is found by eliminating the bottom and top 2.5% of those estimates (e.g. Morgan et al., 2013).

[22] The standard errors of the difference between $\hat{M}^{IMTA}$ and $\hat{M}^{BEFORE}$ (0.035) and $\hat{M}^{CONV} - \hat{M}^{BEFORE}$ (0.041) also confirm that the differences in predicted number of meals would be significant.

suggest that introducing IMTA salmon would increase the average salmon consuming household's welfare by

$$\Delta CS = \frac{2.20 + 0.93 - 1.73}{0.034} = \text{CAD } 41/\text{month} \tag{10}$$

if it is assumed that the hypothetical demand obtained from analyzing $meals_0$ and $meals_1$ reasonably approximates the actual demand relationship.

This result represents a relatively large increase in monthly CS due to the introduction of IMTA salmon. The increase in CS in this case can be matched to our theoretical predictions. The overall level of CS would rise (assuming no changes in the surplus per meal) only because, although, as expected, the predicted number of meals of conventionally farmed salmon would be lower than the number of meals before IMTA, the predicted number of IMTA meals would rise even above that original level of meals, so overall the predicted number of meals would be much higher.

However, and although this effect only appears significant in the more parsimonious Models 1 and 2, it can also be seen by looking at the signs and sizes of the coefficients of the interactions of the price variable and the demand scenario indicators suggest that, with IMTA salmon available, consumers would derive more benefit per salmon meal. This would apply not only, and particularly, in the case of IMTA salmon but also in the case of conventionally farmed salmon. That is, the labeling of the farmed salmon would allow both those who favor IMTA salmon and those who disfavor it to enjoy each of their farmed salmon meals more on average. In essence, since the average consumer would enjoy knowing "which is which" in terms of the salmon farming technique, the consumer surplus per meal would increase in both cases. In sum, having IMTA salmon available and appropriately labeled would increase consumer welfare, because all consumers would each enjoy more their salmon consumption and because they would, therefore, consume salmon more often. In other words, the availability of IMTA salmon would increase demand for farmed salmon both at the intensive (for both types of salmon) and at the extensive (in the case of IMTA salmon only) margins. The variability in our data allows us to show only the first of these two effects using Model 3, which includes a rich specification of sociodemographic effects, so, by reporting changes in consumer surplus that account only for changes in the predicted number of meals, we are reporting a conservative measure of the welfare benefit from introducing IMTA salmon.

Assuming that the proportion of salmon consumers in our sample approximates correctly the proportion of salmon consumers in the population, a reasonable estimate of the aggregate monthly surplus would be $POP \cdot \$41 \cdot 419/1246$, where POP is the number of households in the whole Canadian population and $N = 1246$ is the size of our sample. However, since we over-sampled salmon consumers, discarding 412 responses of non-buyers, an estimate of $POP \cdot \$41 \cdot 419/1658$ would better account for the expected proportion of salmon buyers in the population. $POP \cdot \$10.4$ would then be a reasonable estimate of the welfare increase obtained by Canadians if our sample were representative. Since we obtained a response rate of 18%, an even more conservative estimate would be $POP \cdot \$10.4 \cdot 0.18$. This ensures that there is no overestimation of the effect of IMTA through the increased welfare of salmon purchasers by mistakenly exaggerating the proportion of salmon buyers in the general population, by being mislead by having over-sampled more keen salmon buyers or more environmentally friendly ones, etc. In sum, a most conservative estimate of the increase in welfare per salmon purchasing household would be $POP \cdot \$1.872$/month. A conservative estimate for POP would be 12,435,520 the 2006 Census value for the *number of private dwellings occupied by usual residents* in Canada (Statistics Canada, 2006). These calculations would yield a benefit generated by the introduction of IMTA because of its value to habitual salmon purchasers of about \$23.3 million/month (or about \$280 million/year), based on Model 3 and would represent, due to the several choices described above, the lowest bound for that measure of welfare value according to all of our specifications and assumptions.

The relaxation of the main and most likely most stringent of these conservative assumptions, namely assuming that the sample of respondents who agreed to complete our survey was reasonably representative of the Canadian population in terms of their demand for IMTA versus conventionally farmed salmon, would lead to an estimated change in consumer surplus of around \$1.5 billion per year.

The relative economic significance of these results can be put in perspective by considering that the Canadian aquaculture industry currently generates about \$1 billion in sales annually, employing over 14,500 Canadians (Salmon, 2014). Within the total of the aquaculture industry, farmed salmon is by far the most important finfish species grown in Canada. For example, with a production volume of 123,949 tonnes and a value of \$599 million, farmed salmon accounted for over 80% of volume and value of finfish produced by Canada's aquaculture industry in 2012 (AquaStats, 2012; NLDFA, 2014).

Furthermore, in order to provide a basis to establish the validity of our results, we can compare them with those obtained in similar studies. For example, Parsons et al. (2006) estimated from 2001 data changes in per-meal consumer surplus estimates for seafood consumers following a health risk announcement and the effects of different positive information treatments. Their estimated aggregate welfare change (a loss in their study) following news of a local harmful algal bloom (HAB) event was about \$720 million per year across the Mid-Atlantic region of the USA.[23] Similar results were obtained from different analyses of the same data by Whitehead et al. (2003).

Morgan et al. (2013) conducted a similar contingent behavior study of oyster consumers in the USA and estimated individual consumer surplus measures of between \$24 per month and \$46 per month associated with responses to information and food safety technology treatments.

In both cases, we find that our welfare estimates, although smaller, likely because we are comparing them with analysis of the effects of information about food safety issues, fall within the same order of magnitude of those obtained by earlier studies.

This said, it would always be advisable to improve the reliability of our estimates by increasing not only the sample size but also its geographical scope and the sampling period, since there might be an increased awareness of the benefits of IMTA salmon as this new product slowly penetrates the retail markets.

7. Conclusions

In this paper we undertook the estimation of the non-tangible benefits for current farmed salmon consumers resulting, because of the decrease in external costs imposed on the surrounding marine environment, from the adoption of IMTA techniques in farming of Atlantic salmon. Our contingent behavior analysis suggests that, even under the most conservative assumptions, there would be sizable benefits enjoyed by current consumers if a substantial proportion of aquaculture producers adopted this novel production technique.

In fact, we estimated these benefits to be a minimum of \$280 million/year. This would be a lower bound, because it conservatively accounts for sample selection issues related to our typically low response rate, not extrapolating beyond that proportion of population households, and because it does not consider that some current non-consumers could start enjoying some benefits from salmon consumption once it became available. In fact, just by relaxing the first assumption, assuming that our sample is reasonably representative of Canadian consumers of farmed salmon, we arrive instead at an estimated change in consumer surplus of around \$1.5 billion per year.

[23] Comprising Delaware, Maryland, Washington D.C., Virginia, and North Carolina with about a population of 13 million and a 42% estimated proportion of seafood consumers.

Our results indicate that successful acceptance of IMTA salmon depends on consumers clearly distinguishing between conventionally farmed salmon and IMTA salmon. Since the two types of farmed salmon are not close substitutes, the distinguishing element can be easily highlighted through proper labeling, which, itself, has a significant positive effect on the demand for IMTA salmon.

We also found that those consumers who knew more about IMTA salmon when being interviewed purchase farmed salmon significantly less frequently than the average consumer and might also be less willing to purchase IMTA salmon. Therefore, it might be worthwhile to direct informational efforts to alleviate concerns based on mis-guided perceptions of IMTA products as potentially harmful for one's health.

We have not considered differentials in the price elasticities depending on whether we consider a decrease in price from the status quo or an increase in price. That is, we consider just fully linear components explaining the purchase frequency rates in our demand curves, not allowing for kinks at the current price–quantity combination. Further work should consider further increasing the flexibility of the demand specifications, allowing, for example, for different slope effects of covariates other than price and income depending on whether we are considering conventional or IMTA salmon.

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