Do U.S. consumers value genetically modified farmed salmon?

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Abstract

Although genetically modified (GM) crops and non-animal food products already exist in the market, GM salmon is the first animal GM product approved for human consumption. Genetic modification in the food industry is a highly controversial issue. Understanding of consumers' preferences for GM salmon, especially in comparison to their tradeoff between conventionally farmed and wild-caught salmon, is limited. We use a choice experiment to estimate U.S. consumers' willingness to pay for GM farmed salmon and examine heterogeneity in preferences across levels of consumer perceptions, knowledge, and attitudes. Our results show that U.S. consumers are willing to pay significantly less for GM farmed salmon than conventionally farmed salmon, suggesting their opposition to GM farmed salmon. Consumers who perceive farmed fish as healthier and safer, who are more concerned about the environmental sustainability and welfare issues for wild-caught than farmed fish, and who have a positive attitude toward GM food and technology are more likely to accept GM farmed salmon. Consumers have a larger differentiation in their valuation between wild-caught and farmed salmon in fresh form than frozen form.

Keywords

Genetical modification, farmed salmon, wild-caught salmon, consumer preference

Introduction

Aquaculture is the fastest growing food production sector in the world, which provides sustainable protein supply to the world's increasing population and contributes to food security (FAO, 2018). While aquaculture production is increasing fast, wild fisheries have limitations on supply growth. Since 2014, aquaculture has provided more fish for human consumption than wild fisheries; it is projected that aquaculture will provide 60% of the fish for human consumption by 2030 (FAO, 2018). The U.S. creates a significant demand for seafood, but it ranks 17th in total aquaculture production in the world (NOAA Fishwatch, 2022). The growing demand for seafood in the U.S. is largely met by imported aquaculture seafood products. U.S. consumers consumed 19.2 pounds of seafood per capita in 2019 and salmon is ranked second with a per capita consumption of 3.1 pounds, a 0.54 pounds increase from 2018 (Kearns, 2021). Although the U.S. supplies about one-third of the world's wild salmon, U.S. consumers' salmon consumption has been supplied by rising imports of farmed salmon. About two-thirds of U.S. salmon consumption is imported, and about two-thirds is farmed (Knapp et al., 2007; Knapp, 2014).

Technology advancement drives the growth and expansion of the aquaculture sector (Fletcher, 2020). The emergence of salmon aquaculture has increased salmon supply and made salmon more accessible and affordable to consumers (Knapp et al., 2007). Compared to wild-caught salmon that is captured by fishers in the natural salmon habitat using commercial fishing techniques, farmed salmon's breeding, feed, and health are controlled by the farm operators. However, consumers worry about the risks of contamination and exposure to antibiotics or other harmful substances used in some aquaculture productions (Roheim et al., 2012). Although wild-caught salmon are typically considered more natural, cleaner, and of higher quality, their availability depends on season and logistics. Some consumers are also concerned about the depletion of wild fish stock due to overfishing and the environmental impact of fisheries.

In addition to the debate about the pros and cons of wild-caught versus farmed salmon, genetically modified (GM) salmon made a new addition to the seafood world recently. Approved by FDA in 2015 to be produced at foreign facilities and in 2018 at U.S. domestic facilities (U.S. Food & Drug Administration, 2022), GM salmon turned out to be the first GM animal to be approved for human consumption (Clausen et al., 2016; Grossman, 2016). GM farmed salmon is farmed Atlantic salmon (*Salmo salar*) that is genetically modified to reach a growth marker important to the aquaculture industry. GM salmon grows more rapidly than its non-GM farmed counterpart because it contains an rDNA construct that is composed of the growth hormone gene from Chinook salmon (*Oncorhynchus tshawytscha*) under the control of a promoter (a sequence of DNA that turns on the expression of a gene) from ocean pout (*Zoarces americanus*). This allows the salmon to grow faster and reduces the amount and cost of feed that is needed to produce the fish (Smith et al., 2010; Waltz, 2016; U.S. Food & Drug Administration, 2022). The salmon industry believes GM salmon is more sustainable due to reduced transportation efforts and an in-land controlled growing environment (Conrow, 2021).

GM crops and non-animal food products already exist in the market and researchers have studied consumer perspectives on GM foods. However, GM salmon is the first animal GM product approved. Similar to non-animal GM food products, GM salmon has created considerable controversy and debate among the industry, conservation groups, and consumer community. While some advocate groups believe that GM salmon will take the pressure off wild fish stocks and help provide protein sources to a growing population worldwide, some conservation groups are concerned about its impact on ecosystems. For most consumers, GM salmon is still a product concept and there is limited information about consumers' views about GM farmed salmon. It is also unknown if consumers have similar and robust views about GM salmon or if there is preference heterogeneity across important factors. Hence, due to the controversial nature of GM salmon, there is a need to gain a better understanding of consumers' preferences and valuation for the GM salmon to help policymakers and the aquaculture industry evaluate the market potential of GM salmon and design policies and strategies that meet consumers' needs if they were to consume GM animal in the future.

Few studies have investigated consumers' valuation for GM salmon by directly eliciting consumers' willingness to pay (WTP) for GM salmon using alternative price scenarios (Chern et al., 2002), contingent valuation with two Yes-No questions (Kaneko and Chern, 2005), or a multiple price list (Rickertsen et al., 2017). However, to our best knowledge, no other study has examined consumers' valuation for GM salmon in comparison to the conventionally farmed and wild-caught salmon, which is a real choice scenario facing consumers when purchasing salmon. No study has investigated the important factors determining preference heterogeneity of consumers' valuation for GM salmon.

In this paper, we aim to contribute to the literature by providing a comprehensive understanding of U.S. consumers' valuation for GM salmon, how it adds to their choices between non-GM farmed and wild-caught salmon, and what factors affect their valuation for GM salmon, which is expected to benefit policy design and implementation, labeling regulation, and marketing strategies for GM salmon. Specific objectives include: 1) estimating consumers' WTP for GM farmed salmon, in comparison to conventionally farmed salmon and wild-caught salmon; 2) examining if there is heterogeneity in consumers' preferences for GM salmon across important consumer characteristics; 3) providing helpful information about consumers' preference for salmon using GM technology which potentially helps policymakers and industry stakeholders make market-driven decisions.

Literature review

Consumer preferences for wild-caught vs. farmed salmon

A vast amount of research has investigated consumers' preferences for wild-caught versus farmed salmon. Most studies find that consumers prefer wild-caught over farmed salmon, and are willing to pay more for a wild-caught salmon product (Jaffry et al., 2004; Davidson et al., 2012; Roheim et al., 2012; Uchida et al. 2014; Bronnmann and Asche, 2017; Rickertsen et al., 2017; Bronnmann and Hoffmann, 2018; Zheng et al., 2021). One exception is Holland and Wessells (1998) that shows consumers in northeastern and mid-Atlantic U.S. prefer farmed over wild-caught salmon.

In terms of consumers' perceived differences between wild-caught and farmed fish, Verbeke et al. (2007) shows that Belgian consumers perceive that wild-caught fish has a better taste, is healthier, and somewhat more nutritious than farmed fish, but farmed fish is more available. Rickertsen et al. (2017) finds that French consumers perceive that wild-caught fish is safer and healthier and farmed fish is more environmentally sustainable and has higher welfare. Especially, consumers who were more concerned about the health issues of consuming wild-caught salmon placed a higher value on farmed salmon.

Consumer preferences for GM foods and crops

Genetically modified organisms (GMOs) have been available for commercial purchase since the 1990s, allowing producers to plant herbicide-resistant and insect-resistant varieties to increase crop yields (Wunderlich and Gatto, 2015). The primary GM crops grown commercially include herbicide and insecticide resistant soybeans, corn, cotton, and canola, virus resistant sweet potato, iron and vitamin enhanced rice, and a variety of extreme weather resistant plants (Bawa and Anilakumar, 2013). The use of GMOs in the food industry is a highly controversial topic (Andrews, 2015). Public concerns about GM foods and crops commonly focus on food safety, environmental risks, ethics, food labeling, food security, and poverty reduction (Bawa and Anilakumar, 2013; Zhang et al., 2016). Consumers show opposition to GM food (Noussair et al., 2004), do not prefer GM foods or foods made with GM ingredients, and are willing to pay less for foods with the presence of GM labels or pay more for foods with non-GM claims (Hu et al., 2006; Volinskiy et al., 2009; Gao et al., 2019).

Research has shown that consumers' perceptions, knowledge, and attitudes play a role in affecting their WTP for GM foods. Consumers perceive that GM food is unsafe for consumption (Huang and Peng, 2015) and their concerns about GM food safety is a critical determinant of WTP (McFadden and Malone, 2018). Information about potential health and environmental benefits decreases the amount of monetary compensation needed to consume GM foods, i.e., increases their WTP (Lusk et al., 2004; Jaeger et al., 2004; Rousu and Lusk, 2009), while exposure to the negative perspective of the biotechnology reduces consumers' WTP for GM foods (Huffman et al., 2004; McFadden and Huffman, 2017; Lee et al., 2018; Valente and Chaves, 2018). It is shown that attitude towards GM food is an important predictor of purchase intention of GM food (Zhu et al., 2018) and consumers with a positive attitude toward the biotechnology use in food products need a smaller discount to purchase GM foods (Grimsrud et al., 2004).

Consumers across the world have been showing limited understanding, misconceptions, and unfamiliarity with GM food products (Wunderlich and Gatto, 2015). For example, Wunderlich and Gatto (2015) shows that consumers who are more familiar with GMO tend to be more resistant to bioengineering, while Weir and Sproul (2019) finds that people familiar with GM technology are more likely to be open to consuming GM seafood or seafood with GM feeds. Wunderlich and Gatto (2015) pointed out that consumers who have higher scientific knowledge have less negative attitudes toward GMOs. In contrast, Zheng et al. (2108) shows that consumers with higher subjective knowledge of GM food are less likely to pay for GM food (Zheng et al., 2018).

Consumer preferences for GM salmon

Unlike GM crops, the commercialization of GM livestock and fish is limited and the majority of them are only at the research stage (Forabosco et al., 2013). GM fish, primarily salmon, carp, and tilapia, is modified with the intention of improving economically important traits such as increased growth rates, increased temperature tolerance, and improved disease resistance (Forabosco et al., 2013; Olufeagba, 2015). However, consumers' concerns about the health and environmental risks and aversion of GM foods affect their salmon choice (Weir and Sproul, 2019). Environmental concerns arise if GM fish escape from the aquaculture facilities into the wild and interact with wild species and transfer diseases and parasites (Olufeagba, 2015).

Since the FDA approval of commercial use of AquAdvantage salmon, the first engineered animal for human consumption by a leading U.S. aquaculture corporation AquaBounty Technologies Inc, industry and corporate investors have been championing the development of salmon biotechnology (Clausen et al., 2016). However, the market potential for GM salmon is still relatively unknown. A number of grocery chains such as Costco Wholesale, Kroger, Safeway, Aldi, Whole Foods, Trader Joe's, Hy-Vee, Target, Meijer, and restaurants such as Red Lobster, announced they will not sell or serve GM salmon. Some consumer groups and activists also called for consumers to boycott AquAdvantage salmon (Grossman, 2016).

Survey and Data

We conducted a survey that includes a choice experiment to elicit consumers' preferences for GM farmed salmon vs. non-GM farmed salmon or wild-caught salmon, in fresh or frozen form. In the choice experiment, each choice set is composed of two alternative 1 lb. salmon fillets and a no-buy option. Each salmon fillet is composed of three attributes that include production method, product form, and price. Table 1 presents the product attributes and levels used in the choice experiment.

The production method includes three levels: non-GM farm-raised, GM farm-raised, and wild-caught salmon. The non-GM farmed salmon is Atlantic salmon farmed and harvested under controlled conditions without genetic modifications. GM farmed salmon is farmed Atlantic salmon that is genetically modified under controlled conditions. Wild-caught salmon is captured by fishers in their natural habitat using commercial fishing techniques. The wild-caught salmon live and breed in their native bodies of water. Humans have no control over their breeding, feeding, or health.

The product form attribute includes two levels, fresh and frozen. The product form attribute is tightly related to the production method of salmon. Although fresh wild-caught salmon is limited in the market due to season and logistics constraints, the advance of rapid deep-freeze technologies helps capture the quality of the salmon and increase its availability throughout the year with lower prices. For some consumers, frozen salmon is considered more sustainable since it is more convenient and produces less waste (Benwick, 2018). Hence, to understand consumers' GM salmon preference, it is important to take into consideration the product form and its interaction with the production method.

The price includes six levels, $4.99, $7.99, $10.99, $13.99, $16.99, and $19.99, which were determined based on a range of observed prices for 1 lb. fresh or frozen salmon fillets sold in stores or online.

Given our use of the stated preferences method, we included a "cheap talk script" in the survey to control for potential hypothetical bias. We explained to the participants the importance of responding as truthfully and realistically as possible to mitigate hypothetical bias and asked them to imagine that they are shopping at a retail store where they usually buy their groceries and behave in the same way as they would if they really had to choose between the salmon fillet options in a retail store. (See Appendix 1 for the cheap talk scripts.)

We used a Bayesian efficient design to create the choice experiment. We first conducted a pilot survey to collect a sample of 50 responses to estimate the mean and standard deviation of the distribution, based on which we generated a Bayesian design with 12 choice sets and split them into two blocks so that each respondent answered six choice tasks. The two-way interaction of the production method and product form attributes was included in the utility function of the design. The order of choice tasks and the order of the two alternative products were randomized to avoid the order effect.

In the survey, we also included questions about consumers' perceptions of safety, environmental sustainability, and welfare of wild-caught and farmed fish, their knowledge of GM food products, and attitudes towards GM food products and technology. Table 2 includes summary statistics of the perception, knowledge, and attitude variables. We followed Rickertsen et al. (2017) to include in the survey three groups of questions related to consumers' concerns about health and safety (*Q1a-d*), environmental and sustainability (*Q2a-d*), and welfare issues (*Q3a-b*) for farmed and wild-caught fish and used their methods to create three indexes to measure consumers' concerns about these issues for wild-caught vs. farmed fish. A positive index indicates the consumer is more concerned about the issue for wild-caught than farmed fish. Using the question format in Lusk et al. (2004), we asked participants to rate their knowledge of facts and issues concerning genetic modification in food production (*Q4*) to measure their self-reported subjective GM knowledge. Following Bredahl (2001), we included five questions (*Q5a-e*) to collect information about consumers' attitudes toward GM food products and technology and summed the answers to create an index to measure consumers' general attitudes toward GM.

We distributed the survey using an online survey company's U.S. consumer panel in July 2021 and collected 2,009 responses. Table 3 presents summary statistics of the demographic variables. About 47.6% of the participants were male, 51.7% were female, and 0.7% were non-binary. The average age of the participants were about 45 years old. About 1.8% of the participants had less than high school education, 19.4% had high school or GED, 29.9% had some college or a two-year college associate degree, 26.9% had a bachelor's degree, and 21.9% had a professional or graduate degree. We used nine categories, from less than $15,000 to $150,000 or more, to collect the participants' annual household annual income. About 13.5% of the participants lived in a town with less than 1000 inhabitants, 44.5% lived in a city with between 100 and 99,999 inhabitants, and 41.9% lived in a city with more than 100,000 inhabitants. About 20% of households have only one adult in the household, 54.4% had two adults, and 24.7% had three or more adults. About 42.9% had kids in the households.

Method

Following the Lancaster (1966) theory and a random utility model framework (McFadden and Train, 2000), we estimate U.S. consumers' WTP for GM salmon, in fresh or frozen form, in comparison to conventionally farmed salmon and wild-caught salmon. Under the random utility model framework, we assume that each consumer defines utility in terms of attributes via a common functional form as follows:

$$U_{njt} = -\alpha'_n p_{njt} + \beta'_n x_{njt} + \varepsilon_{njt} \tag{1}$$

where U_{njt} denotes the utility that the nth individual obtained from the jth alternative in choice situation t; p_{njt} is price, x_{njt} is a vector of the attributes except for price; α_n and β_n are parameters for each individual n; and ε_{njt} is a random component reflecting unobserved individual idiosyncrasies of tastes.

Facing choices, a consumer chooses the alternative that provides the highest utility. The consumer will choose alternative j in choice situation t if and only if $U_{njt} > U_{nit}$, $i \neq j$. Thus, the probability of individual n choosing alternative j in choice situation t is

$$\begin{aligned} P_{njt} &= Prob\left(-\alpha'_n p_{njt} + \beta'_n x_{njt} + \varepsilon_{njt} > -\alpha'_n p_{nit} + \beta'_n x_{nit} + \varepsilon_{nit}, \forall i \neq j\right) \\ &= Prob(\varepsilon_{nit} < \varepsilon_{njt} - \alpha'_n p_{njt} + \beta'_n x_{njt} + \alpha'_n p_{nit} - \beta'_n x_{nit}, \forall i \neq j) \end{aligned} \tag{2}$$

Assuming a type I extreme value distribution for the error terms and independence between choice scenarios, the probability is written as

$$P_{njt} = \frac{\exp\left(-\alpha'_n p_{njt} + \beta'_n x_{njt}\right)}{\sum_{i=1}^{J} \exp\left(-\alpha'_n p_{nit} + \beta'_n x_{nit}\right)} \tag{3}$$

To account for the heterogeneity of individual preferences for attributes of salmon, we use a random parameters logit (RPL) model, in WTP space, to allow the coefficients on attribute variables to vary across individuals. Following Train and Weeks (2005) and Hensher et al. (2015), the observed utility can be written as

$$U_{njt} = \alpha_n[-price_{njt} + \theta_{1n} nobuy_{njt} + \theta_{2n} fresh_{njt} + \theta_{3n} farmed_{njt} + \theta_{4n} GMfarmed_{njt} + \theta_{5n} fresh_{njt} \times farmed_{njt} + \theta_{6n} fresh_{njt} \times GMfarmed_{njt}] + \varepsilon_{njt} \quad (4)$$

where *nobuy* equals 1 if the consumer chose the "Neither of them" option and 0 otherwise; *Price* takes values of \$4.99, \$7.99, \$10.99, \$13.99, \$16.99, and \$19.99; *fresh* takes a value of 1 if the salmon fillet is fresh and 0 if frozen; *farmed* takes a value of 1 if the salmon is farm raised without genetic modifications and 0 otherwise; *GMfarmed* takes a value of 1 if the salmon is farm raised with genetic modifications and 0 otherwise. θ_{1n}, …, θ_{6n} are WTP estimates for the independent variables for respondent *n*, which is equivalent to β_{1n}/α_n, …, β_{6n}/α_n. We assume the random WTP parameters on the variables of *nobuy*, *fresh*, *farmed*, and *GMfarmed* follow a normal distribution and allow correlation between the parameters. A simulation with 500 pseudo draws is used to calculate the expected probability of respondent *n* in choice situation *t* choosing alternative *j* over the underline normal distribution. Based on the expected likelihood function, a maximum likelihood estimation method is used. All models are estimated using the "gmnl" package in R 4.0.2 (Sarrias & Daziano, 2017).

We also conducted subgroup analyses by estimating consumers' WTP for GM salmon for subgroups defined by their perceptions of health and safety, environmental and sustainability, and welfare issues of farmed vs. wild-caught fish, their knowledge about GM in food production, and their attitudes towards GM food products and technology.

Results

Table 4 presents estimated WTP premiums based on the WTP space model. For salmon fillet in frozen form, consumers are willing to pay about \$5.84 less for conventionally farmed salmon and \$16.67 less for GM farmed salmon, compared to wild-caught salmon. If the salmon fillet is fresh, consumers are willing to pay about $7.95 less for conventionally farmed salmon and $20.07 less for GM farmed salmon than wild-caught salmon. Consumers' WTP for GM farmed salmon is significantly lower than that for conventionally farmed salmon, with a difference equal to $10.83 for frozen and $12.12 for fresh salmon, suggesting U.S. consumers' opposition to GM farmed salmon.

The difference in consumers' valuation between wild-caught and farmed salmon is larger for fresh than frozen salmon, indicating that consumers care more about the difference between wild-caught and farmed salmon if the salmon fillet is fresh. Especially, consumers' valuation for fresh GM farmed salmon is $3.20 higher than that for frozen GM farmed salmon. This shows that consumers are willing to pay more for fresh than frozen salmon, consistent with Davidson et al. (2012). However, frozen fish is the best-selling processed form on some market due to its convenience (Bronnmann and Hoffmann, 2018). If a consumer particularly focuses on frozen form salmon, their opposition to GM farmed salmon may be lower than consumers who only buy fresh salmon.

Table 5 reports the estimated WTP premiums for three subgroups defined by consumers' concerns about health and safety issues for farmed vs. wild-caught fish. Out of the 2209 participants, about 43% of consumers were more concerned about the health and safety issues for farmed than wild-caught fish, 24% were more concerned about the issues for wild-caught fish, and 33% had no difference. This indicates that on average consumers perceive wild-caught salmon as healthier and safer, consistent with findings in Rickertsen et al. (2017). For salmon in frozen form, consumers who are more concerned about the health and safety issues for farmed fish are willing to pay about $11.63 less for conventionally farmed salmon and $25.75 less for GM farmed salmon, compared to wild-caught salmon. For fresh salmon, they are willing to pay about $16.66 less for conventionally farmed salmon and $30.21 less for GM farmed salmon than wild-caught salmon. In contrast, for frozen salmon, consumers who are more concerned about these issues for wild-caught fish are willing to pay $10.21 more for conventionally farmed salmon, compared to wild-caught salmon. If the salmon fillet is fresh, consumers are willing to pay $5.82 less for GM farmed salmon, compared to wild-caught salmon. Consumers who have no difference in concerns about these issues for farmed and wild-caught fish value conventionally farmed and wild-caught salmon similarly but are willing to pay $8.65 less for GM farmed salmon, compared to wild-caught salmon.

The first two consumer segments show a very different valuation for farmed (including both conventionally and GM farmed) vs. wild-caught salmon, suggesting that consumers' concerns about health and safety issues is an important factor affecting their acceptance and valuation for GM farmed salmon. Consumers' WTP for GM farmed salmon is substantially lower than wild-caught salmon or even conventionally farmed salmon if they are more concerned about the health and safety issues for farmed than wild-caught fish. However, if consumers are more concerned about these issues for wild-caught fish, they prefer farmed to wild-caught salmon and are willing to pay a premium for conventionally farmed salmon. Their WTP for GM farmed salmon is not different from that for wild-caught salmon statistically if the salmon is frozen and only $5.82 lower than that for wild-caught salmon if the salmon is fresh. The results indicate that if consumers are concerned about health and safety issues for wild-caught fish and perceive farmed fish as healthier and safer, they are more likely to accept GM farmed salmon.

Table 6 reports the estimated WTP premiums for three subgroups defined by consumers' concerns about environmental and sustainability issues for farmed vs wild-caught fish. About

29% of consumers were more concerned about the environmental and sustainability issues for farmed than wild-caught fish, 38% were more concerned about the issues for wild-caught fish, and 33% had no difference. In other words, on average, consumers believe farmed fish is more environmentally sustainable, consistent with Rickertsen et al. (2017).

Consumers who are more concerned about these issues for farmed fish are willing to pay $10.75 and $26.79 less for frozen conventionally farmed and GM farmed salmon, respectively, compared to frozen wild-caught salmon. They are willing to pay $12.91 and $33.09 less for fresh conventionally and GM farmed salmon, compared to fresh wild-caught salmon. On the other hand, consumers who are more concerned about these issues for wild-caught fish are willing to pay $3.37 and $12.92 less for frozen conventionally farmed and GM farmed salmon, respectively, compared to frozen wild-caught salmon. They are willing to pay $6.77 and $15.31 less for fresh conventionally and GM farmed salmon in comparison to wild-caught fresh salmon. For this consumer segment, the WTP magnitude for conventionally farmed and GM farmed salmon in comparison to wild salmon is much smaller. In other words, if consumers are more concerned about environmental and sustainability issues for wild-caught fish, they have a higher acceptance for farmed salmon, either non-GM or GM farmed salmon, and place a much smaller difference in their valuation between farmed and wild-caught salmon. The WTP premiums for the consumer segment who had no difference in concerns for wild-caught and farmed fish fall between those of the other two segments.

Table 7 reports the estimated WTP premiums for three subgroups defined by consumers' concerns about welfare issues for farmed vs wild-caught fish. About 22% of consumers were more concerned about the welfare issues for farmed than wild-caught fish, 30% were more concerned about the issues for wild-caught fish, and about half (48%) had no difference. This indicates that on average consumers do not distinguish the welfare levels between wild-caught and farmed fish, different from Rickertsen et al. (2017). Consumers who are more concerned about the welfare issues for farmed fish are willing to pay $12.56 and $25.01 less, respectively, for frozen conventionally farmed and GM farmed salmon. They are willing to pay $17.01 and $34.02 less, respectively, for fresh conventionally farmed and GM farmed salmon. Meanwhile, consumers who are more concerned about these issues for wild-caught fish are willing to pay $8.19 and $19.34 less for frozen conventionally farmed and GM farmed salmon, indicating a higher acceptance level and valuation for GM farmed salmon than their counterparts who are more concerned for farmed fish. In addition, the consumer segment who is more concerned about wild-caught fish welfare does not state a statistically different valuation between fresh and frozen farmed salmon, either conventionally or GM farmed salmon. Consumers who have similar concerns about welfare issues for farmed and wild-caught fish showed WTP difference between conventionally farmed or GM farmed salmon and wild-caught salmon smaller than the other two segments, suggesting this group of consumers is more likely to accept GM farmed salmon.

Table 8 shows estimated WTP premiums for subgroups identified by consumers' knowledge about genetic modification in food production. Median index score is used as cutoff to divide the consumers into two groups. About 55% of consumers have a knowledge score higher than or equal to the median, and 45% having a score lower than the median. Comparing these two segments, consumers' WTPs for conventionally farmed salmon are similar between consumers with higher vs. lower GM knowledge scores. However, consumers who have a higher knowledge score are willing to pay $19.53 less for frozen GM farmed salmon, compared to frozen wild-caught salmon, and $25.28 less for fresh GM farmed salmon, compared to fresh wild-caught salmon. In contrast, consumers having a lower knowledge score are willing to pay

$11.72 less for frozen GM farmed salmon, compared to frozen wild-caught salmon, and $14.47 less for fresh GM farmed salmon, compared to fresh wild-caught salmon. The results indicate that consumers reported a higher level subjective knowledge of GM in food production are willing to pay a much lower amount for GM farmed salmon, compared to what they are willing to pay for wild-caught salmon. Wunderlich and Gatto (2015) discussed the difference between being familiar with GMO and having scientific knowledge about GMO. In our survey, we collected consumers' self-reported GM knowledge, which more reflects consumers' familiarity than scientific knowledge about GMO. Our results are consistent with Wunderlich and Gatto (2015) and Zheng et al. (2018) in that consumers who are more familiar with GMO tend to be more resistant to bioengineering and are less likely to pay for it, but they are different from Wier and Sproul (2019) who found that consumers familiar with GM technology are more likely to be open to GM seafood consumption.

Table 9 shows estimated WTP premiums for subgroups identified by consumers' attitudes towards GM foods and technology. Median score is used as a cut off. About 44% of consumers have an attitude score greater than the median and are considered as having a positive GM attitude, and the remaining 55% are considered as having a negative attitude. Consumers having positive attitudes towards GM are willing to pay $4.87 and $7.38 less for frozen conventionally farmed and GM farmed salmon, compared to frozen wild-caught salmon. They are willing to pay $5.76 and $12.87 less for fresh conventionally farmed and GM farmed salmon, in comparison to fresh wild-caught salmon. In contrast, consumers having a negative attitude toward GM are willing to pay $6.58 and $18.46 less for frozen conventionally farmed and GM farmed salmon than frozen wild-caught salmon. They are willing to pay $9.70 and $21.76 less for fresh conventionally farmed and GM farmed salmon than fresh wild-caught salmon.

Attitudes determine consumers' valuation for GM salmon in that consumers having a negative GM attitude are willing to pay less for GM farmed salmon ($11.08 less for frozen and $8.42 less for fresh salmon) than their counterparts who have a positive attitude.

Conclusion

Given increasing consumer demand for salmon, the aquaculture industry has experienced rapid growth over the last four decades to provide a sustainable supply of protein sources to the world's population. Technology innovation and advancement helped foster the growth in the aquaculture industry, especially in improving efficiency and traits and characteristics of species. In 2015, the U.S. Food & Drug Administration approved AquaBounty salmon, a GM salmon, making it the first GM animal for human consumption. GM use in the food industry is a highly controversial issue, which further adds complication to the existing debate among consumers about the pros and cons of farmed vs. wild-caught salmon. Literature has studied consumers' perceptions, attitudes, preferences, and valuation for GM foods and crops. However, studies about consumers' preferences and valuation for GM farmed salmon, especially in comparison to conventionally farmed and wild-caught salmon, are limited. In this paper, we designed a choice experiment to estimate U.S. consumers' preferences and WTP for GM farmed salmon and assess the influences of perceptions, knowledge, and attitudes in their valuation using subgroup analyses. We contribute to the literature by providing information about consumers' valuation for GM farmed salmon that may help stakeholders understand the market potential for GM salmon and help inform policymakers' decisions on regulation and labeling. We conclude our findings in four perspectives.

First, our results indicate that U.S. consumers value the wild-caught salmon the highest, followed by conventionally farmed and GM farmed salmon. Their WTP for GM farmed salmon is significantly lower than that for conventionally farmed salmon, suggesting their opposition to GM farmed salmon.

Second, our subgroup analyses indicate heterogeneity in the valuation of consumers across levels of consumer perceptions, knowledge, and attitudes. Consumers who in general perceive farmed fish as healthier and safer or are more concerned about the environmental sustainability and welfare issues for wild-caught fish are more likely to accept GM farmed salmon. Consumers having a negative attitude toward GM food and technology are willing to pay less for GM farmed salmon.

The literature has pointed out that consumers' familiarity with GM is not equivalent to their scientific knowledge level about GM. Our subgroup analysis shows that consumers who reported a higher subjective knowledge of GM in food production are willing to pay a much lower amount for GM farmed salmon.

Third, fresh wild-caught salmon is seasonally available in limited geographic locations and fast freezing technology makes it possible for the industry to provide a convenient and high quality wild-caught product to consumers. Hence, to compare consumers' valuation for farmed and wild-caught salmon, it is important to consider the product form, i.e., fresh or frozen. In our main WTP model and subgroup WTP models, we find that the difference in consumers' valuation between wild-caught and farmed salmon is larger for fresh salmon than that for frozen salmon, which means consumers care more about the difference between wild-caught and farmed salmon if the salmon fillet is fresh. This suggests that when the industry stakeholders make decisions on pricing, the product differentiation difference should be considered.

Fourth, our results provide insights into GM salmon labeling and sustainability certifications. The new labeling rule of GM foods issued by U.S. Department of Agriculture which becomes mandatory on January 1, 2022 requires food manufacturers, retailers, and importers to disclose if their foods are bioengineered or contain bioengineered ingredients. AquAdvantage salmon is included on the rule's list that must be labeled as bioengineered foods (Blank, 2018). Our findings indicate consumers place different value on GM farmed salmon, conventionally farmed salmon, and wild-caught salmon. The labeling information will be used by consumers to make their salmon choices. Accordingly, the manufacturers and retailers may set prices differently for these salmon products to meet consumers' expectations of salmon values.

Although our results indicate that in general U.S. consumers oppose to GM farmed salmon, the consumer segments who are more concerned about environmental sustainability and welfare issues for wild-caught fish are more likely to accept GM farmed salmon. This supports reasoning for sustainability certifications on GM salmon. Currently, the Aquaculture Stewardship Council (ASC), a leading international certification organization, prohibits the certification of GM salmon, due to concerns about their unknown impact on wild populations. However, another two leading certification organizations, Global Aquaculture Alliance (GAA)'s Best Aquaculture Practices (BAP) program and Monterey Bay Aquarium Seafood Watch program, confirm AquAdvantage salmon's eligibility to apply for their certifications, due to the use of closed-containment systems in growing GM salmon (Fiorillo, 2019). The sustainability certifications may affect consumers' salmon purchase decisions, especially for the segments of consumers who have more environmental sustainability concerns about wild-caught fish.

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Table 1. Product attributes and levels in the choice experiment

Attribute	Levels
Production method	non-GM farm-raised, GM farm-raised, wild-caught
Product form	fresh, frozen
Price	$4.99, $7.99, $10.99, $13.99, $16.99, $19.99

Table 2. Summary statistics of the perception, knowledge, and attitudes variables

Question	Median	Mean	SD	Min	Max
Farmed fish is healthy food (Q1a)[a]	7	6.53	2.66	1	10
Wild fish is healthy food (Q1b)[a]	8	7.36	2.40	1	10
Farmed fish is safe food (Q1c)[a]	7	6.77	2.41	1	10
Wild fish is safe food (Q1d)[a]	8	7.63	2.24	1	10
Index: Concerns about health and safety issues: wild-caught vs. farmed (Q1a-Q1b+Q1c-Q1d)	0	-1.68	3.81	-18	7
I am concerned about the: Environmental impact of the production of farmed fish (Q2a)[a]	6	6.07	2.92	1	10
I am concerned about the:Environmental impact of wild fish (Q2b)[a]	6	6.06	2.77	1	10
I am concerned about the:Environmental sustainability of fish farming (Q2c)[a]	6	6.21	2.71	1	10
I am concerned about the:Environmental sustainability of wild fisheries (Q2d)[a]	6	6.48	2.58	1	10
Index: Concerns about environmental and sustainability issues: wild-caught vs. farmed (Q2b-Q2a+Q2d-Q2c)	0	0.25	3.11	-9	18
I am concerned about the:Welfare of farmed fish (Q3a)[a]	6	6.34	2.73	1	10
I am concerned about the:Welfare of wild fish (Q3b)[a]	7	6.58	2.70	1	10
Index: Concerns about fish welfare issues: wild-caught vs. farmed (Q3b-Q3a)	0	0.24	1.66	-5	7
Index: Rate your knowledge of facts and issues concerning genetic modification in food production (Q4)[b]	5	4.68	2.74	1	9
Applying gene technology in food production is (Q5a)[c]	4	4.11	1.71	1	7
Applying gene technology in food production is (Q5b)[d]	4	4.20	1.65	1	7
I am_______applying gene technology in food production. (Q5c)[e]	4	3.90	1.81	1	7
Overall, applying gene technology to produce food products will prove beneficial to the environment, myself and other people that are important to me. (Q5d)[f]	4	4.20	1.78	1	7
Overall, applying gene technology to produce food products involves considerable risk to the environment, myself and other people that are important to me. (Q5e)[f]	4	4.65	1.66	1	7
Index: Attitudes towards GM food products and technology (Q5a+Q5b+Q5c+Q5d+7-Q5e)	20	19.75	6.14	5	35

Note: [a] 1=Very strongly disagree; 10=Very strongly agree
[b] 1=Not at all knowledgeable; 9=Extremely knowledgeable
[c] 1=Extremely bad; 7=Extremely good
[d] 1=Extremely foolish; 7=Extremely wise
[e] 1= Strongly against; 7=Strongly for
[f] 1=Strongly disagree; 7=Strongly agree

Table 3. Summary statistics of demographic variables

	Variable	Frequency
Gender	Male	47.6%
	Female	51.7%
	Non-binary	0.7%
Age*	(in years)	45.11
Education	Less than high school	1.8%
	High school/GED	19.4%
	Some college	18.2%
	2-Year College Degree (Associate)	11.7%
	4-Year College Degree (BA, BS)	26.9%
	Professional Degree	2.5%
	Master's Degree	16.1%
	Doctoral Degree	3.3%
Household Annual Income	Less than $ 15,000	11.8%
	$ 15,000 - 29,999	12.6%
	$ 30,000 - 44,999	11.8%
	$ 45,000 - 59,999	12.5%
	$ 60,000 - 74,999	10.4%
	$ 75,000 - 89,999	9.7%
	$ 90,000 - 119,999	10.3%
	$ 120,000 - 149,999	11.4%
	$ 150,000 or more	9.6%
Urban/Rural	in a town less than 1000 inhabitants	13.5%
	in a city between 100-99999 inhabitants	44.5%
	in a city more than 100000 inhabitants	41.9%
Number of Adults	Only 1	20.9%
	2	54.4%
	3	14.9%
	4	7.0%
	More than 4 adults	2.9%
Number of Kids	0	57.1%
	1	20.1%
	2	16.9%
	3	4.1%
	4	1.2%
	More than 4 children	0.6%

Note: *Age is average age in years.

Table 4. Estimated WTP premiums in the WTP space model

Variable	Estimate	Std. Error
nobuy	-47.52***	1.52
fresh	6.60***	0.64
farmed	-5.84***	0.71
GM farmed	-16.67***	0.89
I(fresh * farmed)	-2.11**	0.92
I(fresh * GM farmed)	-3.40***	0.94
α	-1.72***	0.12
sd.nobuy.nobuy	-46.53***	1.84
sd.nobuy.fresh	-0.80	0.58
sd.nobuy.farmed	-8.07***	0.79
sd.nobuy.GM farmed	-4.33***	0.92
sd.fresh.fresh	13.37***	0.69
sd.fresh.farmed	-0.86	0.63
sd.fresh.GM farmed	-17.73***	0.99
sd.farmed.farmed	28.71***	1.15
sd.farmed.GM farmed	32.49***	1.32
sd.GM farmed.GM farmed	3.79***	1.22
tau	-1.11***	0.10
LL	-10756	
OBS	13254	
AIC	21547.7	
BIC	21682.55	

Note: ***p<0.01, **p<0.05, *p<0.1.

Table 5. Estimated WTP premiums for subgroups defined by consumers' concerns about health and safety issues for farmed vs wild-caught fish

Variable	More concerned for farmed fish		More concerned for wild-caught fish		No difference	
	Estimate	Std. Error	Estimate	Std. Error	Estimate	Std. Error
nobuy	-36.67***	1.37	-82.80***	10.69	-60.46***	3.87
fresh	8.12***	0.74	11.44***	2.70	3.02**	1.19
farmed	-11.63***	1.01	10.21***	3.11	-1.19	1.20
GM farmed	-25.75***	1.43	2.39	3.26	-8.65***	1.37
I(fresh * farmed)	-5.03***	1.14	-3.25	3.75	1.96	1.61
I(fresh * GM farmed)	-4.46***	1.21	-8.21**	3.73	-0.46	1.61
α	-1.08***	0.26	-2.74***	0.22	-1.70***	0.19
sd.nobuy.nobuy	30.40***	1.53	92.45***	13.07	-71.55***	5.09
sd.nobuy.fresh	0.58	0.69	5.39**	2.46	-1.13	1.06
sd.nobuy.farmed	5.33***	0.87	29.05***	5.10	-5.76***	1.50
sd.nobuy.GM farmed	2.58**	1.18	20.56***	4.52	-2.64	1.76
sd.fresh.fresh	10.82***	0.79	23.68***	4.00	13.55***	1.12
sd.fresh.farmed	3.92***	0.80	2.84	2.95	0.56	1.00
sd.fresh.GM farmed	-9.54***	1.06	-25.78***	4.78	-14.16***	1.41
sd.farmed.farmed	25.22***	1.36	44.85***	6.41	19.05***	1.41
sd.farmed.GM farmed	31.26***	1.70	47.49***	6.99	21.87***	1.61
sd.GM farmed.GM farmed	10.72***	1.14	16.42***	3.98	1.70	1.77
tau	-1.36***	0.18	0.86***	0.20	-1.10***	0.17
LL	-4535.9		-2622.2		-3384.1	
OBS	5694		3162		4398	
AIC	9107.78		5280.37		6804.11	
BIC	9227.43		5389.43		6919.11	

Note: 1. ***p<0.01, **p<0.05, *p<0.1.

2. Poe test (Poe et al., 1997) results show that the coefficients of the main and interaction terms are all significantly different between the consumers who are more concerned for farmed fish and who are more concerned for wild-caught fish.

Table 6. Estimated WTP premiums for subgroups defined by consumers' concerns about environmental and sustainability issues for farmed vs wild-caught fish

Variable	More concerned for farmed fish		More concerned for wild-caught fish		No difference	
	Estimate	Std. Error	Estimate	Std. Error	Estimate	Std. Error
nobuy	-69.23***	5.18	-43.06***	2.30	-44.19***	2.00
fresh	12.68***	1.50	5.77***	1.03	4.54***	0.93
farmed	-10.75***	1.82	-3.37***	1.09	-6.36***	1.01
GM farmed	-26.79***	2.64	-12.92***	1.31	-15.25***	1.21
I(fresh * farmed)	-2.15	2.14	-3.40**	1.45	0.47	1.35
I(fresh * GM farmed)	-6.31***	2.23	-2.39	1.48	-1.42	1.36
α	-1.88***	0.25	-1.59***	0.21	-1.38***	0.23
sd.nobuy.nobuy	60.14***	5.40	-39.79***	2.65	-43.79***	2.43
sd.nobuy.fresh	1.23	1.40	-1.91**	0.86	-2.31***	0.83
sd.nobuy.farmed	2.05	1.75	-8.45***	1.27	-2.53**	1.02
sd.nobuy.GM farmed	-5.60**	2.39	-4.87***	1.48	1.05	1.31
sd.fresh.fresh	-17.79***	2.00	-11.16***	0.98	13.30***	0.97
sd.fresh.farmed	-4.06**	1.69	-1.48	0.95	1.04	0.89
sd.fresh.GM farmed	15.09***	2.40	14.36***	1.39	-13.34***	1.26
sd.farmed.farmed	39.65***	3.52	22.76***	1.55	24.23***	1.44
sd.farmed.GM farmed	46.30***	4.10	24.73***	1.72	26.69***	1.68
sd.GM farmed.GM farmed	-1.06	3.62	3.18**	1.45	13.84***	1.27
tau	1.29***	0.18	-1.14***	0.18	1.16***	0.17
LL	-3119.9		-3611.2		-3967.7	
OBS	3792		4374		5088	
AIC	6275.75		7258.33		7971.32	
BIC	6388.08		7373.23		8088.95	

Note: 1. ***p<0.01, **p<0.05, *p<0.1.

2. Poe test results show that the coefficients of the main and interaction terms are all significantly different between the consumers who are more concerned for farmed fish and who are more concerned for wild-caught fish.

Table 7. Estimated WTP premiums for subgroups defined by consumers' concerns about welfare issues for farmed vs wild-caught fish

Variable	More concerned for farmed fish		More concerned for wild-caught fish		No difference	
	Estimate	Std. Error	Estimate	Std. Error	Estimate	Std. Error
nobuy	-76.21***	6.97	-47.62***	2.99	-36.38***	1.43
fresh	12.20***	1.72	6.42***	1.30	4.78***	0.81
farmed	-12.56***	2.32	-8.19***	1.42	-4.25***	0.87
GM farmed	-25.01***	2.90	-19.34***	1.87	-11.75***	1.02
I(fresh * farmed)	-4.54*	2.52	-0.94	1.85	-1.07	1.14
I(fresh * GM farmed)	-9.01***	2.49	-1.81	1.93	-2.35**	1.15
α	-1.70***	0.32	-2.20***	0.16	-1.38***	0.19
sd.nobuy.nobuy	-70.16***	7.35	42.65***	3.50	-40.32***	1.98
sd.nobuy.fresh	-0.43	1.78	3.26***	1.23	0.70	0.69
sd.nobuy.farmed	-5.54**	2.22	6.80***	1.57	-5.75***	0.96
sd.nobuy.GM farmed	0.31	2.61	4.64**	1.85	-5.87***	1.16
sd.fresh.fresh	-15.44***	2.00	-15.86***	1.56	12.95***	0.83
sd.fresh.farmed	-2.26	1.82	-3.56***	1.30	6.65***	0.81
sd.fresh.GM farmed	16.36***	2.54	13.01***	1.84	-5.75***	0.84
sd.farmed.farmed	39.80***	4.14	29.14***	2.38	23.33***	1.24
sd.farmed.GM farmed	45.82***	4.72	31.68***	2.70	25.96***	1.39
sd.GM farmed.GM farmed	1.42	2.97	-14.40***	2.20	-12.81***	1.10
tau	1.52***	0.22	0.66***	0.18	-1.08***	0.15
LL	-2406.1		-3272.7		-5036.2	
OBS	2874		3948		6432	
AIC	4848.23		6581.32		10108.37	
BIC	4955.57		6694.37		10230.21	

Note: 1. ***p<0.01, **p<0.05, *p<0.1.

2. Poe test results show that the coefficients of the main and interaction terms are all significantly different between the consumers who are more concerned for farmed fish and who are more concerned for wild-caught fish.

Table 8. Estimated WTP premiums for subgroups defined by consumers' knowledge about genetic modification in food production

Variable	High GM knowledge		Low GM knowledge	
	Estimate	Std. Error	Estimate	Std. Error
nobuy	-114.20***	8.60	-22.11***	0.69
fresh	9.28***	1.49	4.99***	0.59
farmed	-6.13***	1.55	-6.28***	0.72
GM farmed	-19.53***	2.02	-11.72***	0.81
I(fresh * farmed)	-2.96	2.11	-1.72**	0.88
I(fresh * GM farmed)	-5.76***	2.16	-2.75**	0.85
α	-2.57***	0.15	-0.66**	0.25
sd.nobuy.nobuy	-95.60***	7.99	22.02***	0.99
sd.nobuy.fresh	-4.34***	1.61	1.21**	0.48
sd.nobuy.farmed	-2.67	1.85	6.29***	0.69
sd.nobuy.GM farmed	9.02***	2.52	6.03***	0.78
sd.fresh.fresh	21.39***	2.16	9.44***	0.51
sd.fresh.farmed	1.05	1.63	9.63***	0.68
sd.fresh.GM farmed	-22.28***	2.62	-0.23	0.64
sd.farmed.farmed	39.14***	3.22	-18.16***	0.86
sd.farmed.GM farmed	44.68***	3.68	-18.50***	0.92
sd.GM farmed.GM farmed	0.31	5.41	14.36***	0.86
tau	-1.00***	0.13	1.25***	0.16
LL	-5910.2		-4671.7	
OBS	7236		6018	
AIC	11856.5		9379.33	
BIC	11980.46		9499.97	

Note: 1. ***p<0.01, **p<0.05, *p<0.1.

2. Poe test results show that the coefficients of the main and interaction terms are all significantly different between the consumers who have high knowledge and who have low knowledge.

Table 9. Estimated WTP premiums for subgroups defined by consumers' attitudes towards GM food products and technology

Variable	Positive GM attitude		Negative GM attitude	
	Estimate	Std. Error	Estimate	Std. Error
nobuy	-123.49***	11.54	-26.21***	0.76
fresh	6.60***	1.77	7.07***	0.56
farmed	-4.87***	1.75	-6.58***	0.67
GM farmed	-7.38***	1.98	-18.46***	0.95
I(fresh * farmed)	-0.89	2.46	-3.13***	0.82
I(fresh * GM farmed)	-5.48**	2.49	-3.30***	0.88
α	-2.68***	0.15	-0.81***	0.22
sd.nobuy.nobuy	101.23***	10.40	26.94***	1.06
sd.nobuy.fresh	4.10**	1.93	0.55	0.44
sd.nobuy.farmed	2.82	2.37	9.17***	0.66
sd.nobuy.GM farmed	1.86	2.70	9.28***	0.77
sd.fresh.fresh	23.61***	2.56	-10.54***	0.50
sd.fresh.farmed	3.65**	1.78	-3.69***	0.55
sd.fresh.GM farmed	-20.66***	2.87	7.08***	0.61
sd.farmed.farmed	33.70***	3.34	22.15***	0.93
sd.farmed.GM farmed	38.77***	3.78	22.64***	1.05
sd.GM farmed.GM farmed	0.80	6.11	-15.46***	0.88
tau	0.95***	0.14	-1.24***	0.14
LL	-4918.7		-5680.7	
OBS	5898		7356	
AIC	9675.84		11397.41	
BIC	9796.12		11521.66	

Note: 1. ***p<0.01, **p<0.05, *p<0.1.

2. Poe test results show that the coefficients of the main and interaction terms are all significantly different between the consumers who have positive GM attitude and who have negative GM attitude.

Appendix 1. Cheap talk scripts

Studies show that people tend to act differently when they face hypothetical decisions. In other words, they say one thing and do something different. For example, some people would say they would choose an item in a hypothetical situation, but when faced with non-hypothetical or real choices (e.g., in supermarket), they will not actually choose the item that they said they would choose. We want you to behave in the same way that you would if you really had to choose between products in a retail store.