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An Economic Analysis of Private Incentives to Adopt DNA Barcoding Technology for Fish Species Authentication in Canada

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Abstract: The increasing spate of species substitution and mislabelling in fish markets has become a concern to the public and a challenge to both the food industry and regulators. Species substitution and mislabelling within fish supply chains occurs due to price incentives to misrepresent products for economic gain. Emerging authenticity technologies, such as the DNA barcoding technology that has been used to identify plants and animal (particularly fish) species through DNA sequencing, offer a potential technological solution to this information problem, but adoption of authenticity technologies depends also on economic factors. The paper uses economic welfare analysis to examine the effects of species substitution and mislabelling in fish markets, and examines the feasibility of the technology for a typical retail store in Canada. It is assumed increased accuracy of the technology in detecting fraud and enforcement of legal penalties and other associated costs would be likely to discourage cheating. Empirical results suggest that DNA barcoding technology would be feasible presently for a typical retail store only if authentication is done in a third party laboratory, it may not be feasible on an individual retail store level once fixed and other associated costs of the technology are considered.

Keywords: Authenticity, information asymmetry, mislabelling, technology adoption, monitoring

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Introduction

Cases of fraud in fish markets have garnered increasing public attention recently, raising concerns for consumers, and representing a challenge to the food industry and to regulators. Fish is a major source of protein and is traded in high volumes across the world (Anderson, 2003; Smith et al. 2010), with about one third of global production traded across national boundaries (FAO 2012). The growth in fish consumption and trade has been linked to increasing consumers' awareness of the health benefits associated with fish (Tveterås et al. 2012). The increased consumption of fish and the economic gains accruing to sellers of high-valued species have served as incentives for some firms within the fish supply chain to consciously misrepresent their products, and substitute substandard products for economic gain.

Results of studies in various countries show that mislabelling and substitution in fish supply chains have been on the increase relative to other products (e.g. Pepe et al. 2007; Schwartz 2008; Bertoja et al. 2009; Miller and Mariani 2010). For example, survey results from Wong and Hanner (2008) show that 25 percent (23 out of 91) of fish species sampled domestically in Canada and U.S. were mislabelled. In addition, Warner et al. (2013) show that out of 120 samples of "red snapper" collected and tested in the U.S., about 93 percent were mislabelled, with about 20 percent of the mislabelled cases involving substitution of different species of snapper for red snapper, while more than 75 percent involve other species outside the snapper family, especially tilapia and rocket fish.

Species substitution and mislabelling has a number of negative outcomes: sellers of high-valued fish products incur losses, while consumers pay a premium for low-valued fish as they cannot differentiate fillets or species with similar morphological features prior to, or in some cases, even after purchase. Alternatively, consumers may incur transaction (search) costs in seeking information about a product's true quality. Although it is not always the case, substitution and mislabelling in fish markets can create food safety hazards. An example is the consumption of toxic "puffer fish" mislabelled as "monk fish" in the U.S. in 2007, which left many consumers sick (Leschin-Hoar 2011). Mislabelled fish also create potential health hazards for consumers with allergies to specific types of fish.

The inability or low accuracy of the traditional methods of fish species identification (e.g. use of morphological features), especially in filleted or processed forms, potentially diminishes sellers' incentives to play by the stipulated rules. These problems have prompted firms to invest in developing traceability and authenticity technologies to exploit market opportunities for verifiable authenticity assurances (Kemp 1994), as well as to protect their reputations. Furthermore, some consumers and consumers' organizations, are seeking authenticity assurances for products traded in local markets, including those that arrive as a result of international trade. This may motivate the uptake of authenticity technologies by a third party such as an environmental or consumer group as a means of monitoring to verify quality claims and authenticity within fish supply chains.

Authenticity in the context of this paper relates to the capacity to verify and certify the genuineness of a food product and all the claims made by the producer and/or seller concerning

the product¹. Fish authentication processes may assist in reducing market failures due to information problems, fraud, health risks and unfair market competition between genuine and fraudulent producer/sellers.

Emerging technologies have the potential of ameliorating this information problem. The paper focuses on a DNA barcoding technology that has been used to identify plants and animal (particularly fish) species through DNA sequencing. Specifically, the paper examines the incentives for species substitution and mislabelling in fish markets using demand, supply and welfare analysis, discusses private (third party) incentives to adopt the technology for supply chain monitoring within a domestic supply chain context, and examines the feasibility of the technology for a typical retail store in Canada.

The paper is structured as follows: the next section explains the DNA barcoding technology and the barcoding process. The third section examines the effects of species substitution and mislabelling in fish markets using a simple economic model. The fourth section presents a simple empirical analysis of adoption by retailers. The final section offers concluding thoughts.

DNA barcoding technology and IBOL

In 2003, a group of scientists at the Biodiversity Institute of Ontario at the University of Guelph launched IBOL – the International Barcode of Life project. The project involved the collection of specimens from different species, generation and storage of DNA barcode records from the specimens, and the development of a comprehensive database and repository (open access reference library) for storage of the DNA barcode records and taxonomic information of

¹ In the context of this analysis authenticity does not necessarily imply full traceability, although the two concepts are related. Traceability in the agrifood sector has been discussed elsewhere in the literature; interested readers are referred to Hobbs 2004; Boecker et al 2013; Asioli et al 2014.

different species. The intent of the open access reference library is to facilitate cross-matching and identification of species to help reduce trade in harmful, invasive and endangered species, and other food (raw and processed) products, as well as enhancing the discovery of new species².

DNA barcoding technology is an emerging molecular-based authenticity technology that uses variation within a single genetic marker region (i.e., the COI region of mitochondrial DNA) to identify plants and animal species through DNA sequencing (Hebert *et al.* 2003). DNA barcode refers to “*a short gene sequence used to identify species taken from a standard position in the genome*” (Yancy 2007, figure 4). The DNA barcoding process is shown in figure 1 below.

In the IBOL system, a tissue sample is taken from a specimen to be identified after a high resolution photograph of the specimen is taken to produce a scanned digital image that is stored in the reference library. Taxonomy information about the specimen is also recorded. The DNA is extracted from the standard (specific gene region) part of the genome from the sample tissue. The next step involves the amplification of the barcode region using Polymerase Chain Reaction (PCR) and generation of a barcode using a DNA sequencer. The barcode is matched and/or compared with sequenced reference barcodes in the library database for appropriate identification.³

FIGURE 1 here

One major feature that distinguishes DNA barcoding technology is that it can be used to detect the presence of several animal and plant species in a food product and, therefore, potentially goes a step further in identifying the particular species of the animal or plant. For example, the widely publicized scandals involving the substitution of horse meat for beef in a

²<http://ibol.org/about-us/what-is-ibol/>

³ <http://ibol.org/about-us/what-is-dna-barcoding/>

number of processed food products (e.g. hamburgers) across Europe in 2013 (Walker et al. 2013) and substitution of donkey, water buffalo and goat meat for beef in sausages, burger patties and dry meats in South Africa (Cawthorn et al. 2013) were all detected by amplifying DNA using the PCR method. However, DNA barcoding offers an advantage by generating barcodes sequenced using the PCR method and using this information (barcode) to identify the species, e.g. of horse, goat and water buffalo. This type of fraudulent substitution may have been present previously in meat and seafood, especially fish supply chains, but remained undetected presumably because products were not being tested or not tested at a sufficient rate. The emergence of DNA barcoding systems such as IBOL (along with the IBOL reference library) therefore offer the potential to reduce the incidence of food fraud (substitution and mislabelling), particularly in the context of fish markets.

The effect of species substitution and mislabelling in fish markets

The effect of species substitution and mislabelling in fish markets is examined using insights from the economics of information asymmetry and market failure (Akerlof 1970). Information asymmetry arises when one party to a transaction has more information about the true quality of a good than another party, for example, in the classic “Market for Lemons” paper (Akerlof 1970), sellers of used cars have more information about the true quality of the car than buyers. The price buyers are willing to pay is lower, reflecting this quality uncertainty. At this lower price, sellers of high quality goods are less likely to offer their products for sale; the market becomes dominated by “lemons” or low quality goods. A number of solutions to information problems exist, including product warranties, as well as improved quality signalling prior to purchase such as through third party quality verification. Applying these insights to the context of fish substitution and mislabelling, in the absence of quality verification a potential

information asymmetry problem exists wherein sellers have more information about the true quality (species) than buyers. Using DNA barcoding technology to verify authenticity is a potential solution.

Figure 2 illustrates these concepts in a situation where mislabelled *farm-raised* salmon enter the market for *wild-caught* salmon. According to the FAO (2011), more than 90 percent of Atlantic salmon is farmed, while only two species of Pacific salmon (Coho and Chinook) are farmed, usually on a small scale (Cline 2012). This suggests that most farm-raised salmon are currently *Atlantic* salmon while wild-caught salmon is mainly *Pacific* salmon: two different species with similar morphological features but which may differ in perceived quality⁴. Quality in this context reflects differences in market prices for wild-caught Pacific and farmed-raised Atlantic salmon. In this model, the wild-caught salmon is assumed to be perceived by consumers as of higher quality, commanding a higher price, for a number of reasons related to the seasonality of wild-caught salmon, negative perceptions about the production of farmed salmon, such as issues related to chemical contaminants and the use of antibiotics (Beattie and Barnes n.d), and a preference among some consumers for so-called ‘natural’ wild-sourced fish products.⁵

⁴ For the purposes of this analysis, we assume the species of (Atlantic) salmon used in fish hatcheries differs from the wild (Pacific) species. If Pacific salmon species are adopted into fish farming operations on a large scale, the mislabelling of farmed fish from these operations as wild salmon would go undetected by DNA-based authenticity technologies.

⁵ The emphasis on ‘perceived quality’ is important. While wild and farmed salmon may not in fact differ with respect to their exposure to pollutants, and the notion of ‘natural’ in the context of food products is highly subjective, the assumption here is that some consumers *perceive* there to be a difference and therefore view one type of salmon as superior to the other. For the purposes of this analysis, the assumption is that wild salmon are *perceived* to be of higher quality to farmed salmon, and that this quality perception drives the price difference between these two products. In reality, some consumers may prefer farmed over wild salmon (given concerns over the sustainability of wild fish stocks, or ocean pollutants) and the model could be re-specified with farmed fish perceived as superior to wild-caught fish with no loss of generality and similar outcomes for the incentives to mislabel.

Assume there are two types of suppliers in a market for wild-caught salmon – those who supply genuine wild (Pacific) salmon, and those who supply farmed (Atlantic) salmon mislabelled as wild. Assume also that consumers cannot differentiate between wild-caught and farm-raised prior to purchase. Two scenarios illustrate the potential for cheating in this market and are presented in figure 2 where S^H and S^{LM} respectively show the supply curves for wild-caught (S^H) and farm-raised but mislabelled Atlantic salmon fish products (S^{LM}), while S_M and D_M are the total market supply (horizontal summation of S^H and S^{LM}) and demand curves for salmon identified as ‘wild’ salmon.

FIGURE 2 here

At price (P_M), there is no substitution or mislabelling, therefore, only wild-caught Pacific salmon is supplied and sold in the market. The intersection of the market supply (S^H) and demand (D_M) curves at E_1 gives the market equilibrium price (P_M) and quantity (Q_M). The high price for wild-caught Pacific salmon serves as an economic incentive for ‘dishonest’ firms to introduce mislabelled farmed Atlantic salmon into the market. This increases total market supply of wild and farmed (but mislabelled) salmon to Q_M' at the intersection of the total market supply (S_M) and demand (D_M) curves at E_2 ; and all other things being equal reduces the market price to P_M' . At this price (P_M'), it is assumed that consumers cannot differentiate between the products and hence pay the same price for wild-caught and farm-raised salmon. At the original price P_M , producer surplus is area $(a+b+c+d)$ ⁶. With the decrease in price to P_M' , the wild harvesters lose producer surplus area $(a+b)$ while suppliers of mislabelled farmed fish gain area $(c+d+e+f+g+h+i+j)$ ⁷ given their different cost structures.

⁶ Producer surplus is a measure of the economic rents to suppliers and is represented by the area above the supply curve (which represents costs of production) and below the price.

⁷ The area above supply curve S^{LM} and below price P_M' .

If consumers become aware of the substitution of farm-raised Atlantic salmon for wild-caught Pacific in the market for wild salmon, market demand would fall, shifting the demand curve from D_M to D_M' with quantity falling from Q_M' to Q_M'' as quality uncertainty now exists in this market. All other things being equal, this would lead to a lower market price at P_M'' , where the new market demand D_M' intersects total supply S_M at point E_3 . Consumers suffer a loss in consumer surplus (CS)⁸ due to an “adverse quality effect” (shown by the shaded area between the two demand curves), and the suppliers’ surpluses reduce to areas (d) for suppliers of genuine wild-caught salmon and $(d+e+f+h)$ for suppliers of mislabelled salmon, respectively. If demand continues to decline and eventually demand for wild-caught salmon collapses, the market price drops to point ‘A’ and wild harvest would end leaving only the ‘lemons’ (mislabelled farmed salmon). This simple model illustrates how information asymmetry due to quality (species) uncertainty can have a deleterious effect on consumers, as well as on suppliers of ‘high’ quality goods - in this case, suppliers of wild salmon. The potential cost to suppliers (or consumers) serves as an incentive for the wild-caught salmon supplier (or consumer organizations) to seek third-party certification of authenticity. Adoption of authenticity technologies is examined in the next section.

The fish supply chain and adoption of authenticity technologies

A fish supply chain refers to a network of interdependent fish producers (suppliers), processors, distributors, wholesalers, retailers and food service establishments who are involved in the production, processing and delivering of fish products to consumers (UNEP 2009). For the purpose of this analysis, in Canada, the domestic fish supply chain is assumed to comprise

⁸ Consumer surplus is the difference between a consumer’s willingness to pay for a good (as captured by the demand curve) and the price of the good.

fishermen/fish farmers (producers), processors, wholesalers and retailers. Fishermen supply their captured fish to processors who sell their processed fish products to wholesalers (distributors). The wholesalers store and transport the fish and sell to retailers, food service establishments and restaurants. The retailers through their outlets (supermarkets) finally sell to consumers, as do restaurants. Sometimes, the processors sell directly to retailers, restaurants and food service establishments.

Private incentives to adopt DNA barcoding technology

As discussed in the previous section, incentives to cheat arise in the fish supply chain when premiums exist for specific species or types of fish. There are a number of points along the supply chain at which cheating may occur, warranting adoption of the authenticity technology. For example, a third party (e.g. the Canadian Food Inspection Agency, an environmental or consumer group) could adopt the DNA barcoding technology, and uses it to monitor the fish supply chain in order to identify mislabelled products and/or deter cheating. Alternatively, a retailer may adopt the technology to monitor the authenticity of fish from suppliers and/or due to the threat of authenticity testing by a third party. While recognizing that cheating (substitution or mislabelling) may occur at any point in the fish supply chain (i.e. by fish suppliers, processors or retailers), a major assumption here is that the processor or distributor sources fish from a known producer/supplier. The stylized supply chain is depicted in figure 3.

FIGURE 3 here

Following figure 3, assume a fish processor and/or distributor buys *wild-caught* and *farm-raised* salmon from known suppliers. The processor supplies both wild and farmed salmon to the retailer who sells to consumers. It is assumed that at every stage along the supply chain, the player has more information about the product than the next player, hence, there is an

incentive to cheat for economic gain. The processor and retailer have two choices when selling to retailers and consumers, respectively, – either truthfully sell wild and farmed salmon separately to the next stage of the supply chain without deception, or misrepresent farm-raised salmon and sell it as wild-caught at a higher price. Under such a situation, the processor's (retailer's) profit would be a weighted average of profits from wild salmon (labelled as “wild and tested”), and farmed salmon (mislabelled as “wild and tested”).

The decision whether to cheat depends on a number of factors: the likelihood of detection, the penalty if caught cheating, and the difference in expected profits from dishonest versus honest behaviour. Undetected cheating allows the processor (retailer) to enjoy the premium associated with wild salmon. Furthermore, it is assumed that the probability of being caught cheating or mislabelling fish is a function of increased accuracy of the technology, the sampling frequency (percentage of fish tested), and leakage (Popkova 2013). Leakage in this context refers to the quantity of *farmed* fish that are misrepresented and sold as *wild*. It also reflects the inability of the existing system (use of morphological features) to detect substitution as the consumer cannot differentiate between the two through physical examination. We might therefore expect that the probability of being caught cheating will be high the higher the accuracy of the technology in detecting fraud and the larger the sampling frequency and leakage.

Penalties for cheating take a number of forms. There may be a legal penalty for cheating in the form of a fine in addition to other indirect costs (e.g. reputation loss, reduced sales, withdrawal of license to operate). The legal penalty or other indirect costs negatively affect a processor's (retailer's) profit if caught cheating by a retailer (third party) using the DNA barcoding technology. Taking this one step further, a retailer may be liable for selling mislabelled fish even if the misrepresentation occurred further up the supply chain. Regulators

may expect retailers to exhibit a sufficient degree of due diligence in monitoring the authenticity of supplies and/or the retailer may suffer a loss in consumer confidence if it is found to be selling (even inadvertently) mislabelled fish. Thus, the threat of third party monitoring may incentivize adoption of the technology by fish retailers. This scenario is examined in the next section.

Feasibility of DNA barcoding technology for a typical retail store in Canada

The threat of third party monitoring of the fish supply chain (e.g. by a regulator or a consumer or environmental interest group) could provide retailers with an incentive to adopt a technology such as IBOL and use it to test fish supplied by upstream suppliers in order to protect their reputation. Determining the testing rate above which the costs for a retailer of using the technology outweigh the benefits, would give an indication of the feasibility of the technology for a typical retail store. A retailer may also face a decision over whether to incur the fixed costs of acquiring the means to apply the authentication technology in-house or to outsource testing to an external laboratory for authentication. To assess the feasibility of IBOL adoption an empirical analysis uses data on the estimated fixed and variable costs of fish authentication collected from the Biodiversity Institute of Ontario, University of Guelph as well as fish market survey data gathered from retail stores in Canada.

Table 1 shows fees for authenticating fish samples based on information provided by the Biodiversity Institute of Ontario. This data is used to derive the cost function of a prospective retailer who would adopt the technology. The key message is that the average cost of testing a fish sample is expected to decrease with a higher number of fish samples. The data in table 1 can be used to approximate a cost function for authenticating fish.

TABLE 1 here

Assume the retailer's cost function for authentication fish is given as:

$$C = AX^\alpha, \alpha \in [0,1] \quad (1)$$

Where A is a constant and X is the number of fish samples authenticated. Taking the derivative of (1) with respect to X will yield the marginal cost. That is:

$$\frac{\partial C}{\partial X} = MC = \alpha AX^{\alpha-1} \quad (2)$$

Estimating the values of α and A by considering two points ($X = 1$; $MC = \$200$ and $X = 1000$; $MC = \$25$) in table 1 and substituting them into equation (2), we have:

$$200 = \alpha A \quad (2a)$$

and

$$25 = \alpha A 1000^{\alpha-1} \quad (2b)$$

From (2a) and (2b), $\alpha = 0.7$ and $A = 285.71$

Therefore, the retailer's cost function is given by

$$C = 285.71X^{0.7} \quad (3)$$

and

$$MC = 1999.997X^{-0.3} \quad (4)$$

Using a range of samples (1-50,000), the estimated average total costs (ATC) of fish authentication (testing) are shown in figure 4.

FIGURE 4 here

Figure 4 shows that the estimated average total costs of authenticating a fish sample decreases as the number of samples increases, suggesting that large scale retailers are likely to enjoy economies of scale, while small scale retailers will incur higher costs to authenticate a fish sample.

A market survey of two food retail stores (A and B) in Saskatoon, Saskatchewan was carried out in May 2014 to inform the empirical analysis. Information on the average standard weight (1.098kg) of Atlantic salmon sold in the stores, number of kilograms sold daily and average price per fish were collected through observation at the stores and discussion with the store managers. The information is used to compute other variables such as the number of fish sold per day (month) and total revenue per month from fish sales. The analysis is based on one month of sales and the results are shown in Table 2.

For the analysis, it is assumed that the testing (authentication) is done at an external laboratory (e.g. the IBOL laboratory in Guelph) once a month, therefore the fixed costs of the technology, as well as other associated costs (e.g. inputs, transportation) are not considered⁹. The idea is to see whether use of the technology would be feasible for a typical retail store able to access an external laboratory for authentication. In the absence of an external laboratory testing service, however, the retailer would incur additional fixed costs of acquiring testing equipment and facilities (not shown in Table 2)¹⁰. Column ‘G’ of Table 2 shows the estimated monthly revenue for a retail store that sells fish without authentication. This implies that the magnitude of the net revenue is contingent on the retailer’s scale of operation and the number of samples tested at a particular time.

TABLE 2 here

We assume a price premium of \$6 per 1.098kg for authenticated fish. Comparing stores ‘A’ and ‘B’, store ‘A’ sells an estimated 820 wild and farmed Atlantic salmon respectively in a month, generating revenue of \$50,382 without authentication and related premiums; while store

⁹ Inputs and transportation costs were not available at the time when data were collected.

¹⁰ Estimates of the current fixed costs of establishing a DNA barcoding laboratory are not available, although estimates from the year 2000 range from \$130,000 to \$350,000 (Zakharov 2013)

‘B’ sells 410 wild and farmed salmon respectively with total revenue of \$26,541. Considering scale effects, and using the simulated cost functions in equations 3 and 4, it would cost stores ‘A’ and ‘B’ an average of \$38.32 and \$46.66 respectively to test a fish sample.¹¹ To account for the declining average cost of testing a fish sample as the number of samples increases, equations 3 and 4 were used to derive estimated testing costs for 1 to 50,000 fish samples, as shown in figure 4, which shows a reduction in testing cost per fish sample as the quantity of fish tested increases. The testing costs for 850 and 410 fish samples used in the calculations for stores A and B below are used to plot the graph (figure 4).

Given an assumed premium of \$6 per whole fish, the total number of fish sold in a month, and the costs of authenticating a fish sample, what testing rate (δ) would yield the same net revenue obtained without authentication? Or in other words, what is the maximum testing rate whose additional costs can be covered by the added premium consumers are assumed to be willing to pay for each wild caught salmon? This would give an idea of the break-even testing rate beyond which a retailer may not use the technology and would prefer to sell his fish without authentication given that consumers cannot distinguish between farmed and wild salmon. Calculating the testing rates for stores ‘A’ and ‘B’, we have:

Store A:

Net revenue from authentication = total mark-up – variable costs of authentication¹²

$$[820 * 6] - \left[38.22 * \frac{\delta}{100} * 820 \right]$$

¹¹ Retail prices are for a whole fish, while testing (authentication) is conducted on a piece of a whole fish (sample).

¹² Total mark-up for wild salmon in store ‘A’ is calculated by multiplying the total number of fish sold in a month by the assumed premium. The product of the average total cost of testing a fish sample, number of fish sold in a month and the testing rate ($\delta/100$) gives the variable cost of authentication for store ‘A’.

Solving, $\delta = 16\%$

Store B:

$$[410 * 6] - \left[46.66 * \frac{\delta}{100} * 410 \right]$$

$\delta = 12.8 \sim 13\%$

This shows that a large company (retail level) such as store ‘A’ comprised of ‘X’ number of stores would spend less on authentication using DNA barcoding technology and generate higher revenue at a testing rate of 16 percent or less, while small retail stores (e.g. store B) would pay more for every fish sample authenticated, and potentially may not use the technology for a testing rate above 13 percent. The contribution margin¹³ at different testing rates for a large retail store is shown in figure 5.

FIGURE 5 here

Figure 5 suggests that a large retail store in Canada potentially would use the technology if the testing rate does not exceed 16 percent, given the assumptions in this illustrative example. A testing rate above 16 percent will result in a loss and would be a disincentive for technology adoption. If we consider the fixed and other variable costs (e.g. staff salaries) associated with establishing a DNA barcoding/testing laboratory given the assumed premium of \$6 for authenticated fish, these results suggest that the technology may not be feasible for a typical retail store at this time. A large-scale food retailer with multiple retail stores, however, would be in a position to spread the fixed costs of establishing a DNA barcoding/testing facility over a larger number of retail stores.

Conclusions

¹³ The contribution margin is the difference between the selling price and variable costs (in this case, the costs of authentication)

The DNA barcoding technology and reference library is an improvement over the existing DNA-based techniques in detecting food fraud, particularly in fish markets. Adoption of the technology depends both upon its technical feasibility and accuracy, as well as on the economic incentives for adoption. This paper has provided an initial overview of the economic incentives for species substitution and mislabelling in fish markets, modelled the effect of private (third party) adoption of the DNA barcoding technology for supply chain monitoring and examined the feasibility of the technology for a typical retail store in Canada.

It is anticipated that increased accuracy of DNA barcoding technology in detecting fraud and enforcement of legal penalties and other associated costs could deter cheating as well as provide an incentive for the adoption of an authenticity verification technology such as IBOL by retailers. As such, governments have a role to play in shaping the regulatory landscape with respect to food fraud. The empirical analysis provides an opportunity to scope out the key economic parameters that are likely to affect adoption of the technology by retailers. Based on the assumptions underlying this illustrative case, the analysis suggests that adoption is feasible at testing rates of 1 – 13% for small and 1-16% for large scale retailers, with the use of external testing facilities. The latter is a key caveat: the fixed costs of an individual retail store establishing a testing laboratory, and other associated costs of the technology, may be prohibitive. Given the magnitude of the fixed costs and low food safety risk associated with fish species substitution in Canada presently adoption of the technology, particularly by small scale retailers, is only likely if external testing facilities are available. In the longer run, the potential for retailers to pool resources by investing jointly in industry testing facilities may be worthy of examination, for example, small independent retailers may find it worthwhile to cooperate in the establishment of shared testing infrastructure. Although not directly derived from the analysis,

large food retail stores with multiple outlets could spread the fixed costs associated with testing infrastructure over multiple stores with testing occurring at the retailers' central warehouse. Indeed, this would be the most likely scenario for large retailers (e.g. Loblaw, Superstore) operating centralized distribution systems.

This analysis has examined potential break-even testing rates for retailers but it is unlikely that retailers would need to test every fish. The establishment of optimal testing rates would depend upon a number of factors, including the accuracy of the technology, the number of suppliers (whether the retailer sources from one or two fish suppliers or multiple suppliers), and the prior expectation of the retailer of the probability of cheating by a supplier. The latter may be influenced by the newness of the supply relationship and the track record and reputation of the supplier: whether a new, relatively unknown supplier or a trusted, long-term supplier with an established industry reputation. While these factors lie beyond the scope of the present analysis they provide a fruitful avenue for further research.

Over time as DNA testing technologies evolve, reducing both the time and cost of DNA testing, optimal testing rates (from an economic perspective) will change, as will the fixed costs of testing facilities or equipment. If hand-held DNA testing tools became available, for example, on-site testing at retail locations could become considerably more affordable. As more data become available on the changing nature of DNA barcoding/testing costs, further research could explore the feasibility of technology adoption at different stages of the supply chain.

The empirical analysis provides a starting point for assessing the incentives to adopt the technology and a number of assumptions were necessary, including the potential premium for authenticated fish. In future research, opportunities exist to explore in more depth the potential market premiums for authenticated fish, the extent to which these premiums are affected by

actual versus expected testing rates (i.e. whether consumers would expect more than 16% of fish to be tested) and the extent to which verification through a technology such as IBOL enhances consumer confidence in authenticity assurances.

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Table 1: Fees for authenticating fish samples

Table 2: Market (store-level) data analysis for Atlantic salmon

Draft

Figure 1: DNA Barcoding process

Figure 2: Effect of mislabelled farmed salmon entering the market for wild salmon

Figure 3: Stylized supply chain featuring technology adoption for supply chain monitoring

Figure 4: Average total costs of testing fish samples

Figure 5: Estimated contribution margin at different testing rates

Draft

Table 1: Fees for authenticating fish samples

No. of samples (X)	Actual fees (CAD\$)
1	200
15	125
1000	25
>1000	Negotiable but < 25

Data source: Biodiversity Institute of Ontario (2013)

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Table 2: Market (store-level) data analysis for Atlantic salmon

Retail store	Fish type	Std weight /fish (Kg)	No. of Kg sold/day	No. of fish sold/day (Kg)	No. of fish sold/month	Ave. price/ kg sale(\$)	Ave. price/ Fish (\$/Kg)	TR/month without testing (\$)	Price premium (\$/fish)	ATC of testing /fish sample (\$)
		(A)	(B)	(C)	(D)	(E)	(F)	(G)		
Store A	wild	1.098	30	27	820	30.99	34.03	27891.00	6.00	38.32
	farmed	1.098	30	27	820	24.99	27.44	22491.00	6.00	38.32
	total		60	55	1640			50382.00		31.01
Store B	wild	1.098	15	14	410	31.99	35.13	14395.50	6.00	46.66
	farmed	1.098	15	14	410	26.99	29.64	12145.50	6.00	46.66
	total		30	27	820			26541.00		38.18

Source: Market survey data, 2014 (columns A, B, E)

- Note:
- 1. Average Total Cost (ATC) for testing a fish sample is derived using data on table 1
 - 2. Premium of \$6 for authenticated fish is assumed by the authors
 - 3. Revenue (column G) is for the total number of fish sold in a month
 - 4. Other calculations as follows:
Column C = B/A
Column D = C*30
Column F = A*E
Column G = F*D

Figure 1: DNA Barcoding process

Sources: Adapted from Floyd et al. (2010), Yancy (2007)

Figure 2: Effect of mislabelled farmed salmon entering the market for wild salmon

Figure 3: Stylized supply chain featuring technology adoption for supply chain monitoring

Figure 4: Average total costs of testing fish samples

Source: Calculated from data on actual fees (table 1) for fish authentication obtained from The Biodiversity Institute of Ontario in 2013

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Figure 5: Estimated contribution margin at different testing rates

Source: Authors' calculation

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