Eco-Labelling under Imperfect Certification: An Economic Analysis

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Abstract

Environmental quality is often a credence good and consumers are unable to distinguish between green and brown products. The paper aims to investigate the role of certification in providing information about product quality and reducing market inefficiencies when the certification process is imperfect. We consider a duopoly in a vertically differentiated product model where firms compete in quantities . We find that in the absence of labelling, the brown firm drives out the green firm if the cost of producing green product is sufficiently high. If both firms produce positive quantities in the market, the green firm covers a higher market share and obtains larger revenue. We then characterise pooling and separating equilibrium under imperfect certification contingent on certification fee.

Keywords: Eco-Labelling; Environmental quality; Imperfect Certification; Incomplete Information; Vertical differentiation.

1 INTRODUCTION

Consumers' concern for the environment has grown in recent years. This concern is getting translated into their willingness to pay for environmental attributes such as sustainable, recycled, non-toxic and biodegradable products. Evidence has shown that firms are aware of consumers willingness to pay a premium for environmentally friendlier products. An example illustrating this is consumer's preference for dolphin safe tuna. Teisl et al. (2002) provided evidence that consumers responded to the implementation of dolphin-safe labelling. Consumers were willing to pay a price premium in order to avoid personally contributing to dolphin mortality as a result of tuna fishing. Consumers also have preference for the organic products. Griffith and Nesheim (2008) used hedonic prices to show 80 percent of the households surveyed were willing to pay a higher price for organic food products in U.K.

A problem with environmental attributes is that they are not observable. Although consumers prefer environment friendly products, but they are unable to ascertain the quality attributes of the products either on inspection or even after consumption. Such goods whose quality is not verifiable even after consumption are called credence goods (Nelson, 1970). Examples of such goods include energy efficiency, organically produced food, green electricity, etc. The consumers cannot observe whether the electricity is generated with renewable energy sources or not.

The credence goods nature of these products give rise to inefficiency in the market outcome. Since these attributes are not observable, producers of bad quality have incentives to cheat. Consumers anticipate this and are willing to pay a lower amount for the products available in the market. This may lead to a breakdown of the market for environmentally superior firms or in other words, there would be adverse selection(Akerlof, 1970). One possible solution for the informational asymmetry problem is to signal the attributes by using eco-labels. The strategies adopted to increase information provided on the environmental friendly products are known as the "Third wave " of environment policy (Tietenberg, 1998).

Eco-labelling informs consumers about the quality attribute, by assuring the consumer that producer has complied with predetermined standards. A wide variety of eco-labels are introduced in various countries. Some of them are German Blue Angel (1977), Nordic Swan (1989), Japanese Eco-Mark (1989), Swedish Environmental Choice (1990), U.S. Energy Star (1992), EU Eco-label (1992) and Thai Green Label (1994). There are large diversity of eco-labels with respect to content, precision and reliability. Firms may have incentives to mislabel. In addition, there are differences in respect to the certifying agency. The certification process entails cost and thus may not be perfect.

The paper aims to investigate the role of certification in providing information and reducing market inefficiencies when the "*certification process is imperfect.*". Most of the existing literature analysing eco-labels assumes perfect certification. The paper intends to contribute to the literature by investigating the equilibria that may occur with eco-labelling under imperfect certification. Our framework models certification as a noisy test under vertical product differentiation framework. It allows for the possibility of errors in the third party certification by considering random monitoring. The paper analyses (i) the conditions on the parameters for adverse selection to exist, in the absence of eco-labelling; (ii) the conditions under which the separating and pooling equilibrium would exist under imperfect certification and quantity competition. The rest of the paper is structured as follows. Section 2 gives the existing literature on eco-labelling. Section 3 and 4 develops the duopoly model under vertical product differentiation framework. In these section, we first discuss the benchmark case of complete information, followed by incomplete information. Under incomplete information the paper models two situations, one in which there is absence of labelling, and the other in which third party certifies the product, and there is imperfect certification. Finally Section 5 contains the concluding remarks.

2 LITERATURE REVIEW

An emerging literature in environment economics focuses on consumer's preference to purchase from green firms. The literature on eco-labelling can be discussed both on empirical and theoretical grounds.

The empirical literature showed the evidence on the consumers' willingness to pay for green products. Bjorner et al. (2003) conducted an empirical analysis for the Nordic Swan Label using data for Danish consumers from 1997 - 2001. It reported statistically significant levels of consumer's preferences for more expensive labelled toilet paper brands and laundry detergents. Junyi Shen (2008) found that Chinese consumers prefer environmental conservation more than life convenience, and are willing to pay 8.71 - 9.51 percent for products awarded with China eco-label. Marette S. (2012) showed that the additional information on organic products about its pesticides use significantly increased the consumers' willingness to pay.

Among the theortical literature, the early literature on this issue assumed that consumers are able to observe the environmental attribute of the product. Arora and Gangopadhyay (1995) showed that the minimum quality standard binding on the dirty firm leads to improvement in the performance of clean firm. Amacher et al. (2004) discussed the impact of green technology investment, which allowed firms to attach a eco-label to their products. He showed in the market equilibrium, if green firm is more efficient in investing then lower qualities are being provided in the market. However, if the green firm is less efficient then higher qualities will be provided to mitigate price competition. Amacher et al. (2004) discussed a duopoly model to analyze the impact of technology investment, where as Ibeas (2007) considered a duopoly model of vertical product differentiation to discuss the impact of environment consciousness on environment. Ibeas (2007) showed that if the marginal cost of producing environmentally differentiated products is sufficiently low, then an increase in the proportion of green consumers results in reduction of pollution. However, when the proportion of green consumers is low, then both the firms don't care about the environment attributes. Thus, there is less product differentiation and cost advantage allows brown firm to capture the market. Despite willingness to pay for environmental attributes the problems of adverse selection (Akerlof, 1970) can occur, as products are credence in nature (Darby and Karni, 1973).

The next set of literature discusses the issue, where only producers know the quality of the product they have chosen, but unobservable by the consumers. To overcome these market inefficiencies, environmentally friendly firms need credible signalling. Most of the initial literature assumed perfect certification, where the certifying agency is able to signal the quality of the product accurately. There are some works e.g. Marette et al. (1999), Zago and Pick (2004), Auriol and Schilizzi (2013), Arguedas and Blanco (2013), which assumed perfect certification under vertical product differentiation framework. Marette et. al. (1999) analyzed a three stage game under imperfect competition, using cartel theory. The firms decide whether to certify their goods independently or to form a cartel to share the labelling cost and/or collude in quantities. The symmetric Nash equilibrium of the game is separating equilibrium in which if the certification cost is high compared with the profit, the high quality firms can share the cost of certification, and enforce quantity collusion. On contrary, Das (2013) analysed the situation of perfect certification under horizontal product differentiation model. The paper showed for the profit maximising certifier, below the threshold value of the degree of horizontal product differentiation, the certifier charges a very high fees. Thus, only one firm opts for certification and produces highest quality, where as other firms don't opt for certification and produces low quality products. However, above the threshold value, there is less competition among the firms and thus, both the firms opt for certification and produce high quality.

The vast applied literature on eco-labelling assumed perfect certification. By contrast, the issue of third party certification being imperfect, until recently, has very little theoretical work. The literature on imperfect certification is analysed in two different perspectives. First, when the certifying agency certifies the product accurately, but there is a possibly of fraud. Some brown firms could cheat, by attaching spurious labels to their product. Thus, allowing for the possibly of mislabelling by the firms. Secondly, when the certifying agency doesn't certify the product accurately. Thus, certification agency could mistakenly certify some brown products as green or may not certify certain green products.

De and Nabar (1991), Giannakas (2002), Liang and Jensen (2007), Baksi and Bose (2007) discussed the models for mislabelling by the firms. The above papers on imperfect certification mainly assume competitive markets. Giannakas (2002) examines the consequences of mislabelling on consumers welfare in organic food market. However, Ependitis (1998) conducted an empirical study for food certification. It reported that the 15 -40 percent of the organic labelled products are mislabelled. Mislabelling creates uncertainty about the nature of the organic labelled product. Thus, it reduces consumer's welfare and drives part of the consumers out of the market. Liang and Jensen (2007) discussed a theoretical framework for analyzing the imperfect food certification. Marette et al. (1999) showed separating equilibrium under perfect certification, however Liang and Jensen (2007) showed pooling equilibrium under imperfect certification. Liang and Jensen (2007) discussed the role of the monitoring and enforcement process, to account for the fraud by the firms. The paper showed that the fraudulent output can be eliminated with high monitoring rate and the imposition of penalty on being caught. Hamilton and Zilberman (2006) assumed that technology used is not observered by the consumers. Due to which there is possibility of fraudalent brown products to be sold in the green markets. The paper showed that if there are entry barriers, then the extent of fraud in the green market is reduced. Eco-certification policies, increases the cost for use of green techniques, thereby reducing fraud. However, the extent of improvement in social welfare depends on the monitoring and enforcement effort.

Mason (2011) and Botttega and Freitas (2013) allowed for the possibility of errors by the certification agency. Mason (2006) assumed that the certification process gives accurate results with some probability. The green firms are more likely to pass the certification than brown firms. It showed the conditions for the existence of separating, pooling and partial pooling equilibrium. The separating equilibrium can exist when the test cost is sufficiently large. The Green firms produce a larger amount and brown firms produce a smaller amount, and thus this situation is welfare enhancing. The ultimate impact on net surplus is unclear, as if the test cost is sufficiently large, then green firms and brown firm profits would be smaller in separating equilibrium than in no information case. However, the Pooling equilibrium can exist when the test cost is sufficiently small. Green firms could be better off or worse off in pooling equilibrium, compared to no information. However, brown firms are at least well off in pooling equilibrium as they are in no information case.

Mason (2011) analysed imperfect certification under perfect competition. However, Bottega and Freitas (2013) analysed imperfect certification under imperfect certification. Bottega and Freitas (2013) considered a vertical product differentiation model with price competition. The paper showed that the equilibrium price equals marginal costs, if both the firms awarded label or none of them are awarded label. However, if one firm is awarded label, then firms are able to differentiate. The paper showed separating equilibrium is Perfect Bayesian equilibrium and label allows firms to extract benefits from differentiation.

Leaving a few exceptions such as Mason (2011); Bottega and Freitas (2013), the majority of the literature on eco-labelling assumes perfect certification. There is not much literature on imperfect certification. The present study aims to extend this literature to analyse the firms strategies under imperfect certification. The model assumes certification as noisy test under vertical product differentiation framework. Bottega and Freitas (2013) assume market is fully covered and analysed imperfect certification under vertical product differentiation framework with price competition. In the Bertand model, we don't allow for positive profits if there is no product differentiation. However, under quantity competition, we can have the possibility of positive profits. Here we assume that market is uncovered and there is quantity competition under imperfect certification. We allow for the possibility of errors in the third party certification by considering random monitoring. Thus, the focus is on the role of information by providing certification.

3 MODEL STRUCTURE

Consider a vertical differentiation model with two firms - "Green Firm (g)" and "Brown Firm (b)", producing products with different technologies. The green firm produces goods with non-polluting technology and the brown firm produces goods with polluting technology. Let s_g and s_b denote the qualities of the green and brown good, respectively. Without loss of generality, assume $s_g > s_b$.

A.1: Let the green firm cost function be denoted by $C(s_g)$ and brown firm cost function by $C(s_b)$. Assume fixed costs of providing quality is given by -

$$C(s_i) = \frac{ks_i^2}{2}$$

where k is positive parameter, $i = g$ or b. As $s_g > s_b$, the green production is more expensive as compared to brown production.

There exists a continuum of consumers who are identical in all respects except their preferences for the quality attribute. The utility function of consumer is given by -

$$U(\theta_i, p) = \theta E(s) + y - p_i$$

where θ is the marginal willingness to pay for environmental quality of the product, $E(s)$ is the quality of the product available in the market as perceived by the consumer, y is the income of the consumer and p is the price charged by firm i, where $i =$ Green (g) or Brown (b). This utility function implies that all consumers unanimously prefer a higher quality at a given price and that consumers with higher θ have higher willingness to pay for higher quality.

A.2: Assume the parameter θ is uniformly distributed over $[0, 1]$ and the distribution of θ is denoted by $F(\theta)$.

As consumers do not observe the true quality of the product, their consumption decisions are based on the perceived quality. Assume qualities to be exogenously given. Firms compete in quantities and we allow for market to be partially covered. As a benchmark case, we first discuss the situation of complete information. Next, we analyse the incomplete information situation under absence of eco-labelling and the role played by third party certification.

3.1 Complete Information

Under complete information, consumers observe the quality level chosen by the firms. The utility function of the consumer is given by -

$$U(\theta_i, s_i) = \theta s_i + y - p_i \tag{1}$$

The two qualities corresponds to the two types of firms, $i =$ Green (g) and Brown (b). The consumer who is indifferent between purchasing a green good and brown good is given by $\theta_1 = \frac{p_g - p_b}{s_g - s_b}$. The consumer who is indifferent between buying and not buying is given by $\theta_2 = \frac{p_b}{s_b}$. The demand for the green good and the brown good is $q_g = 1 - \theta_1$ and $q_b = \theta_1 - \theta_2$, respectively. Figure 1 shows the covered and uncovered market shares. The consumers with willingness to pay less than θ_2 don't buy the product, between θ_2 and θ_1 buy from brown firm, and with willingness to pay greater than θ_1 buy from green firm.
The firms maximise profits to choose quantities. The profit of the firm i is given by -

$$\pi_i = p_i q_i - \frac{k s_i^2}{2}$$

We rearrange the prices in terms of quantities of two firms and subsitute in the profit equation. The Nash equilibrium of the game given by maximising firms profits with respect to quantity is -

$$q_g = \frac{2s_g - s_b}{4s_g - s_b} \tag{2}$$

$$q_b = \frac{s_g}{4s_g - s_b} \tag{3}$$

The second order conditions for profit maximisation are satisfied. The prices of the green and brown firm are given by -

$$p_g = \frac{2s_g^2 - s_b s_g}{4s_g - s_b} \quad (4)$$

$$p_b = \frac{s_b s_g}{4s_g - s_b} \quad (5)$$

The profits of the green and brown firm are given by -

$$\pi_g = \frac{s_g(2s_g - s_b)^2}{(4s_g - s_b)^2} - \frac{ks_g^2}{2} \quad (6)$$

$$\pi_b = \frac{s_g^2 s_b}{(4s_g - s_b)^2} - \frac{ks_b^2}{2} \quad (7)$$

In our model, we allow for the market to be uncovered. The necessary condition for quantity to form equilibrium is $0 \leq \theta_2 \leq \theta_1 \leq 1$. The uncovered market share is given by $\theta_2 = \frac{s_g}{4s_g - s_b} > 0$. Also, as $\theta_1 = \frac{2s_g}{4s_g - s_b}$, the above condition is satisfied for the model.

Proposition 1: Assume $s_g, s_b > 0$ and $k < min(\frac{2(2s_g - s_b)^2}{s_g(4s_g - s_b)^2}, \frac{2s_g^2}{s_b(4s_g - s_b)^2})$, and complete information. In market equilibrium -

(a) Both firms produce in the market, i.e., $q_g > 0, q_b > 0$.

(b) The price charged and the quantity produced by the green firm is greater than the price charged and quantity produced by the brown firm, respectively.

(c) The revenue of each firm is increasing in its own quality, given the quality of the other firm and decreasing in the quality of the other firm, given its own quality.

Proof: See Appendix A.1.

The results stated in Proposition 1 are interesting as they show that when firms are competing in quantities both firms have an incentive to increase their quality. Thus as compared to a Bertrand game, there is less product differentiation in a Cournot game.

3.2 Incomplete Information

Suppose that the consumers cannot observe the good's type, so there is a need for certification to signal the higher quality. The literature mainly focuses on perfect certification and there are few papers on imperfect certification under price competition. However, we model imperfect certification under quantity competition, which is different from other papers. Under quantity competition, we first discuss the case of absence of eco-labelling and next focus third party certification.

3.2.1 Absence of Eco-Labelling

Suppose firms do not label their product. The consumer can formulate different subjective probabilities (beliefs) concerning which good has higher quality in terms of unobservable characteristics.

A.3: Assume consumers are able to observe the quantities being produced by the green and the brown firms.

Let q_g and q_b denote the goods produced using the green (non-polluting) technology and brown (polluting) technology, respectively. Thus, the utility function of the consumer is given by -

$$U(\theta_i, p) = \theta E(s) + y - p \tag{8}$$

As consumers cannot distinguish between the goods, the perceived quality is same for all goods. In other words, there is only one perceived quality. Define the probability of drawing a green unit as $P(g) = \frac{q_g}{q_g+q_b}$ and probability of drawing a brown unit as $P(b) = \frac{q_b}{q_g+q_b}$. The perceived quality available in the market is given by the weighted average of two qualities, where the weight for each quality is given by the ratio of quantity produced by that quality and total quantity available in the market -

$$E(s) = \frac{q_g}{q_g + q_b} s_g + \frac{q_b}{q_g + q_b} s_b \tag{9}$$

The consumer who is indifferent between buying a good or not buying is given by $\overline{\theta}$, where $\overline{\theta} = \frac{p}{E(s)}$. The prices for the green and brown good are the same. The demand for good is $q = q_g + q_b = 1 - \overline{\theta} = 1 - \frac{p}{E(s)}$. Thus, using equation (9) the price of the good in terms of quantity is -

$$p = (1 - q_g - q_b)(\frac{q_g s_g + q_b s_b}{q_g + q_b}) \tag{10}$$

For solving the game, each firm maximise profits to choose quantities. The profit of firm i is given by -

$$\pi_i = pq_i - \frac{ks_i^2}{2} \tag{11}$$

On substituting the value of p from equation (10), the profits of the green and brown firm are given as -

$$\pi_g = (1 - q_g - q_b)(\frac{q_g s_g + q_b s_b}{q_g + q_b})q_g - \frac{ks_g^2}{2} \tag{12}$$

$$\pi_b = (1 - q_g - q_b)(\frac{q_g s_g + q_b s_b}{q_g + q_b})q_b - \frac{ks_b^2}{2} \tag{13}$$

Maximising profits with respect to quantity, gives the best response function of the Green and Brown Firm -

$$\frac{\partial \pi_g}{\partial q_g} = \frac{(q_g + q_b)((q_g - q_g^2 - q_g q_b)s_g + (q_g s_g + q_b s_b)(1 - 2q_g - q_b)) - (q_g s_g + q_b s_b)(q_g - q_g^2 - q_g q_b)}{(q_g + q_b)^2} = 0$$

$$\frac{\partial \pi_b}{\partial q_b} = \frac{(q_g+q_b)((q_b-q_b^2-q_gq_b)s_b+(q_gs_g+q_bs_b)(1-2q_b-q_g))-(q_gs_g+q_bs_b)(q_b-q_b^2-q_gq_b)}{(q_g+q_b)^2} = 0$$

We have checked $\frac{\partial \pi_g}{\partial q_g} > 0$ for some values of q_g and $\frac{\partial \pi_b}{\partial q_b} > 0$ for some values of q_b. Solving for interior solution, i.e, the two best response functions are solved simulatenously on Matlab. Under the constraint $q_g \geq 0$ and $q_b \geq 0$, the unique Nash Equilibrium of the game is -

$$q_g = \frac{2}{3} + \frac{-(4s_g - 2s_b) + 2(s_g^2 + s_b^2 - s_gs_b)^{\frac{1}{2}}}{9(s_g - s_b)} \tag{14}$$

$$q_b = \frac{4s_g - 2s_b - 2(s_g^2 + s_b^2 - s_gs_b)^{\frac{1}{2}}}{9(s_g - s_b)} \tag{15}$$

The calculations of the solution are shown in Appendix B. Also, the second order conditions are satisfied for both the firms (shown in Appendix C).

It might seem intuitive that both firms should produce the same quantity as consumer's cannot distinguish between them and costs are fixed costs. However, in equilibrium $q_g > q_b$. This is because consumer's perceived quality $E(s)$ and thereby price is increasing in q_g. Thus, the willingness to pay also increases with an increase in q_g. For brown firm, there is a trade off as its profits are increasing in its quantity sold and prices. These forces work in such a manner that in equilibrium $q_g > q_b$.

Range on the parameters for various Equilibrium Configurations

As consumers are unable to observe the environmental attributes of the products, the brown firms have an incentive to cheat. The brown firms can pretend to be green firms in order to increase their profits. In the absence of credible mechanisms for information disclosure, the consumers are not able to verify the greenness of the products. As green products are costly to produce, due to which the green firms are driven out of the market, i.e., adverse selection. The proposition below gives the range on the cost parameter for green and brown firm to operate in the market.

<u>**Proposition 2:**</u> For different values of k, the equilibrium configurations are defined as -

(a) When $0 \leq k \leq \frac{4(s_g+s_b+A)}{27s_g^2} - \frac{2B}{s_g^2}$, both firms produce in the market earning positive profits.

(b) When $\frac{4(s_g+s_b+A)}{27s_g^2} - \frac{2B}{s_g^2} < k \leq \frac{2B}{s_b^2}$, only brown firm produces in the market, earning positive profits. Thus, there is existence of adverse selection, where polluter (brown firm) drives the environmental friendly (green firm) out of the market.

(c) When $k > \frac{2B}{s_b^2}$, none of the firm operates in the market.

where $A = (s_g^2 + s_b^2 - s_g s_b)^{\frac{1}{2}}$ and $B = \frac{2(s_g+s_b+A)(2s_g-s_b-A)}{81(s_g-s_b)}$.

<u>Proof:</u> See Appendix A.2

The results of the above proposition are interpreted as -

(a) For sufficiently small values of k, both firms produce in the market, earning positive profits. If k takes the value 0, the equilibrium quantity and profits of the green firm always exceeds the equilibrium quantity and profits of the brown firm.

(b) For large values of k and small values of s_b, as the gap between the two qualities increases, the profit of the brown firm is positive, and profits of green firm is negative. Thus, green firms are driven out of the market (Adverse Selection). For small values of s_b, the brown firm cost will be lower. Also, the values of s_g should be large enough to offset the cost of brown firm. As with increase in s_g, the price charged in the market increases ($\frac{\partial p}{\partial s_g} > 0$), which leads to increase in the profits of the brown firm. Thus, only brown firm operates in the market giving rise to adverse selection.

(c) For sufficiently large values of k, s_b and s_g, no firm produces in the market. Thus, it leads to market failure.

Thus, we observe that except under certain parameters values, due to lack of information disclosure mechanisms, the green firms are driven out of the market (Adverse Selection). Adverse selection causes the lemon problem in which green firm doesn't sell in the market, even though consumers have higher willingness to pay for green products. Therefore, polluter (brown firm) drives out of the market the environmentally friendly firm (Green). The problem arises because parties don't have relevant information about each other. The possible solution is to motivate the seller to reveal his private information, i.e., labelling by the third party certification.

4 THIRD PARTY CERTIFICATION

Third party certification allows firms to signal their product quality and differentiate their products. Suppose that the third party conducts a certification test for the firm's product at a specified cost, C. The certification provides consumers with credible information on the quality attributes of the product. The certification agencies adopt random monitoring, as it is costly to monitor continuously (Mason, 2011). Thus, there is possibility of error in the certification process. The third party could mistakenly certify some brown firm products or may not certify certain green firm products. The utility function of the consumer is given by -

$$U(\theta, s) = \theta E(s|j) + y - p_j \tag{16}$$

where $j = c$ (certified) or un (uncertified), $E(s|j)$ is the perceived quality of the product, which is conditional on whether the product is being certified or uncertified, y is income of the consumer and p_j is the price of the good.

To model the idea, the game theoretic approach is used. Consider the extensive form of the game with two firms - Green and Brown firm, certifying agency and consumers (shown in Figure 2).

- As incomplete information, each firm observes its type, but unobservable by consumers and certifying agency. For simplicity, assume that consumers think that the probability of each firm type being choosen is $\frac{1}{2}$.

- Conditional on its type, the firm chooses simultaneously whether to seek certification test (t) or not seek certification test (n).

- Conditional on the firm's decision on certification, certifying agency adopts random monitoring to label the firm's product. The firms which seek certification and pass the test are labelled as "Certified (c)". The firms which either don't seek certification test or fail are labelled as "Uncertified (un)". The probability of green firm passing the test is ϕ_g and brown firm passing the test ϕ_b. It is reasonable to assume $1 \geq \phi_g > \phi_b \geq 0$.

- Next, certified and uncertified green and brown firms simultaneously choose quantity to maximise their profits.

- Finally, consumers observe the label provided by the certifying agency, formulates beliefs about the firm's type and accordingly purchase the quantity of the products.

A pure strategy for the green firm is $\psi_g = \{\eta_1, q_g\}$, where $\eta_1 \in \{t, n\}$ and the pure strategy for brown firm is $\psi_b = \{\eta_2, q_b\}$, where $\eta_2 \in \{t, n\}$. The certifying agency gets a chance to take an action once firms have taken its decision on seeking or not seeking certification. A pure strategy for the certifying agency is $\Omega \in \{c, un\}$. The certifying agency labels the firms product passing the test, and consumers formulates the belief about the quality of the product. For simplicity, we now assume the consumer's prior belief on the good to be of high quality or low quality is equal. Thus, the consumer's belief on the expected quality is $E(s) = \frac{s_g+s_b}{2}$. However, when consumers face labelled products, the beliefs are updated using Bayes' rule. Let probability $\beta(s_g, c) = Pr(s_g|c)$ denote consumer's updated belief that the good is of high quality provided it is certified. The probability $\alpha(s_g, un) = Pr(s_g|un)$ denote consumer's updated belief that the good is of high quality provided it is not certified. Thus, the probability $\beta(s_b, c) = 1 - \beta(s_g, c) = Pr(s_b|c)$ denote consumer's updated belief that the good is of low quality provided it is certified; the probability $\alpha(s_b, un) = 1 - \alpha(s_g, un) = Pr(s_b|un)$ denote consumer's updated belief that the good is of low quality provided it is not certified. The expected quality of the certified unit is $E(s|c)$ and expected quality of the uncertified good is $E(s|un)$, where they are defined as -

$$E(s|c) = Pr(s_g|c)s_g + Pr(s_b|c)s_b \tag{17}$$

$$E(s|un) = Pr(s_g|un)s_g + Pr(s_b|un)s_b \tag{18}$$

The consumer's belief's are based on the firm decision to seek the certification and the probability of firm passing the test. Let σ_i be the probability of firm i asking for certification ($i = g$ or b) and $1 - \sigma_i$ be the probability of firm i not asking for certification. Assume that the probability of firm seeking certification and probability of firm passing the test are independent and exogenously given. Consider the case where only one firm product is certified. As if both the products are certified or not certified, then it corresponds to no information case (discussed above). Thus, using Bayes' rule, the updated consumer's belief that the product is of high quality (green), given it is certified is defined as -

$$Pr(s_g|c) = \frac{\phi_g\sigma_g(1-\sigma_b) + \phi_g(1-\phi_b)\sigma_g\sigma_b}{\phi_g\sigma_g(1-\sigma_b) + \phi_b\sigma_b(1-\sigma_g) + \phi_g(1-\phi_b)\sigma_g\sigma_b + \phi_b(1-\phi_g)\sigma_g\sigma_b} \tag{19}$$

The numerator is the joint probability that the product is of high quality and is certified. It is obtained as the product of the marginal probability that the product is high quality, i.e., green firm and the conditional probability that product is certified, given it is of high quality. The terms in numerator of equation (19) indicates that green firm pass the test and is certified. However, the brown firm doesn't seek certification (First Term) or the brown firm seek certification and fails (Second term) and thus is unlabelled. The denominator is the marginal probability that firm's product is certified. The first and the third term indicate that green firm is certified, and brown firm either doesn't seek the certification or fails. The second and fourth term indicate that brown firm is certified and green firm either doesn't seek certification or fails.

Similarly, the rest of the consumer's beliefs are defined as -

$$Pr(s_g|un) = \frac{\phi_b\sigma_b(1-\sigma_g) + \phi_b(1-\phi_g)\sigma_b\sigma_g}{\phi_b\sigma_b(1-\sigma_g) + \phi_g\sigma_g(1-\sigma_b) + \phi_b(1-\phi_g)\sigma_b\sigma_g + \phi_g(1-\phi_b)\sigma_b\sigma_g} \tag{20}$$

$$Pr(s_b|c) = 1 - Pr(s_g|c) \tag{21}$$

$$Pr(s_b|un) = 1 - Pr(s_g|un) \tag{22}$$

The paper aims to determine the Perfect Bayesian Equilibrium of the game. It includes firm's equilibrium decision on certification tests and consumer's equilibrium beliefs on the product qualities. The consumer's beliefs are consistent with the firm's strategies and derived using Bayes' rule. The firm's strategies are sequentially rational, given the consumer's beliefs.

Definition 1: Third Party Certification Game Perfect Bayesian Equilibrium - The assessment $(\psi_g, \psi_b, \Omega, \beta(.), \alpha(.))$ forms a Perfect Bayesian Equilibrium of the third party certification signalling game as -

(a) Given certification agency strategy Ω, firms simultaneously choose the quantity to maximise its profits.

(b) The consumer's belief satisfy the Bayes' Rule, that is

  (i) $\beta(s_g, c) \in [0,1]$, $\alpha(s_g, un) \in [0,1]$ for certification agency certifying the product.

  (ii) If $\eta_1 = \{t\}$, then $\beta(s_g, c) = 1$ and if $\eta_2 = \{n\}$, then $\alpha(s_g, un) = 0$.

  (iii) If $\eta_1 = \eta_2 = \{t\}$, then $\beta(s_g, c) = \gamma_1$ and $\alpha(s_g, un) = \gamma_2$, where $\gamma_1 = \frac{\phi_g(1-\phi_b)}{\phi_g(1-\phi_b)+\phi_b(1-\phi_g)}$ and $\gamma_2 = \frac{\phi_b(1-\phi_g)}{\phi_g(1-\phi_b)+\phi_b(1-\phi_g)}$.

(c) For firms choice ψ_g, ψ_b, the consumer purchases the product which maxmises their utility, and the certification agency certifies the firm's product which pass the test.

Condition (a) and (c) ensure that assessment is sequentially rational. Each firm will choose the quantity that maximises its profits, given the strategy followed by the other firm and the belief structure of the consumer. Condition (b) ensures that consumer's beliefs satisfy Bayes' rule. The consumer's beliefs about the firms product being green or brown are consistent with equilibrium strategies both on and off the equilibrium path.

Analysing the Game

In the first stage of the game, the firms decide whether to go for testing of the product (t) or not (n). The third party certifier awards label to the firm passing the test. Assume that certification test could involve error, i.e., it is noisy. In the second stage of the game, the firms compete by choosing quantities for their products to maximise profits. The game is solved using backward induction.

Quantity Competition

The firms simultaneously choose quantities to maximise the profits. The consumer who is indifferent between buying a certified and uncertified good is given by $\widetilde{\theta}_1 = \frac{p_c - p_{un}}{E(s|c) - E(s|un)}$. The consumer who is indifferent between buying an uncertified good and not buying is given by $\widetilde{\theta}_2 = \frac{p_{un}}{E(s|un)}$. The firms which are certified receive price p_c and firms which are uncertified receive price p_{un}. The demand for the certified good and the uncertified good is given by $q_c = 1 - \widetilde{\theta}_1$ and $q_{un} = \widetilde{\theta}_1 - \widetilde{\theta}_2$, respectively.

As the firms fixed costs don't influence the quantity to be produced and there is no variable cost in the model. For solving the game, we maximise the revenue of the certified and uncertified firm ($j = c$ or un), given by -

$$R_j = p_j q_j$$

We rearrange for the prices in terms of the quantities of the two firms and substitute in the revenue equation. The Nash Equilibrium of the game is -

$$q_c = \frac{2E(s|c) - E(s|un)}{4E(s|c) - E(s|un)} \tag{23}$$

$$q_{un} = \frac{E(s|c)}{4E(s|c) - E(s|un)} \tag{24}$$

The second order conditions for profit maximisation are satisfied (shown in Appendix D). The prices of the green and brown firm are given by -

$$p_c = \frac{(2E(s|c) - E(s|un))E(s|c)}{4E(s|c) - E(s|un)} \tag{25}$$

$$p_{un} = \frac{E(s|c)E(s|un)}{4E(s|c) - E(s|un)} \tag{26}$$

The revenue of the green and brown firm are given by -

$$R_c = \frac{(2E(s|c) - E(s|un))^2 E(s|c)}{(4E(s|c) - E(s|un))^2} \tag{27}$$

$$R_{un} = \frac{(E(s|c))^2 E(s|un)}{(4E(s|c) - E(s|un))^2} \tag{28}$$

Next, solve for the first stage in which firms decide whether to certify their products or not, based on the beliefs formed by the consumers about the product quality.

Testing Decisions

The producer knows the quality of the product produced; however, the consumer is unable to observe the quality due to credence nature of the product. Thus, consumer forms the beliefs regarding the product quality being sold in the market. The firm's testing decisions depends on the consumer's belief about the product quality. Under this stage, the profits of the green and brown firm are calculated, based on firm's testing decisions. Table 1 gives the payoff matrix for green and brown firm, under the two strategies (t or n).

Table 1: **Payoff Matrix**

Green/Brown Firm	Test (t)	Not Test (n)
Test (t)	$\pi_g(t,t), \pi_b(t,t)$	$\pi_g(t,n), \pi_b(t,n)$
Not Test (n)	$\pi_g(n,t), \pi_b(n,t)$	$\pi_g(n,n), \pi_b(n,n)$

Given the firm strategy and probability of passing the test, the profits for each firm is calculated, using profits calculated in stage 2.

Green Firm -

$$\pi_g(t,t) = \frac{\phi_b(1-\phi_g)(E(s|c))^2 E(s|un) + \phi_g(1-\phi_b)(2E(s|c) - E(s|un))^2 E(s|c)}{(4E(s|c) - E(s|un))^2} - \frac{ks_g^2}{2} - C$$

$$\pi_g(t,n) = \frac{\phi_g(2E(s|c) - E(s|un))^2 E(s|c)}{(4E(s|c) - E(s|un))^2} - \frac{ks_g^2}{2} - C$$

$$\pi_g(n,t) = \frac{\phi_b(E(s|c))^2 E(s|un)}{(4E(s|c) - E(s|un))^2} - \frac{ks_g^2}{2}$$

$$\pi_g(n,n) = \frac{(E(s|c))^2 E(s|un)}{(4E(s|c) - E(s|un))^2} - \frac{ks_g^2}{2}$$

Brown Firm -

$$\pi_b(t,t) = \frac{\phi_b(1-\phi_g)(2E(s|c)-E(s|un))^2E(s|c)+\phi_g(1-\phi_b)(E(s|c))^2E(s|un)}{(4E(s|c)-E(s|un))^2} - \frac{ks_b^2}{2} - C$$

$$\pi_b(t,n) = \frac{\phi_g(E(s|c))^2E(s|un)}{(4E(s|c)-E(s|un))^2} - \frac{ks_b^2}{2}$$

$$\pi_b(n,t) = \frac{\phi_b(2E(s|c)-E(s|un))^2E(s|c)}{(4E(s|c)-E(s|un))^2} - \frac{ks_b^2}{2} - C$$

$$\pi_b(n,n) = \frac{(E(s|c))^2E(s|un)}{(4E(s|c)-E(s|un))^2} - \frac{ks_b^2}{2}$$

The paper focuses on the conditions required for different equilibrium (separating and pooling) to exist. An equilibrium is a separating equilibrium if the two firms choose different testing decisions. In this way, firms separate themselves from one another. On this basis, the consumer is able to identify the green and brown firm, when making their purchasing decisions. However, an equilibrium is a pooling equilibrium if both firms propose the same testing decisions. Thus, consumer cannot identify the firm's types in making their purchasing decisions.

Definition 2 - A Perfect Bayesian Equilibrium $(\psi_g, \psi_b, \Omega, \beta(.), \alpha(.))$ is separating if $\eta_1 = \{t\}$ and $\eta_2 = \{n\}$ and pooling if $\eta_1 = \eta_2 = \{t\}$.

We are mainly interested in looking at $(g,b) = (t,n)$ in separating equilibrium, i.e., when green firm seeks certification and brown firm doesn't seek certification, as separating equilibrium $(g,b) = (n,t)$ is a wrong signal of quality. Also, the pooling equilibrium $(g,b) = (n,n)$ is not explicitly solved as we assume only firm is certified. For (n,n) case to be pooling equilibrium, we need to drop the assumption that atleast one firm is certified, so it comes out to be status quo.

4.1 Separating Equilibrium

A separating equilibrium is where the firm offering a high quality product conveys a signal about its quality and that it cannot be mimicked by the low quality firm. Under separating equilibrium green firm seeks certification and brown firm doesn't seek certification, i.e., $\sigma_g = 1$ and $\sigma_b = 0$. Thus, certification helps consumer's to distinguish between the high and low quality product.

Defination 3 - The strategy of the green firm $\psi_g = \{\eta_1, q_g\}$ and brown firm $\psi_b = \{\eta_2, q_b\}$ is separating equilibrium if and only if -

(a) $\eta_1 = \{t\}$, i.e., $\sigma_g = 1$ and $\eta_2 = \{n\}$, i.e., $\sigma_b = 0$.

(b) Each firm maximises profits to choose quantity, given others players strategy.

(c) $\pi_g(t, n) > \pi_g(n, n)$ and $\pi_b(t, n) > \pi_b(t, t)$

Condition (a) implies given separate strategies by the two firms, the green firm decides to seek certification test, i.e., $\sigma_g = 1$ and brown firm decides not to seek certification, i.e., $\sigma_b = 0$. Condition (b) implies each firm simultaneous choose quantity. Condition (c) implies that green firm prefers to seek certification and brown firm prefers not to seek certification than mimicking the other firm strategies. That is given brown firm chooses (n), the green firm profits are higher when it chooses (t) than when it chooses (n). Similarly, given green firm chooses (t), the brown firm profits are higher when it chooses (n) than when it chooses (t). The next proposition calculates the conditions under which separating equilibrium will hold true.

Proposition 3: The separating equilibrium (t, n) of the game in which green firm ask for certification and brown firm doesn't ask for certification is a Perfect Bayesian Equilibrium if

$Max(\underline{C}_{tn}, 0) < C < \overline{C}_{tn}$ holds, .i.e.,

$$Max(\underline{C}_{tn} = \frac{\phi_b(1-\phi_g)(2s_g - s_b)^2 s_g - \phi_b\phi_g s_g^2 s_b}{(4s_g - s_b)^2}, 0) < C < \frac{\phi_g(2s_g - s_b)^2 s_g - s_g^2 s_b}{(4s_g - s_b)^2} = \overline{C}_{tn}$$

Proof: See Appendix A.3

The lowest certification fee for the separating equilibrium $(g, b) = (t, n)$ is given by $Max(\underline{C}_{tn}, 0)$. When $\phi_g = 1$ or $\phi_b = 0$, the lowest certification fee for the separating equilibrium to exist is 0. In General, when $\phi_g \geq \frac{4s_g^2+s_b^2-4s_g s_b}{4s_g^2+s_b^2-3s_g s_b}$, the lowest certification fee for the separating equilibrium to exist is 0. The above equation gives zero lowest certification fee for sufficiently large values of s_g or sufficiently large gap between s_g and s_b,. For example, given $s_g = 100, s_b = 2$, when the probability of green firm passing the test is sufficiently high ($\phi_g \geq 0.9949$), then minimum certification fees is zero for separating equilibrium (t, n) to exist. Thus, even for certification fees as low as 0, the brown firm doesn't prefer to seek certification as its profits are higher when there is product differentiation.

4.2 Pooling Equilibrium

A pooling equilibrium is where both firms are proposing same testing decisions. The high quality firm is unable to convey a signal about its quality and the consumers cannot distinguish between the firms products in making their purchase decisions. Note that "pooling equilibrium" is in the sense that both firms seek or do not seek certification and not on whether they receive or not receive certification. It may still be possible that consumers see a certified and a non-certified product.[1] Under pooling equilibrium, both green firm and brown firm seek certification, i.e., $\sigma_g = 1$ and $\sigma_b = 1$.

Defination 4 - The strategy of the Green Firm $\psi_g = \{\eta_1, q_g\}$ and brown firm $\psi_b = \{\eta_2, q_b\}$ is pooling equilibrium if and only if -

[1] To be more precise, we can call it Partial Pooling Equilibrium, but here we call it Pooling Equilibrium.

(a) $\eta_1 = \{t\}$, i.e., $\sigma_g = 1$ and $\eta_2 = \{t\}$, i.e., $\sigma_b = 1$.

(b) Each firm maximises profits to choose quantity, given others players strategy.

(c) $\pi_g(t,t) > \pi_g(n,t)$ and $\pi_b(t,t) > \pi_b(t,n)$

Condition (a) implies that the green and brown firm both seek certification test, i.e., $\sigma_g = 1$ and $\sigma_b = 1$. Condition (b) implies each firm simultaneously choose quantity. Condition (c) implies that given brown firm chooses (t), the green firm profits are higher when it chooses (t) than when it chooses (n). Similarly, given green firm chooses (t), the brown firm profits are higher when it chooses (t) than when it chooses (n). Thus, in the next proposition calculates the conditions under which pooling equilibrium will hold true.

Proposition 4: The pooling equilibrium (t,t) of the game in which green and brown firm ask for certification is a Perfect Bayesian Equilibrium if $C < \overline{C}_{tt}$ holds, .i.e.,

$$C < \overline{C}_{tt} = \frac{\phi_b(1-\phi_g)(2E(s|c) - E(s|un))^2 E(s|c) - \phi_b\phi_g(E(s|c))^2 E(s|un)}{(4E(s|c) - E(s|un))^2}$$

where $E(s|c) = \frac{\phi_g(1-\phi_b)s_g + \phi_b(1-\phi_g)s_b}{\phi_g(1-\phi_b)+\phi_b(1-\phi_g)}$ and $E(s|un) = \frac{\phi_b(1-\phi_g)s_g + \phi_g(1-\phi_b)s_b}{\phi_g(1-\phi_b)+\phi_b(1-\phi_g)}$.

Proof: See Appendix A.4

For both firms to seek the certification fees should be sufficiently small. For sufficiently large values of ϕ_g, close to 1, the certification fees come out to be negative. Thus, when the green firm is certain to pass the test, the brown firm prefers not to seek certification.
Thus, to conclude when there is separating equilibrium, consumers are able to identify the green and brown firm product in their purchasing decisions. However, under pooling equilibrium, when both the firms seek certification, the consumers are unable to distinguish between the firms product.

4.3 Graphical Analysis

4.3.1 Separating Equilibrium

The range of certification fees for separating equilibrium (t, n) to exist is computed.

First, for given $s_g = 100, s_b = 20, \phi_b = 0.2$, determine how the optimal fees changes for different values of ϕ_g. Figure 3 shows that for given values of s_g, s_b and ϕ_b , as ϕ_g increases, i.e., the probability of green firm passing the test increases, the range $\underline{C}_{tn}$ and $\overline{C}_{tn}$ increases. With ϕ_g close to 0.9, the minimum certification fees ($\underline{C}_{tn}$) is close to 0. This is because as the probability of green firm passing the test increases, brown firm has the incentive to differentiate the product by not labelling.

Second, for given $s_g = 100, s_b = 20, \phi_g = 0.8$, determine how the optimal fees changes for different values of ϕ_b. Figure 4 shows that for given values of s_g, s_b and ϕ_g , as ϕ_b increases, i.e., the probability of brown firm passing the test increases, the minimum certification fees ($\underline{C}_{tn}$) required for separating equilibrium to exist increases. Also, the maximum certification fees ($\overline{C}_{tn}$) for separating equilibrium to exist doesn't depend on ϕ_b.

4.3.2 Pooling Equilibrium

The range of certification fees for pooling equilibrium (t, t) to exist is computed.

First, for given $s_b = 20, \phi_b = 0.2$, determine the cutoff for the certification fees, i.e., $\overline{C}_{tt}$, for different values of ϕ_g. The cases are considered, one in which $s_g = 100$, and other in which $s_g = 1000$. For any certification fees below $\overline{C}_{tt}$, pooling equilibrium (t, t) will exist. Figure 5 clearly shows that for given values of s_g, s_b and ϕ_b, the certification fees needs to be sufficiently low for pooling equilibrium to exist. However, this value is comparatively higher for large values of s_g. The graph shows as ϕ_g increases, the certification fees increases initially and then becomes negative, for sufficiently large values of ϕ_g. Thus, with ϕ_g close to 1, the certification fees comes out be negative.

Second, for given $s_b = 20, \phi_g = 0.8$, determine the cutoff for the certification fees, i.e., $\overline{C}_{tt}$, for different values of ϕ_b. The cases are considered, one in which $s_g = 100$, and other in which $s_g = 1000$. Figure 6 clearly shows that for given values of s_g, s_b and ϕ_g, the certification fees needs to be sufficiently low for pooling equilibrium to exist. However, this value is comparatively higher for large values of s_g. The graph shows as ϕ_b increases, the certification fees increases initially and then becomes negative, for sufficiently large values of ϕ_g. Thus, with $\phi_b = 0$, the certification fees is zero, for pooling equilibrium to exist.

5 CONCLUSION

We have analysed the role of the certification under asymmetric information. Certification by third party acts as an information disclosure mechanism by providing information on the hidden attributes of the product. For example, some consumers may have preference to buy organic products. Labelling helps consumers to distinguish between conventional and organic products. Eco-labelling is imperative for the development of green markets, in order to overcome the problem of adverse selection. To study the role of labelling, the paper considers duopolistic market for credence goods under vertical product differentiation. The existing literature mainly focuses on perfect certification; however the focus of this paper is on imperfect certification. Under perfect certification, the certifying agency accurately certifies the product. We refer imperfect certification as when certifying agency doesn't certify the product accurately, i.e., there could be errors in certification. "*With imperfect certification, we have shown the range of the certification fees for separating and pooling equilibrium to exist under quantity competition.*" Also, the paper shows the range on the cost parameter for various equilibrium configurations to exist.

For the above analysis, we assume fixed cost of providing quality for the firms. It costs more to produce high quality products, thereby creating an incentive for the brown firm to deviate from the honest behaviour. Each firm's quality choice is exogenously given, and there is quantity competition. Consumers have preferences for environmental attributes. However, as credence goods the consumers are unable to observe the quality of the product. Thus, the consumers form beliefs regarding the product quality being sold. Under above assumptions, the paper has shown the results for (i) Absence of Eco-labelling (ii) Third party certification; under incomplete information. It allows for the possibility of errors in the certification process. The results of the incomplete information are compared with the benchmark case of complete information, where consumers are able to observe the quality chosen by the firms.

Under complete information, both green and brown firms produce in the market, earning positive profits. We found that there is less product differentiation between the firms, as firms profits are increasing in its quality. In general, for environmental friendly products, the consumers are unable to observe the quality of the product, i.e., incomplete information. In the absence of labelling information by the third party, consumers are unable to distinguish the product type. Thus, consumers formulate beliefs regarding the product being sold in the market. Under these conditions, we found the existence of a unique Nash equilibrium and there are three possible equilibrium configurations. First, when both firms produce in the market earning positive profits. This holds for sufficiently small values of k, .i.e., when there is no difference in the cost of producing green and brown products. The equilibrium quantity and the profits of the green firm are higher than that of brown firm. Second, only brown firm produce in the market, leading to problem of adverse selection. This holds when the quality differential is sufficiently large and the cost of producing green products increases. Thereby, leading the honest producers to not sell their products in the market. It allows fraud producers to free ride in the market of credence goods and thus, market failure. Third, none of the firm produces in the market. This holds for large values of k, and increase in the cost of producing green and brown products. We observe except for k close to zero, green firms are driven out of the market (Adverse Selection). Due to the credence nature of the products, market fails to provide pareto optimum.

Third party certification is a possible solution for the market failure resulting from information asymmetry problem. The paper shows the strategies adopted by the firms to differentiate their products under third party certification, where the certification process is imperfect. As it costly to monitor continuously, there is random monitoring by the certification agency. Certification is modelled as noisy, i.e., allows for the possibility of errors. The third party could certify some brown firms as green or may not certify the green firm. In the model, the consumers form probabilistic belief about the quality of the product. Firms decide whether to seek certification for their product or not. The certification decisions are based on the probabilistic beliefs formed by the consumers. The paper finds the conditions on the certification costs for separating and pooling equilibrium to exist. Under separating equilibrium, the two firms choose different testing decisions, i.e., green firm seek certification and brown firm doesn't seek certification. Thus, consumers are able to differentiate between the firms product. It occurs when green firm conveys a signal about its product, which can't be mimicked by the brown firm. Any deviation by the firms from this equilibrium implies that consumers will not able to distinguish the green product from brown product. The above analysis, shows the range on the certification costs for which separating equilibrium exist. It is found that when the quality differential increases and probability of green firm passing the test is sufficiently high, the minimum certification fees for the separating equilibrium to exist is zero. When the certification fees is close to zero, brown firm doesn't prefer to seek certification as its profits are higher with differentiation of the product. Thus, in the Perfect Bayesian Equilibrium of the game, label allows firms to benefit from differentiation of the products. However, under pooling equilibrium, both firms choose same testing decisions, i.e., both green and brown firm seek certification. Thus, the consumers are unable to differentiate between the firms product, as green firm is not able to signal its product quality. For sufficiently large value of the green firm quality, the certification fee for the pooling equilibrium to exist is large. In general, for both firms to seek the certification, fees should be sufficiently small. Thus, the we have analysed the range of certification costs for separating and pooling equilibrium to exist under imperfect certification.

It is worth noting that we have conducted my research assuming duopoly market structure and quality as exogenous variable. For future research, it would be an interesting area to extent the analysis to "n" firms under quantity competition. Also, the analysis could be extended by treating quality as an endogenous variable.

APPENDIX

A Proof of Propositions

A.1 Proof of Proposition 1

(a) As $s_g > s_b$, it follows trivally from equation (2) and (3) that $q_g > 0$ and $q_b > 0$.

(b) As $s_g > s_b$, we have $2s_g^2 - s_b s_g > s_b s_g$. Thus, it follows $p_g > p_b$ from equation (4) and (5). Also, as $s_g > s_b$, we have $2s_g - s_b > s_g$. Thus, it follows $q_g > q_b$ from equation (2) and (3).

(c) The revenue of the green firm is increasing in s_g, given s_b and is decreasing in s_b, given s_g, i.e.,

$$\frac{\partial R_g}{\partial s_g} = \frac{(2s_g - s_b)(2s_g(4s_g - s_b) + s_b^2)}{(4s_g - s_b)^3} > 0$$

$$\frac{\partial R_g}{\partial s_b} = \frac{-4s_g^2(2s_g - s_b)}{(4s_g - s_b)^3} < 0$$

The revenue of the brown firm is increasing in s_b, given s_g and is decreasing in s_g, given s_b, i.e.,

$$\frac{\partial R_b}{\partial s_b} = \frac{s_g^2(4s_g + s_b)}{(4s_g - s_b)^3} > 0$$

$$\frac{\partial R_b}{\partial s_g} = \frac{-2s_g s_b^2}{(4s_g - s_b)^3} < 0$$

A.2 Proof of Proposition 2

Using equation (10) and the equilibrium quantity of green and brown firm (equation (14), (15)), price of a good is given as -

$$p = \frac{s_g + s_b + A}{9} \tag{29}$$

On the substituting the values of q_g (equation (14)), and p (equation (29)) in the profit equation of green firm (i.e., equation (11)) , we get -

$$\begin{aligned} \pi_g &= \frac{2}{3} + \frac{s_g + s_b + A}{9}\left(\frac{2s_b - 4s_g + 2A}{9(s_g - s_b)}\right) - \frac{ks_g^2}{2} && (30) \\ &= \frac{2(s_g + s_b + A)}{27} - B - \frac{ks_g^2}{2}. && (31) \end{aligned}$$

On the substituting the values of q_b (equation (15)), and p (equation (29)) in the profit equation of brown firm (i.e., equation (11)) , we get -

$$\begin{aligned} \pi_b &= \frac{(s_g + s_b + A)(4s_g - 2s_b - 2A)}{81(s_g - s_b)} - \frac{ks_b^2}{2} && (32) \\ &= \frac{2(s_g + s_b + A)(2s_g - s_b - A)}{81(s_g - s_b)} - \frac{ks_b^2}{2} = B - \frac{ks_b^2}{2}. && (33) \end{aligned}$$

Thus, the result of the proposition follows from equations (31) and (33). For case (a), when both firms produce in the market, we have $\pi_g \geq 0$ and $\pi_b \geq 0$. For case (b), when only brown firm produces in the market ,i.e., there is adverse selection, we have $\pi_g < 0$ and $\pi_b \geq 0$. For case (c), none of the firms produce in the market, i.e., $\pi_g < 0$ and $\pi_b < 0$.

A.3 Proof of Proposition 3

Substituting $\sigma_g = 1$ and $\sigma_b = 0$ in equation (19), (20), (21) and (22), $Pr(s_g|c) = 1$, $Pr(s_g|un) = 0$, $Pr(s_b|c) = 0$ and $Pr(s_b|un) = 1$. Substituting these probabilities in equation (17) and (18), $E(s|c) = s_g$ and $E(s|un) = s_b$.

<u>Condition 1</u> - $\pi_g(t,n) > \pi_g(n,n)$

Substituting the values of the profits calculated, we get -

$$\frac{\phi_g(2E(s|c) - E(s|un))^2 E(s|c)}{(4E(s|c) - E(s|un))^2} - \frac{ks_g^2}{2} - C > \frac{(E(s|c))^2 E(s|un)}{(4E(s|c) - E(s|un))^2} - \frac{ks_g^2}{2}$$

$$\frac{\phi_g(2E(s|c) - E(s|un))^2 E(s|c) - (E(s|c))^2 E(s|un)}{(4E(s|c) - E(s|un))^2} > C$$

Substituting $E(s|c) = s_g$ and $E(s|un) = s_b$, the condition 1 is -

$$\frac{\phi_g(2s_g - s_b)^2 s_g - s_g^2 s_b}{(4s_g - s_b)^2} > C \tag{34}$$

<u>Condition 2</u> - $\pi_b(t,n) > \pi_b(t,t)$

Substituting the values of the profits calculated, we get -

$$\frac{\phi_g(E(s|c))^2 E(s|un)}{(4E(s|c) - E(s|un))^2} - \frac{ks_b^2}{2} > \frac{\phi_b(1-\phi_g)(2E(s|c) - E(s|un))^2 E(s|c) + \phi_g(1-\phi_b)(E(s|c))^2 E(s|un)}{(4E(s|c) - E(s|un))^2} - \frac{ks_b^2}{2} - C$$

$$C > \frac{\phi_b(1-\phi_g)(2E(s|c) - E(s|un))^2 E(s|c) - \phi_g\phi_b(E(s|c))^2 E(s|un)}{(4E(s|c) - E(s|un))^2}$$

Substituting $E(s|c) = s_g$ and $E(s|un) = s_b$, condition 2 is -

$$C > \frac{\phi_b(1-\phi_g)(2s_g - s_b)^2 s_g - \phi_g \phi_b s_g^2 s_b}{(4s_g - s_b)^2} \tag{35}$$

Thus, from equation (34) and (35), result is derived. The separating equilibrium (t, n) exists when C lies between $(\underline{C}_{tn}, \overline{C}_{tn})$.

A.4 Proof of Proposition 4

Substitute $\sigma_g = 1$ and $\sigma_b = 1$ in equation (19), (20), (21) and (22), $Pr(s_g|c) = Pr(s_b|un) = \frac{\phi_g(1-\phi_b)}{\phi_g(1-\phi_b)+\phi_b(1-\phi_g)}$ and $Pr(s_g|un) = Pr(s_b|c) = \frac{\phi_b(1-\phi_g)}{\phi_g(1-\phi_b)+\phi_b(1-\phi_g)}$. Substituting these probabilities in equation (17) and (18), values of $E(s|c)$ and $E(s|un)$ defined in proposition 4.

Condition 1 - $\pi_g(t,t) > \pi_g(n,t)$

Substituting the values of the profits calculated, we get -

$$\frac{\phi_b(1-\phi_g)(E(s|c))^2 E(s|un) + \phi_g(1-\phi_b)(2E(s|c) - E(s|un))^2 E(s|c)}{(4E(s|c) - E(s|un))^2} - \frac{ks_g^2}{2} - C > \frac{\phi_b(E(s|c))^2 E(s|un)}{(4E(s|c) - E(s|un))^2} - \frac{ks_g^2}{2}$$

$$C < \frac{\phi_g(1-\phi_b)(2E(s|c) - E(s|un))^2 E(s|c) - \phi_b \phi_g (E(s|c))^2 E(s|un)}{(4E(s|c) - E(s|un))^2} \tag{36}$$

Condition 2 - $\pi_b(t,t) > \pi_b(t,n)$

Substituting the values of the profits calculated, we get -

$$\frac{\phi_b(1-\phi_g)(2E(s|c) - E(s|un))^2 E(s|c) + \phi_g(1-\phi_b)(E(s|c))^2 E(s|un)}{(4E(s|c) - E(s|un))^2} - \frac{ks_b^2}{2} - C > \frac{\phi_g(E(s|c))^2 E(s|un)}{(4E(s|c) - E(s|un))^2} - \frac{ks_b^2}{2} - C$$

$$C < \frac{\phi_b(1-\phi_g)(2E(s|c)-E(s|un))^2 E(s|c) - \phi_g\phi_b(E(s|c))^2 E(s|un)}{(4E(s|c)-E(s|un))^2} \tag{37}$$

Thus, the pooling equilibrium exists when $C < \overline{C}_{tt}$, given by equation (37) (i.e., lowest cutoff).

B Analysis of solution under Absence of Eco-Labelling

Simulatenously solving the best response functions of green and browm firm on Matlab, we get the following solutions -

(a) $q_g = 0, \quad q_b = 0.$

This cannot be the solution, as it is not defined for the best response functions of green and brown firm.

(b) $q_g = \frac{-s_b}{s_g - s_b}, \quad q_b = \frac{s_g}{s_g - s_b}.$

As $s_g > s_b$, we have $q_g < 0$. Thus, this is not a feasible solution.

(c) $q_g = \frac{2}{3} - \frac{8s_g - 4s_b + 4(s_g^2 + s_b^2 - s_g s_b)^{\frac{1}{2}}}{18(s_g - s_b)}, \quad q_b = \frac{8s_g - 4s_b + 4(s_g^2 + s_b^2 - s_g s_b)^{\frac{1}{2}}}{18(s_g - s_b)}.$

Here, $q_g < 0$ and $q_b > 0$ for all values of s_g and s_b. Thus, this is not a feasible solution.

(d) $q_g = \frac{4s_b - 8s_g + 4(s_g^2 + s_b^2 - s_g s_b)^{\frac{1}{2}}}{18(s_g - s_b)} + \frac{2}{3}, \quad q_b = \frac{-(4s_b - 8s_g + 4(s_g^2 + s_b^2 - s_g s_b)^{\frac{1}{2}})}{18(s_g - s_b)}.$

Here, $q_g > 0$ and $q_b > 0$ for all values of s_g and s_b. Thus, the unique Nash Equilibrium is given by solution (d).

C Second Order Conditions for Profit Maximisation under Absence of Eco-Labelling

The second order condition for Green firm -

$$\frac{\partial^2 \pi_g}{\partial q_g^2} = \frac{-2q_g^3 s_g - 6q_g^2 q_b s_g - 6q_g q_b^2 s_g + 2q_b^2 s_g - 2q_b^2 s_b - 2q_b^3 s_g}{(q_g + q_b)^3} < 0$$

The second order condition for Brown firm -

$$\frac{\partial^2 \pi_b}{\partial q_b^2} = \frac{-2q_b^3 s_b - 6q_b^2 q_g s_b - 6q_b q_g^2 s_b + 2q_g^2 s_b - 2q_g^2 s_g - 2q_g^3 s_b}{(q_g + q_b)^3} < 0$$

For both the firms, the second order condition for profit maximisation is satisfied, as the numerator is always negative, and the denominator is always positive.

D Second Order Conditions for Profit Maximisation under Third Party Certification

The second order condition for Certified firm -

$$\frac{\partial^2 R_c}{\partial q_c^2} = -2E(s|c) < 0$$

The second order condition for Uncertified firm -

$$\frac{\partial^2 R_{un}}{\partial q_{un}^2} = -2E(s|un) < 0$$

Thus, the second order condition for profit maximisation is satisfied.

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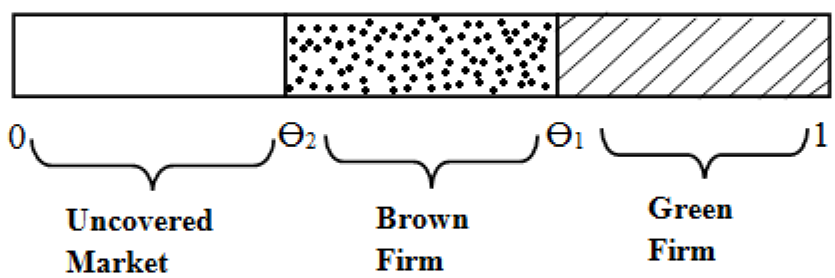

Figure 1: **Covered and Uncovered Market**

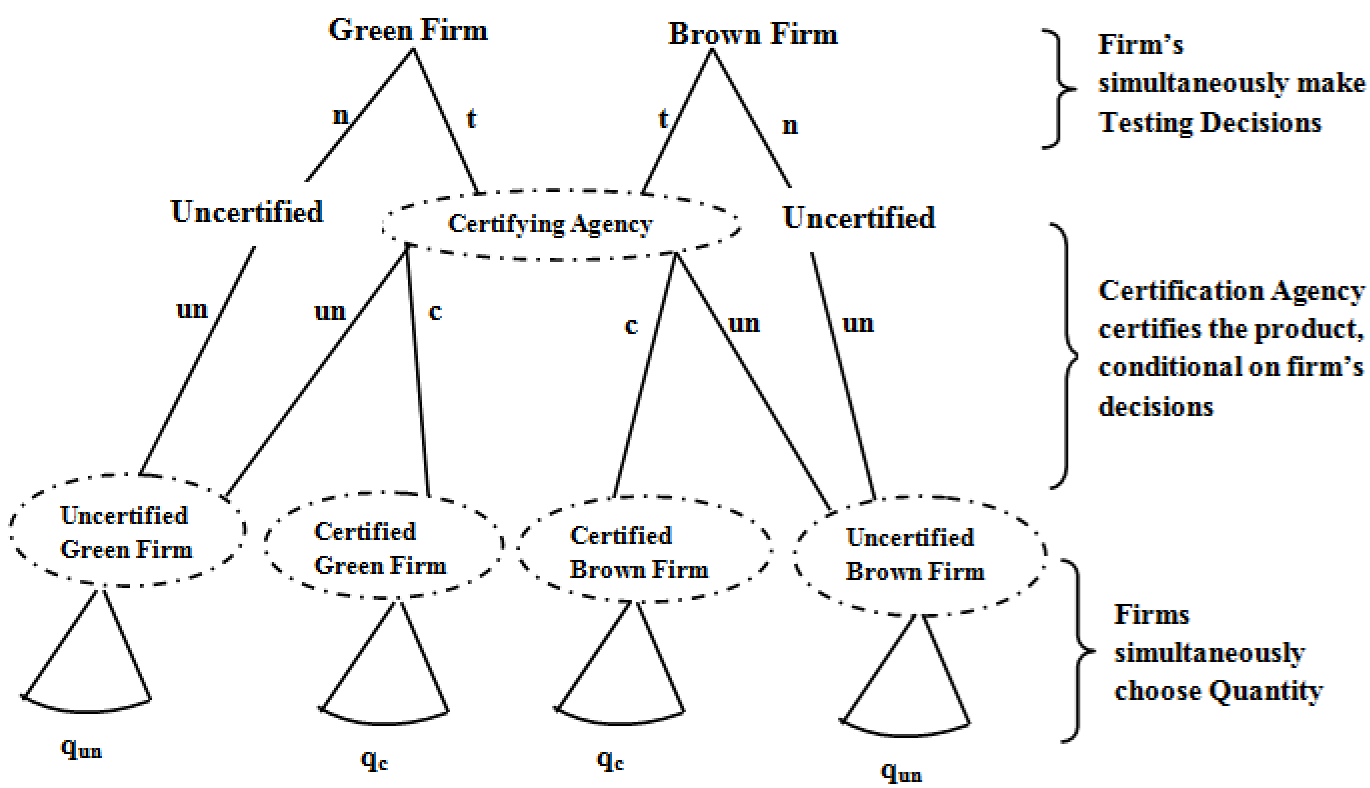

Figure 2: **Extensive Form Game under Third Party Certification**

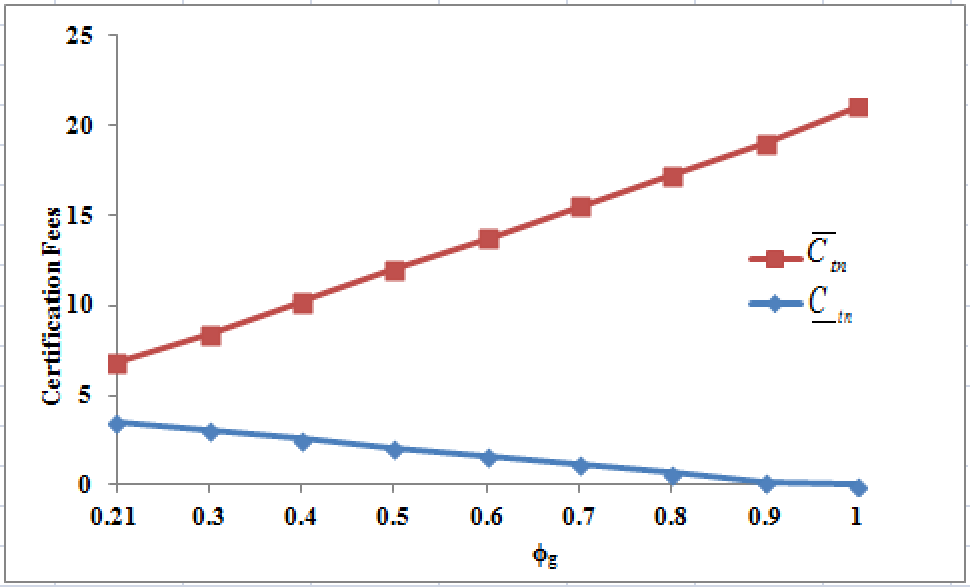

Figure 3: **Certification Fees for Separating Equilibrium, given** $s_g = 100, s_b = 20, \phi_b = 0.2$

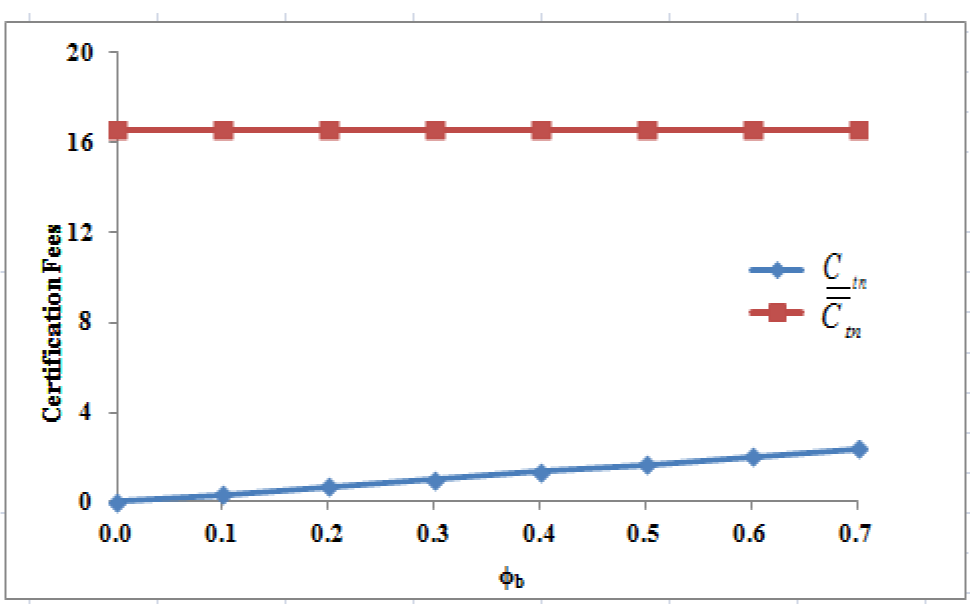

Figure 4: **Certification Fees for Separating Equilibrium, given** $s_g = 100, s_b = 20, \phi_g = 0.8$

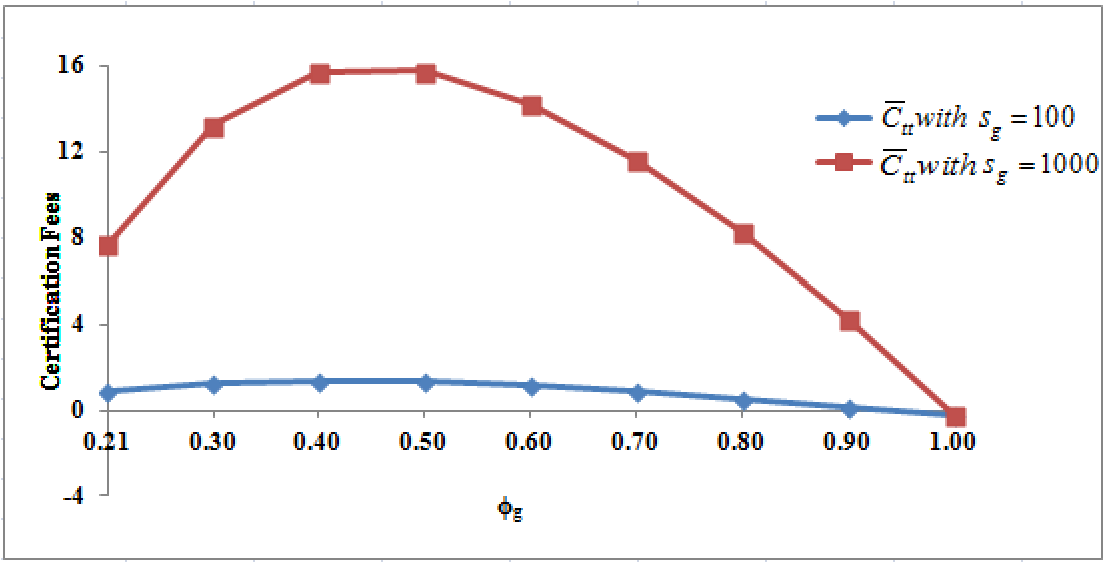

Figure 5: **Certification Fees for Pooling Equilibrium** ($C < \overline{C}_{tt}$), **given** $s_b = 20, \phi_b = 0.2$

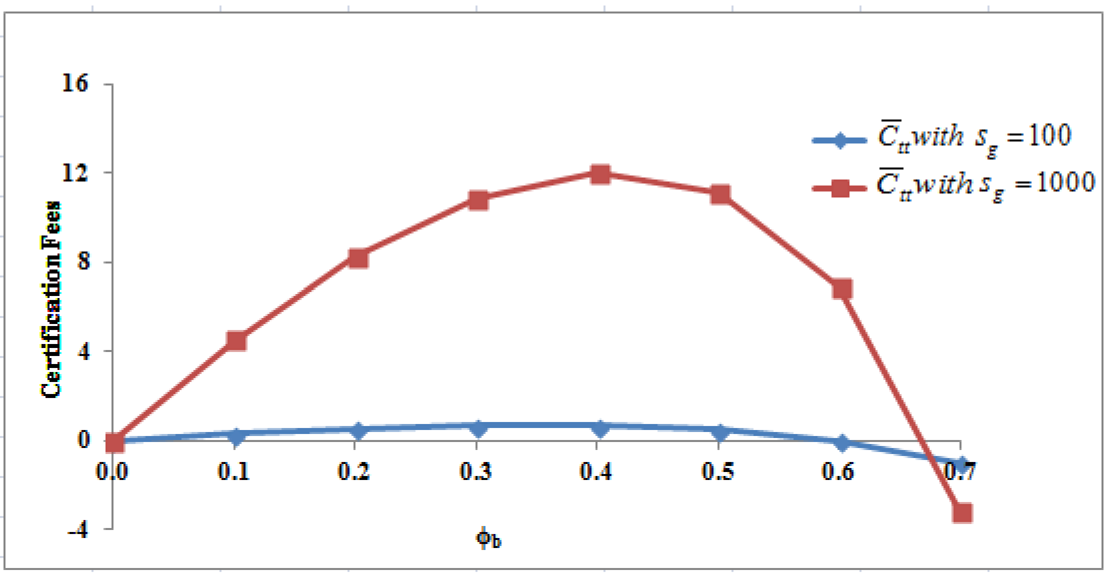

Figure 6: **Certification Fees for Pooling Equilibrium** ($C < \overline{C}_{tt}$), **given** $s_b = 20, \phi_g = 0.8$