Effect of Green Network and Emission Tax on Consumer Choice under Discrete Continuous Framework with Conflicting Quality Dimensions

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Abstract

We consider a vertical product differentiation model with two firms (high quality and low quality) and two conflicting quality dimensions - intrinsic quality and environmental quality. The high quality firm has higher intrinsic and lower environmental quality. The low quality firm has lower intrinsic and higher environmental quality. In our model, consumers' faces discrete-continuous choice where discrete choice is concerning the decision on purchasing the product and continuous choice is on the usage of the product. Using the above framework, the paper examines the impact of green network effect and government policies such emission taxes on market equilibrium. We show that an increase in green network effect leads to increase in intrinsic quality (reducing environmental quality), prices of both firms, increase in market share, profits of low quality (environmental friendly) firm. In the absence of network effect, an emission tax results in increasing environmental quality of high quality firm and no change in environmental quality of low quality firm. In the presence of network effect, an emission tax constraints consumer usage of the product of both firms and results in decreasing emissions.

Keywords: Conflicting Quality Dimensions; Discrete-Continuous; Emission Tax; Green Network Effect; Vertical differentiation

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1 INTRODUCTION

Consumers' concern for the environment has grown in recent years resulting in a higher willingness to pay for environment-friendly products. A large strand of literature modelling such consumer preferences has focused on the qualities that firms will choose in a vertically differentiated product framework, and how the regulation affects these qualities (Bansal and Gangopadhyay, 2003; Amacher et al., 2004; Brecard, 2013). Often consumers not only have to decide what quality of product to buy but also need to decide on the usage of the product. Another assumption made in the above literature is that the intrinsic quality is homogeneous across firms, and firms product differentiate in environmental quality only. Often products compete in more than one quality dimension, and the environment-friendly products face competition from the existing standard products. A few papers in the literature have taken cognizance that the intrinsic quality and the environmental quality may be interrelated. While Birg and Vobwinkel (2018) considers these qualities to be substitutes, Mantovani et al. (2016) models them as conflicting.

ln this paper, we incorporate both choice and usage of the product, and assume intrinsic quality to be in conflict with the environmental quality. While purchasing cars consumers not only consider characteristics of the car they are purchasing but also how much fuel they are going to use. They also face trade-offs in terms of different dimensions of quality. For example, electric cars are more environment friendly but may not be as convenient as gasoline cars because of the limited storage capacity of batteries of electric cars. Similarly, luxury cars, SUVs, etc. have high intrinsic quality in terms of size, engine, comfort, safety features, etc. but usage of these cars requires much more fuel as compared to standard small cars. Solar thermal panels are considered environment friendly but may not ensure uninterrupted supply of energy and their installation requires space in the house. Eco-friendly cleaning products are mostly natural in origin and chemical free, therefore, less harmful to the eco-system but their performance may not match that of chemical based cleaning products.

We use a discrete continuous framework to model choice and usage of the product. The discrete choice faced by the consumers is decision on the choice of the product, for example, which brand of a car to buy, whether to buy an electric or gasoline car. The continuous choice faced by the consumers is on the usage of the product say fuel or electricity consumption associated with the usage of the product. The literature on discrete continuous models includes Burtless and Hausman (1978); Dubin and McFadden (1984); Hanemann (1984); De Jong (1990); Matsukawa (2012), etc. Hanemann (1984) developed econometric model of discrete choice for different brands of a commodity and continuous choice of the quantity of a commodity to be purchased. De Jong, (1990) and Matsukawa (2012) analyze vehicle ownership choices based on the hypothesis that a household maximizes utility from discrete choice of vehicle ownership and a continuous choice of vehicle usage. Using data from Netherlands, De Jong (1990) shows that the cost of the car and the fuel price are effective in reducing car ownership levels and also have an effect on car usage. Matsukawa (2012) examine welfare impact of emission taxes and subsidies, and show that as compared to a subsidy, an emission tax results in greater reduction in environmental pollution and higher welfare. Glerum et al. (2014) extends the literature by discussing dynamic discrete continuous model of car ownership, usage and fuel type. The paper models forward looking behaviour of the households for acquisition of the car.

The literature has also recognised the fact that consumer preferences for environmental friendly products get influenced by what their peers are doing. In other words, demand for green product increases because other consumers are using the same product, which gives rise to green network effect. The empirical studies have indicated that network effects increases willingness to pay for environmental friendly products (Rasouli and Timmermans, 2016; Grover et al., 2018). The theoretical studies such as Conrad (2006); Griva and Vettas (2011); Greaker and Midttomme (2014) have focused on network effects. Griva and Vettas (2011) under a standard Hotelling model with network effect showed that if firms' have different product quality, then for relatively weak network effects high quality firm captures a larger market share and for stronger network effects either high quality or low quality firm captures the entire market. Greaker and Midtomme (2014) using a dynamic model discussed that if a consumer purchases a brown good, it causes more pollution due to network effect. This may warrant a brown good tax to be in excess of pigovian tax. Lambertini and Orsini (2005); Brecard (2013) and Hauck et al. (2014) are few of the studies theoretically modelling green network effect under vertical product differentiation model. Lambertini and Orsini (2005) showed that when network externalities are large, then there is possibility of bertand equilibrium, even though the product differentiation is positive. Brecard (2013) showed that if green network effect is stronger than brown product network effect, then optimum could be achieved by ad-valorem tax on products and tax on purchasing green products. However, if brown network effect is stronger, then optimum would be achieved by providing a subsidy on green products. Hauck et al. (2014) showed that higher the strength of the network effect, lower is the firms' environmental quality, fewer externalities and thus, total welfare may decrease. The regulators would choose a minimum environment quality standard in the presence of the network effect. The above papers consider green network effect under one quality dimension.

The objective of our study is to analyse a discrete-continuous framework when two qualities are in conflict. With in this framework, we examine the the impact of green network effect and government policies such emission taxes on market equilibrium. Our theoretical model adds value on several counts. Firstly, papers in previous literature mainly consider one dimension of quality, i.e., environmental quality (Marette et al.,1999; Zago and Pick, 2004). We contribute to the literature by considering products which have two dimensions of quality (intrinsic quality and environmental quality), which are in conflict with each other (Mantovani et al., 2016). Secondly, except for a few studies such as Brecard (2013); Hauck et al. (2014), majority of the theoretical literature has not incorporated the impact of green network effect in influencing consumer behaviour. The above papers have analysed the impact of green network effect under vertical product differentiation but model only choice of the product. The present study aims to extend this literature by analysing the impact of green network effect under discrete continuous framework. Thirdly, this is the first study which analyses impact of government policies such as emission tax on market equilibrium both in absence and presence of network effect.

Our paper showed that larger green network effect reduces environmental quality and increases prices of both firms, decreases the market share, profits of high quality firm (high intrinsic and low environmental quality), and increases the market share, profits of low quality firm (low intrinsic and high environmental quality). Our results are different from Lambertini and Orsini (2005) which showed that qualities are independent of the network effect and prices decreases due to network effect. The results are similar to Brecard (2013) in terms of environmental quality but differs in terms of prices. In terms of the profits, our paper results differs from Lambertini and Orsini (2005), which showed profits of both firms decrease due to network effects. In addition, we show the impact of green network effect on intrinsic as well as environmental quality, and with/without government regulation. The government policies such as emission taxes are effective in influencing consumers towards green products. Emission tax in the absence of network effect results in increasing environmental quality of high quality firm and no change in environmental quality of low quality firm. This result is different from Matsukawa (2012), which showed an increase in emission tax rate in discrete-continuous framework increases environmental quality of both firms. However, when we introduce green network effect then the result in terms of increasing environmental quality corresponds to Matsukawa (2012) paper. In addition, our paper shows the impact of emission tax on prices, market share, prices and profits in absence and presence of network effect. Our results are different from Bansal (2008) which shows effect of emission tax depends only on costs parameter. However, our study shows that effect of emission tax depends on costs parameter as well as usage of firms' product parameter.

The paper is structured as follows. Section 2 develops duopoly model under discrete continuous framework and analyses equilibrium. The section also analyses various possible regulatory scenarios. Section 3 and 4 analyses the impact of green network and policy instrument of emission tax on equilibrium. Section 5 contains the concluding remarks.

2 Model Structure

Consider a vertically differentiated product market where the product has two quality dimensions. The first dimension is intrinsic quality (pure performance), which is observable. The second dimension is environmental quality, which is not observable. There are two firms - high quality firm (H) and low quality firm (L), $i = H,\ L$. Let s_i, where $i = H,\ L$ denote the intrinsic quality of the firm i product, where $s_i \in [\underline{s},\ \bar{s}]$. We assume firm H has higher intrinsic quality as compared to firm L, i.e., $s_H > s_L$. Since the two quality dimensions are in conflict, in our model firm H has lower environmental quality as compared to firm L.

A.1: Let $C(s_i), i = H, L$, denote cost function of firm i, given by

$$C(q_i, s_i) = \frac{b{s_i}^2 q_i}{2} + F_i$$

where b is the marginal cost parameter for intrinsic quality of firm i, $b > 0$, F is the fixed cost, q is the quantity produced. The total cost is increasing in the quantity of good produced as well as intrinsic quality. The marginal costs with respect to intrinsic quality are increasing.

The usage of the product requires fuel or electricity, which generates emissions. Let x_i denote fuel consumption and ρ denote emissions per fuel consumption. We assume high quality firm (H) requires more fuel on usage as compared to low quality firm (L), i.e., $x_H > x_L$. Assume emissions are generated only by the consumption of fuel/electricity and not from the production of the products by the firms. The emissions generated by the consumption of fuel on usage of firm i product is denoted by e_i. The emissions generated by usage of the product is assumed to be the product of emissions per fuel consumption (denoted by ρ) and fuel consumption (denoted by x_i), i.e., $e_i = \rho x_i$. Since firm H product requires more fuel on usage, therefore it generates higher emissions as compared to firm L product, i.e., $e_H > e_L$. Firm H has lower environmental quality (brown good) as compared to firm L (green good).

The discrete choice is whether to buy a high quality or low quality firm product, and the continuous choice is concerning the usage of product, i.e., amount of fuel (x_i) used. Conditional on the choice that consumer makes on firms' type, each consumer faces a choice between a private and composite good. Private good (x_i) is measured by fuel consumption on usage of the product. The composite good (z_i) includes expenditure on all other goods, except fuel consumption.

There exists a continuum of consumers, with each consumer buying one unit of the product to maximise its utility. The utility function of consumer is given by

$$\begin{aligned} \max_{x_i, z_i} \quad & U(x_i, z_i) + \theta s_i + \gamma(e_j - e_i) + \alpha q_L \\ \text{s.t.} \quad & y - p_i \geq (\omega + t_e \rho) x_i + p_z z_i \end{aligned} \tag{1}$$

where $U(x_i, z_i)$ is the utility from fuel consumption (x_i) and composite good (z_i), θ is the marginal willingness to pay for intrinsic quality of the product, which is assumed to be uniformly distributed over $[0, 1]$, e_i is the emissions on usage of firm i product with $i \neq j$, α is the network effect, q_L is the number of consumers buying firm L product, y is the income of the consumer, p_i is the purchase price of firm i product, ω is the price of fuel, t_e is the tax rate on emissions ($t_e \geq 0$), p_z is the price of composite good.

In addition to the intrinsic utility component of the indirect utility function (θs_i), consumers' also care for the environmental quality which gets reflected in the term $\gamma(e_j - e_i)$. The term $\gamma(e_j - e_i)$ measures relative emissions affecting the utility. The parameter $\gamma \geq 0$ measures the intensity of the relative emissions affecting utility. The higher the value of γ, stronger is the weightage for environmental quality. When the environmental qualities are not observable or $\gamma = 0$, we have the standard utility function for intrinsic quality along with green network effect.

Another term that distinguishes utility function from the standard function is green network effect which gets reflected in term (αq_L). We assume that the green network effect is present only for low quality firm, L (green firm) and there is no network effect for high quality firm, H (brown firm). This is because social norms emerge for green products. By purchasing green product (i.e., firm L product) they feel that they follow the social norm.

The budget constraint given by equation (1) states that income (y) net of the purchase price of the product (p_i) is allocated between fuel consumption, x_i and composite good, z_i. In the presence of emission taxes imposed on consumers using fuel, the amount spent by the consumer on fuel consumption is $(\omega + t_e\rho)x_i$ and the amount spent by the consumer on composite good is $p_z z_i$. For simplification, we assume $\rho = 1$ for rest of the paper. Each consumer maximises its utility subject to the budget constraint. The consumers will buy the product if the utility of owning the product exceeds the utility of not having the product.

2.1 Specification of the Utility Function

In order to obtain discrete continuous choice model in which above utility function is consistent with the utility maximization, we can proceed by specifying the functional form for the indirect utility function. Using the indirect utility function we can derive demand using Roy's identity. Another possible way is to specify the fuel demand function and use Roy's identity as a partial differentiation equation (De Jong, 1990; Matsukawa, 2012). We follow the latter approach. Let the fuel demand function conditional on firm i product be given by

$$x_i = \lambda s_i - \frac{\beta(\omega + t_e)}{p_z} + \delta \tag{2}$$

where $\lambda > 0$, $\beta > 0$ and δ are the parameters. The fuel demand is a function of intrinsic quality of the firm from which it is buying (s_i), fuel price (ω), emission tax rate (t_e), price of composite good (p_z) and socio economic characteristics of the individual (denoted by δ). The parameter λ measures the usage of the firms' product, independent of the consumers' choice of the product. The term (λs_i) which captures fuel consumption associated with firm i product, i.e., firm H has high intrinsic quality and therefore requires more fuel on usage. The higher the price of fuel (ω) or the emission tax rate (t_e), lower will be the demand for fuel (x_i). The socio-economic characteristics (δ) such as age, gender, average commuting distance, number of household members, etc. also influence the demand for fuel.

The conflict in the two dimensions of qualities is evident from the demand function (2) and the utility function (1). As intrinsic quality (s_i) increases, there is an increase in fuel consumption (x_i), which in turn increases emissions (e_i). In equation (1) intrinsic quality positively affects utility but emissions negatively affect utility.
Conditional on the consumer's choice of the firm, each consumer's conditional indirect utility function is given by

$$U_i = \psi((\omega + t_e)/p_z, Y_i/p_z, s_i) + \theta s_i + \gamma(e_j - e_i) + \alpha q_L \tag{3}$$

where $Y_i \equiv y - p_i$. Applying Roy's identity to equation (3) and using equation (2) we get the following partial differentiation equation

$$\begin{aligned} -\frac{\partial U_i/\partial \omega}{\partial U_i/\partial y} &= x_i \\ -\frac{\partial \psi_i/\partial((\omega + t_e)/p_z)}{\partial \psi_i/\partial(Y_i/p_z)} &= \lambda s_i - \frac{\beta(\omega + t_e)}{p_z} + \delta \end{aligned} \tag{4}$$

Following Burtless and Hausman (1978) and Matsukawa (2012), keeping utility fixed at some level, we derive the conditional indirect utility function using implicit function theorem in equation (3)

$$\frac{\partial \psi_i}{\partial((\omega + t_e)/p_z)} d((\omega + t_e)/p_z) + \frac{\partial \psi_i}{\partial(Y_i/p_z)} d(Y_i/p_z) = 0 \tag{5}$$

Using equation (4) and (5), we get the following equation

$$\frac{d(Y_i/p_z)}{d((\omega + t_e)/p_z)} = x_i = \lambda s_i - \frac{\beta(\omega + t_e)}{p_z} + \delta \tag{6}$$

Integrating the equation both sides and using separability of the differentiation equation, we have

$$\frac{Y_i}{p_z} = c + (\lambda s_i + \delta)\frac{(\omega + t_e)}{p_z} - \frac{\beta}{2}(\frac{\omega + t_e}{p_z})^2 \tag{7}$$

where c is the constant of integration. We choose c as our cardinal measure of utility (Burtless and Hausman, 1978), i.e., $c = \psi((\omega + t_e)/p_z, Y_i/p_z, s_i) = \frac{Y_i}{p_z} - (\lambda s_i + \delta)\frac{(\omega+t_e)}{p_z} + \frac{\beta}{2}(\frac{\omega+t_e}{p_z})^2$. Substituting $\psi((\omega + t_e)/p_z, Y_i/p_z, s_i)$ in equation (3) we get conditional indirect utility function as

$$U_i = \theta s_i + \gamma(e_j - e_i) + \alpha q_L - (\lambda s_i + \delta)\frac{(\omega + t_e)}{p_z} + \frac{\beta}{2}(\frac{\omega + t_e}{p_z})^2 + \frac{Y_i}{p_z} \tag{8}$$

The conditional indirect utility function given in equation (8) satisfies all the properties of an indirect utility function. It is continuous and homogenous of degree zero in fuel price, emission tax rate, price of the product, price of the composite good and income; non-increasing in price of the fuel (ω), price of the composite good (p_z) and non-decreasing in the income (y), i.e.,

$$\begin{aligned} \frac{\partial U_i}{\partial \omega} &= -\frac{\lambda s_i + \delta}{p_z} + \frac{\beta(\omega + t_e)}{p_z^2} = -\frac{x_i}{p_z} < 0 \\ \frac{\partial U_i}{\partial p_z} &= -\frac{-p_z Y_i + p_z(\lambda s_i + \delta)(\omega + t_e) - \beta(\omega + t_e)^2}{p_z^3} = -\frac{z_i}{p_z} < 0 \\ \frac{\partial U_i}{\partial y} &= \frac{1}{p_z} > 0 \end{aligned} \tag{9}$$

The conditional indirect utility function must be quasi-convex in prices, i.e., the diagonal elements of Slutsky matrix must be non-positive. We use expenditure function to calculate diagonal elements of Slustky matrix. Rearranging terms in equation (8) and using $Y_i \equiv y - p_i$, we get expenditure function as

$$e(p_z, \omega, \overline{U}) = y = \overline{U} p_z - \theta s_i p_z - \gamma(e_j - e_i) p_z - \alpha q_L p_z + (\lambda s_i + \delta)(\omega + t_e) - \frac{\beta}{2} \frac{(\omega + t_e)^2}{p_z} + p_i$$

The diagonal elements of Slustky equation, s_{11} and s_{22} are given by

$$\begin{aligned} s_{11} = \frac{\partial^2 e(p_z, \omega, \overline{U})}{\partial \omega^2} = -\frac{\beta}{p_z} < 0 \\ s_{22} = \frac{\partial^2 e(p_z, \omega, \overline{U})}{\partial p_z^2} = -\frac{\beta(\omega + t_e)}{p_z^3} < 0 \end{aligned} \tag{10}$$

Therefore, equation (10) shows that quasi-convexity condition is met by the conditional indirect utility function. For the rest of our analysis, for simplicity, we assume $p_z = 1$.

2.2 Equilibrium Analysis

In our model, we consider a two stage game of quality and price. In the first stage, firms choose intrinsic quality and in the second stage, firms compete in prices. In these kinds of games literature has considered both partially covered market (Amacher et al., 2005, Bansal and Gangopadhyay, 2003; Grover and Bansal, 2019) and fully covered market (Bansal, 2008; Bottega and Freitas, 2013). In this study, we assume a fully covered market. The conditional indirect utility function is given by equation (8). Using $e_i = x_i = \lambda s_i - \beta(\omega + t_e) + \delta$ (from equation (2)), the consumer who is indifferent between purchasing from high quality firm (H) and low quality firm (L) is given by $\theta_2 = (p_H - p_L + \lambda(2\gamma + \omega + t_e)(s_H - s_L) + \alpha q_L)/(s_H - s_L)$. The demand for high quality firm (H) is $q_H = 1 - \theta_2$ and demand for low quality firm (L) is $q_L = \theta_2$. Substituting q_L value, we get $\theta_2 = (p_H - p_L + \lambda(2\gamma + \omega + t_e)(s_H - s_L))/(s_H - s_L - \alpha)$. It can be shown that for $\lambda(2\gamma + \omega + t_e) \leq 1$ we have $0 < \theta_2 < 1$. The demand for firm i is given by

$$q_H = \frac{(s_H - s_L - \alpha) - (p_H - p_L) - \lambda(2\gamma + \omega + t_e)(s_H - s_L)}{s_H - s_L - \alpha}$$
$$q_L = \frac{p_H - p_L + \lambda(2\gamma + \omega + t_e)(s_H - s_L)}{s_H - s_L - \alpha} \quad (11)$$

It follows that if firms prices are equal, both firms will have positive market share. We solve the above two stage game by backward induction.

Stage 2 - Price Competition

The firms simultaneously choose prices to maximize profits. The profit of firm i is given by

$$\pi_i = (p_i - \frac{bs_i^2}{2})q_i - F_i$$

We assume both firms obtain positive profits in equilibrium, i.e., F_i is sufficiently small. Substituting demand function, q_i, in the profit function and maximizing with respect to prices gives the following best response functions

$$p_H = \frac{2p_L + 2(s_H - s_L - \alpha) - 2\lambda(2\gamma + \omega + t_e)(s_H - s_L) + bs_H^2}{4}$$
$$p_L = \frac{2p_H + 2\lambda(2\gamma + \omega + t_e)(s_H - s_L) + bs_L^2}{4}$$

From the best responses function it can be seen that prices are strategic complements. We define $s_H - s_L$ as degree of product differentiation and is denoted by Δs. Solving the best response functions simultaneously give equilibrium prices

$$p_H^{**} = \frac{4(\Delta s - \alpha) - 2\lambda\Delta s(2\gamma + \omega + t_e) + 2bs_H^2 + bs_L^2}{6}$$
$$p_L^{**} = \frac{2(\Delta s - \alpha) + 2\lambda\Delta s(2\gamma + \omega + t_e) + bs_H^2 + 2bs_L^2}{6} \quad (12)$$

where superscript $**$ denote equilibrium value to the variables under green network effect with regulation. The price of high quality firm is rising in quality gap Δs. The price of low quality firm is rising in higher quality s_H, but effect of s_L is ambiguous. For given qualities, an increase in fuel price or emission tax results in decrease in the price of high quality firm and increase in the price of low quality firm.

The equilibrium quantities are

$$\begin{aligned} q_H^{**} &= \frac{4(\Delta s - \alpha) - 2\lambda\Delta s(2\gamma + \omega + t_e) - b\Delta s(s_H + s_L)}{6(\Delta s - \alpha)} \\ q_L^{**} &= \frac{2(\Delta s - \alpha) + 2\lambda\Delta s(2\gamma + \omega + t_e) + b\Delta s(s_H + s_L)}{6(\Delta s - \alpha)} \end{aligned} \tag{13}$$

It can be seen from equation (12) that for given qualities, an increase in green network effect results in decrease in the price for both firms. The price effect would result in an increase in demand for both firms. However, green network effect would also impact demand. From equation (13) we find that an increase in green network effect results in net decrease in the demand for high quality firm suggesting that green network effect dominates the price effect. However, for low quality firm both effects work in same direction of increasing quantity.

Stage 1 - Intrinsic Quality Competition

We now turn to firms' choice of intrinsic quality in Stage 1. Substituting prices and quantity from equation (12), (13) into profit equation we have

$$\begin{aligned} \pi_H &= \frac{(4(\Delta s - \alpha) - 2\lambda\Delta s(2\gamma + \omega + t_e) - b\Delta s(s_H + s_L))^2}{36(\Delta s - \alpha)} - F_H \\ \pi_L &= \frac{(2(\Delta s - \alpha) + 2\lambda\Delta s(2\gamma + \omega + t_e) + b\Delta s(s_H + s_L))^2}{36(\Delta s - \alpha)} - F_L - C \end{aligned} \tag{14}$$

Maximizing profits with respect to intrinsic quality gives the following first order conditions

$$\begin{aligned}\frac{\partial \pi_H}{\partial s_H} &\leq (4(\Delta s-\alpha)-2\lambda\Delta s(2\gamma+\omega+t_e)-b\Delta s(s_H+s_L))\\ &\quad \frac{(4(\Delta s-\alpha)(1-bs_H)-2\lambda(2\gamma+\omega+t_e)(\Delta s-2\alpha)+b\Delta s(s_H+s_L))}{36(\Delta s-\alpha)^2}\\ \frac{\partial \pi_L}{\partial s_L} &\leq (2(\Delta s-\alpha)+2\lambda\Delta s(2\gamma+\omega+t_e)+b\Delta s(s_H+s_L)\\ &\quad \frac{(-2(\Delta s-\alpha)(1+2bs_L)-2\lambda(2\gamma+\omega+t_e)(\Delta s-2\alpha)+b\Delta s(s_H+s_L))}{36(\Delta s-\alpha)^2}\end{aligned} \tag{15}$$

The above analyses serves as a general set of equations using which we will now solve for specific cases. We discuss the following cases (i) Benchmark case where green network effect is absent and there is no regulation (ii) Absence of green network effect with regulation (iii) Presence of green network effect with no regulation (iv) Presence of Green network effect with regulation.

Benchmark - Absence of Green Network Effect with No Regulation

Suppose consumers do not take into account green network effect, i.e., $\alpha = 0$ and government doesn't impose emission tax, i.e., $t_e = 0$. For the equilibrium to exists under benchmark case, we need $\lambda(2\gamma + \omega) \leq 1$ [3]. Solving the two first order conditions simultaneously given by equation(15) and using $\alpha = 0$; $t_e = 0$, we get equilibrium qualities as [4]

$$\begin{aligned} s_H^* &= \frac{4-2\lambda(2\gamma+\omega)}{3b}\\ s_L^* &= \underline{s} \end{aligned} \tag{16}$$

The firm H quality (high intrinsic and low environmental quality) depends on the consumers' usage of firm's product parameter (λ), intensity of relative emissions (γ), price of

[3] Using $0 < \theta_2 < 1$, we get the condition $\lambda(2\gamma + \omega) \leq 1$

[4] This is the only solution which satisfies second order conditions

fuel (ω) and cost parameter (b). The choice of low quality firm intrinsic quality is the corner solution, i.e., $s_L^* = \underline{s}$. The quality of firm L (low intrinsic and high environmental quality) is the lowest possible quality.

Substituting the value of qualities from equation (16) in equation (12) - (14) and using $\alpha = 0$; $t_e = 0$, we get equilibrium prices, quantity and profits of firm H and L as

$$\begin{aligned} p_H^* &= \frac{10(2-\lambda(2\gamma+\omega))^2}{27b} \\ p_L^* &= \frac{2(2-\lambda(2\gamma+\omega))(5+2\lambda(2\gamma+\omega))}{27b} \\ q_H^* &= \frac{2(2-\lambda(2\gamma+\omega))}{9} \\ q_L^* &= \frac{5+2\lambda(2\gamma+\omega)}{9} \\ \pi_H* &= \frac{2(2-\lambda(2\gamma+\omega))^3}{2187b} - F_H \\ \pi_L* &= \frac{(2-\lambda(2\gamma+\omega))(5+2\lambda(2\gamma+\omega))^2}{4374b} - F_L \end{aligned} \tag{17}$$

where superscript $*$ denote equilibrium value to the variables under the benchmark case. The second order conditions for profit maximisation are satisfied (refer Appendix A). From equation (16), we get that an increase in fuel price (ω) results in decrease in intrinsic quality of the high quality firm (H) and no change in the quality of low quality firm (L). An increase in fuel price reduces price of both firms; reduces market share of high quality firm (H); increases market share of low quality firm (L) and reduces profits of high quality firm (H) (using equation (17)). It increases profits of the low quality firm (L) for $\lambda(2\gamma+\omega) < 1/2$ and decreases profits of the low quality firm (L) for $\lambda(2\gamma+\omega) > 1/2$.

Absence of Green Network Effect with Regulation

In the absence of green network effect we have $\alpha = 0$ and suppose government imposes a regulation in the form of emission tax, t_e on the usage of the firm's product. Using equation

(12) - (15) and $\alpha = 0$, the equilibrium quality, prices, quantity and profits of firm H and L are given by

$$
\begin{aligned}
\hat{s_H} &= \frac{4 - 2\lambda(2\gamma + \omega + t_e)}{3b} \\
\hat{s_L} &= \underline{s} \\
\hat{p_H} &= \frac{10(2 - \lambda(2\gamma + \omega + t_e))^2}{27b} \\
\hat{p_L} &= \frac{2(2 - \lambda(2\gamma + \omega + t_e))(5 + 2\lambda(2\gamma + \omega + t_e))}{27b} \\
\hat{q_H} &= \frac{2(2 - \lambda(2\gamma + \omega + t_e))}{9} \\
\hat{q_L} &= \frac{5 + 2\lambda(2\gamma + \omega + t_e)}{9} \\
\hat{\pi_H} &= \frac{2(2 - \lambda(2\gamma + \omega + t_e))^3}{2187b} - F_H \\
\hat{\pi_L} &= \frac{(2 - \lambda(2\gamma + \omega + t_e))(5 + 2\lambda(2\gamma + \omega + t_e))^2}{4374b} - F_L
\end{aligned}
\tag{18}
$$

where superscript ˆ denote equilibrium value to the variables under absence of green network with regulation.

Green Network Effect with No Regulation

Suppose consumers take into account green network effect and there is no regulation. When green network effect is taken into account, the term αq_L is included in the utility function. Solving the two first order conditions simultaneously given by equation (15) and using $t_e = 0$ gives equilibrium qualities as

$$
\begin{aligned}
\widetilde{s_H} &= \tfrac{15 - 16b\alpha}{4b(3 - 4b\alpha)} - \tfrac{\lambda(2\gamma + \omega)}{b} \\
\widetilde{s_L} &= \tfrac{8b\alpha - 3}{4b(3 - 4b\alpha)} - \tfrac{\lambda(2\gamma + \omega)}{b}
\end{aligned}
\tag{19}
$$

Under $0.375 < b\alpha < 0.75$ and $(8b\alpha - 3)/(4(3-4b\alpha)) > \lambda(2\gamma+\omega)$, both firms qualities are in interior, i.e., $\widetilde{s_H} > 0, \widetilde{s_L} > 0$. The second order conditions are satisfied for $b\alpha < 0.5625$ (refer Appendix A). Thus, in the presence of green network effect, we assume $0.375 < b\alpha < 0.5625$. Substituting the value of s_H and s_L from (19) in equation (12) - (14) and using $t_e = 0$, we get equilibrium prices, quantity and profits of firm H and L as

$$
\begin{aligned}
\widetilde{p_H} &= \frac{6 - 4b\alpha - 3\lambda(2\gamma+\omega) + 3(\lambda(2\gamma+\omega))^2}{6b} + \frac{153 + 192(b\alpha)^2 - 336b\alpha}{32b(3-4b\alpha)^2} \\
&\quad - \frac{\lambda(2\gamma+\omega)(9-8b\alpha)}{4b(3-4b\alpha)} \\
\widetilde{p_L} &= \frac{3 - 2b\alpha + 3\lambda(2\gamma+\omega) + 3(\lambda(2\gamma+\omega))^2}{6b} + \frac{81 + 128(b\alpha)^2 - 192b\alpha}{32b(3-4b\alpha)^2} - \frac{3\lambda(2\gamma+\omega)}{4b(3-4b\alpha)} \\
\widetilde{q_H} &= \frac{9 - 16b\alpha}{6(3-4b\alpha)} \\
\widetilde{q_L} &= \frac{9 - 8b\alpha}{6(3-4b\alpha)} \\
\widetilde{\pi_H} &= \frac{(3-2b\alpha)(9-16b\alpha)^2}{72b(3-4b\alpha)^2} - F_H \\
\widetilde{\pi_L} &= \frac{(3-2b\alpha)(9-8b\alpha)^2}{72b(3-4b\alpha)^2} - F_L
\end{aligned} \tag{20}
$$

where superscript $\tilde{}$ denote equilibrium value to the variables under green network with no regulation.

Green Network Effect with Regulation

Suppose green network effect is present and government imposes an emission tax t_e on the usage of the product. Using equation (12) - (15), the equilibrium quality, prices, quantity and profits of firm H and L are given by

$$
\begin{aligned}
s_H^{**} &= \frac{15-16b\alpha}{4b(3-4b\alpha)} - \frac{\lambda(2\gamma+\omega+t_e)}{b} \\
s_L^{**} &= \frac{8b\alpha-3}{4b(3-4b\alpha)} - \frac{\lambda(2\gamma+\omega+t_e)}{b} \\
p_H^{**} &= \frac{6-4b\alpha-3\lambda(2\gamma+\omega+t_e)+3(\lambda(2\gamma+\omega+t_e))^2}{6b} + \frac{153+192(b\alpha)^2-336b\alpha}{32b(3-4b\alpha)^2} \\
&- \frac{\lambda(2\gamma+\omega+t_e)(9-8b\alpha)}{4b(3-4b\alpha)} \\
p_L^{**} &= \frac{3-2b\alpha+3\lambda(2\gamma+\omega+t_e)+3(\lambda(2\gamma+\omega+t_e))^2}{6b} + \frac{81+128(b\alpha)^2-192b\alpha}{32b(3-4b\alpha)^2} - \frac{3\lambda(2\gamma+\omega+t_e)}{4b(3-4b\alpha)} \quad (21) \\
q_H^{**} &= \frac{9-16b\alpha}{6(3-4b\alpha)} \\
q_L^{**} &= \frac{9-8b\alpha}{6(3-4b\alpha)} \\
\pi_H^{**} &= \frac{(3-2b\alpha)(9-16b\alpha)^2}{72b(3-4b\alpha)^2} - F_H \\
\pi_L^{**} &= \frac{(3-2b\alpha)(9-8b\alpha)^2}{72b(3-4b\alpha)^2} - F_L
\end{aligned}
$$

where superscript $**$ denote equilibrium value to the variables under green network with regulation of emission tax. For both firms qualities to be interior ($s_H^{**} > 0, s_L^{**} > 0$), we assume $0.375 < b\alpha < 0.5625$ and $(8b\alpha - 3)/(4(3-4b\alpha)) > \lambda(2\gamma + \omega + t_e)$. The second order conditions for profit maximisation is shown in Appendix A. From equation (21), an increase in fuel price reduces the intrinsic quality and increases environmental quality of both firms; reduces the prices of both firms and has no impact on market shares, profits of both firms.

3 Impact of Green Network Effect

Consumer preferences for environmental friendly products could be influenced by what their peers are doing, in other words, social norms which generally conforms in a group or community. Social norms take the form of approval or disapproval from the society and the feeling of pride or shame. These social norms arise from the networks formed by the individuals in the society. Previous studies have discussed the existence of network effects such as bandwagon effect, i.e., demand for good increases because other consumers are using the same good (Leibenstein, 1950). It is the phenomenon where beliefs, ideas and fads arise, the more it is been adopted by others. The individuals consuming certain products could be considered as forming a network because of being physically connected or having close market relationship. When the network effect is present, the value of the product depends on the number of consumers purchasing that product, i.e., size of the market. There is a possibility of network effect existing in green market, i.e., green network effect (Brecard, 2013). The Green Network Effect is when consumers' valuation for the green products increases with number of other consumers using green products. It manifests in the form of increasing consumers' utility from buying a green product with an increase in the number of consumers buying such products. Proposition 1 analyses the impact of green network effect under without regulation and with regulation on market outcomes.

Proposition 1: Assume that optimal intrinsic quality level for both firms are in interior in the presence of green network effect. An increase in the green network effect under without regulation and with regulation

(i) increases the intrinsic quality and decreases environmental quality of both firms

(ii) increases the prices of both firms

(iii) reduces the market share of high quality firm (H) and increases the market share of low quality firm (L)

(iv) reduces the profits of high quality firm (H) and increases the profits of low quality firm (L)

(v) doesn't depend on degree of product differentiation

Proof: See Appendix B

We observe that the impact of green network effect is similar both under without regulation and with regulation. An interesting result in our paper is because of green network effect the intrinsic quality of the product for both firms goes up, which in turn implies that environmental quality goes down. The main economic intuition of our results is the following. The low quality firm will increase its intrinsic quality as consumers are willing to pay more for its product due to network effect. Since qualities are strategic complements, the high quality firm also increases its intrinsic quality. The main contribution of our study is the impact of green network effect on intrinsic as well as environmental quality. Our results differ from Lambertini and Orsini (2005) where qualities are independent of the network effect, as in Lambertini and Orsini (2005) equilibrium prices decrease linearly in the network effect. Our results are similar to Brecard (2013) in terms of environmental quality, but different in terms of prices. In our paper the increase in intrinsic quality increases costs, resulting in increase in prices of both firms. Similar to Hauck et al. (2014), there exists a demand effect of green network resulting in an increase in the market share of low quality firm. Due to green network effect profits of high quality firm reduce and low quality firm increases. In contrast, Lambertini and Orsini (2005) showed that profits of both firms decrease due to network externalities. For large value of network effect, a Bertand equilibrium with zero profits may arise. However, in our paper, green firms profits increases due to network effects. The main reason for the difference in the results is that qualities are in conflict in our model. It may be observed that degree of product differentiation, $\Delta s^{**} = \frac{3}{2b}$ is only dependent on cost parameter, b and is independent of green network effect, fuel price (ω), intensity of relative emissions (γ) and emission tax (t_e). In terms of the effect of green network effect on product differentiation, our results are similar to Brecard (2013).

4 Policy Instruments - Emission Taxes

Emission taxes are widely used as a policy instrument to address environmental problems. They have also been used to encourage green products (Lombardini-Riipinen, 2005; Bansal, 2008). Other possible policy instruments to promote green consumption are minimum quality standards, labeling, ad-valorem taxes/subsidy, emission subsidies, etc. Emission tax is defined as a tax imposed on emissions generated through industrial processes or fuel used in transportation. In our study, we impose emission taxes on the usage of the products. The proposition below discusses the impact of emission taxes on consumers' choice of the product and its usage on product qualities, prices, market share and profits in the absence and presence of green network effect.

Proposition 2: In the absence of green network effect, an increase in an emission tax rate

(i) reduces the intrinsic quality and increases environmental quality of high quality firm (H) and no change in intrinsic quality and environmental quality of low quality firm (L)

(ii) reduces the prices of both firms

(iii) reduces market share of high quality firm (H) and increases market share of low quality firm (L)

(iv) reduces profits of high quality firm (H); increases profits of low quality firm (L) for $\lambda(2\gamma+\omega+t_e) < 1/2$ and reduces profits of low quality firm (L) for $\lambda(2\gamma+\omega+t_e) > 1/2$.

Proof: See Appendix C

Proposition 3: In the presence of green network effect, an increase in an emission tax rate

(i) reduces the intrinsic quality and increases environmental quality of both firms

(ii) reduces the prices of both firms

(iii) has no impact on market shares of both firms

(iv) has no impact on profits of both firms

Proof: See Appendix D

Our results show that in the absence of green network effect, an emission tax increases environmental quality (decreases intrinsic quality) of high quality firm and no change in intrinsic as well as environmental quality of low quality firm. This result is different from Matsukawa (2012), which showed an increase in emission tax rate in discrete-continuous framework increases environmental quality of both firms. However, when we introduce green network effect then the result in terms of increasing environmental quality corresponds to Matsukawa (2012) paper. As qualities are in conflict, increasing environmental quality implies reduction in intrinsic quality, which reduces the fuel consumed on usage of the product. The effect of emission taxes depends on usage of firms product by consumers parameter, λ, and cost parameter, b. The larger is the λ and lower is b, the larger is the effect of emission taxes on intrinsic quality. The results differ from Bansal (2008), where the effect of emission taxes depends only on the cost parameter, b, in our study, the effect of emission tax effect on quality depends both on usage of firms' product parameter, λ and cost parameter, b. In the presence of network effect, the degree of the product differentiation given by $\Delta s^{**} = 3/2b$, does not depend on the emission taxes.

Our study contributes by discussing the effect of emission tax in discrete continuous framework both in absence and presence of network effect. However, Matsukawa (2012) only discusses the effect of emission tax on qualities in absence of network effect. In addition, we discuss the impact of emission tax on intrinsic and environmental quality, prices, market share and profits of both firms. In the presence of network effect, an increase in emission tax rate reduces price of both firms and have no impact on market share and profits of both firms.

To conclude, our model shows that emission tax is an effective measure to reduce emissions. Emission taxes results in decrease in consumers' usage of the product, thereby motivating firms to increase environmental quality of the product.

5 Conclusion

The model analysed the impact of green network effect and emission tax on market outcomes in a discrete-continuous framework. The discrete choice is on the decision on purchasing the product and continuous choice is on usage of the product. We show that an increase in green network effect leads to increase in intrinsic quality (reducing environmental quality), prices of both firms, increase in market share and profits of low quality (environmental friendly) firm. The results showed that the environmental friendly firm benefits from green network effect, as its market share and profits increases, as compared to the less environmental friendly firm. We also show that in the presence of network effect, an emission tax constraints consumer usage of the product and results in decreasing emissions.

APPENDIX

A Second Order Conditions for Profit Maximization

Absence of Green Network Effect with No Regulation

The second order conditions at the market equilibrium are given by (using equation (14) and $\alpha = 0$)

$$\begin{aligned}\frac{\partial^2 \pi_H}{\partial s_H^2} &= -b(4 - 2\lambda(2\gamma + \omega + t_e)) < 0 \\ \frac{\partial^2 \pi_L}{\partial s_L^2} &= -\frac{b(8 + 5\lambda(2\gamma + \omega + t_e))}{27} < 0\end{aligned}$$

The second order conditions also holds for benchmark case (subsituting $t_e = 0$).

Green Network Effect with Regulation

Using equation (14), we get second order conditions at the market equilibrium as

$$\begin{aligned}\frac{\partial^2 \pi_H}{\partial s_H^2} &= -\frac{b(9 - 16b\alpha)(32(b\alpha)^2 - 56b\alpha + 27)}{36(3 - 4b\alpha)^2(3 - 2b\alpha)} < 0 \\ \frac{\partial^2 \pi_L}{\partial s_L^2} &= -\frac{b(9 - 8b\alpha)(32(b\alpha)^2 - 32b\alpha + 15)}{36(3 - 4b\alpha)^2(3 - 2b\alpha)} < 0\end{aligned}$$

The above condition for high quality firm holds for $b\alpha < 0.5625$. The second order conditions is same for green network with no regulation.

B Proof of Proposition 1

Impact of Green Network Effect with Regulation

(i) From equation (21), we have $\frac{ds_i^{**}}{d\alpha} = \frac{3}{(3-4b\alpha)^2} > 0$

(ii) From equation (21),we have

$$\begin{aligned}\frac{dp_H^{**}}{d\alpha} &= -\frac{2}{3} + \frac{3(9-8b\alpha)}{4(3-4b\alpha)^3} - \frac{3\lambda(2\gamma+\omega+t_e)}{(3-4b\alpha)^2} > 0 \\ \frac{dp_L^{**}}{d\alpha} &= -\frac{1}{3} + \frac{9}{4(3-4b\alpha)^3} - \frac{3\lambda(2\gamma+\omega+t_e)}{(3-4b\alpha)^2} > 0\end{aligned}$$

(iii) From equation (21),we have

$$\begin{aligned}\frac{dq_H^{**}}{d\alpha} &= -\frac{2b}{(3-4b\alpha)^2} < 0 \\ \frac{dq_L^{**}}{d\alpha} &= \frac{2b}{(3-4b\alpha)^2} > 0\end{aligned}$$

(iv) From equation (21),we have

$$\begin{aligned}\frac{d\pi_H^{**}}{d\alpha} &= -\frac{(9-16b\alpha)(63-108b\alpha+64(b\alpha)^2)}{36(3-4b\alpha)^3} < 0 \\ \frac{d\pi_L^{**}}{d\alpha} &= \frac{(9-8b\alpha)(9+36b\alpha-32(b\alpha)^2)}{36(3-4b\alpha)^3} > 0\end{aligned}$$

(v) From equation (21), we have $\Delta s^{**} = s_H^{**} - s_L^{**} = 3/2b$

Under green network effect with no regulation, we have $t_e = 0$. The above results hold true without regulation.

C Proof of Proposition 2

Impact of Emission Tax in the Absence of Green Network Effect

(i) From equation (18),we have $\frac{d\hat{s_H}}{dt_e} = -\frac{2\lambda}{3b} < 0$ and $\frac{d\hat{s_L}}{dt_e} = 0$.

(ii) From equation (18),we have $\frac{d\hat{p_H}}{dt_e} = -\frac{20\lambda(2-\lambda(2\gamma+\omega+t_e))}{27b} < 0$ and $\frac{d\hat{p_L}}{dt_e} = -\frac{2\lambda(1+4\lambda(2\gamma+\omega+t_e))}{27b} < 0$.

(iii) From equation (18),we have $\frac{d\hat{q_H}}{dt_e} = -\frac{2\lambda}{9} < 0$ and $\frac{d\hat{q_L}}{dt_e} = \frac{2\lambda}{9} > 0$.

(iv) From equation (18),we have $\frac{d\hat{\pi_H}}{dt_e} = -\frac{6\lambda(2-\lambda(2\gamma+\omega+t_e))^2}{2187b} < 0$ and $\frac{d\hat{\pi_L}}{dt_e} = \frac{\lambda(1-2\lambda(2\gamma+\omega+t_e))(5+2\lambda(2\gamma+\omega+t_e))}{1458b} > 0$ for $\lambda(2\gamma+\omega+t_e) < 1/2$ and < 0 for $\lambda(2\gamma+\omega+t_e) > 1/2$.

D Proof of Proposition 3

Impact of Emission Tax under Green Network

(i) From equation (21),we have $\frac{ds_H^{**}}{dt_e} = \frac{ds_L^{**}}{dt_e} = -\frac{\lambda}{b} < 0$.

(ii) Change in the prices can be written as

$$\frac{dp_i^{**}}{dt_e} = \frac{\partial p_i^{**}}{\partial s_H^{**}}\frac{ds_H^{**}}{dt_e} + \frac{\partial p_i^{**}}{\partial s_L^{**}}\frac{ds_L^{**}}{dt_e} + \frac{\partial p_i^{**}}{\partial t_e}, i = H, L$$

Using equation (12) and $\frac{ds_H^{**}}{dt_e} = \frac{ds_L^{**}}{dt_e} = -\frac{\lambda}{b}$, we have

$$\frac{dp_H^{**}}{dt_e} = \frac{b(2s_H^{**} + s_L^{**})\frac{ds_H^{**}}{dt_e}}{3} - \frac{\lambda\Delta s^{**}}{3} = -\lambda s_H^{**} < 0$$

$$\frac{dp_L^{**}}{dt_e} = \frac{b(s_H^{**} + 2s_L^{**})\frac{ds_H^{**}}{dt_e}}{3} + \frac{\lambda\Delta s^{**}}{3} = -\lambda s_L^{**} < 0$$

(iii) Change in the quantity can be written as

$$\frac{dq_i^{**}}{dt_e} = \frac{\partial q_i^{**}}{\partial s_H^{**}}\frac{ds_H^{**}}{dt_e} + \frac{\partial q_i^{**}}{\partial s_L^{**}}\frac{ds_L^{**}}{dt_e} + \frac{\partial q_i^{**}}{\partial t_e}, i = H, L$$

Using equation (13) and $\frac{ds_H^{**}}{dt_e} = \frac{ds_L^{**}}{dt_e} = -\frac{\lambda}{b}$, we have

$$\frac{dq_H^{**}}{dt_e} = -\frac{b\Delta s^{**}\frac{ds_H^{**}}{dt_e}}{3(\Delta s^{**} - \alpha)} - \frac{\lambda \Delta s^{**}}{3(\Delta s^{**} - \alpha)} = 0$$
$$\frac{dq_L^{**}}{dt_e} = \frac{b\Delta s^{**}\frac{ds_H^{**}}{dt_e}}{3(\Delta s^{**} - \alpha)} + \frac{\lambda \Delta s^{**}}{3(\Delta s^{**} - \alpha)} = 0$$

(iv) Change in the profits can be written as

$$\frac{d\pi_i^{**}}{dt_e} = \frac{\partial \pi_i^{**}}{\partial s_H^{**}}\frac{ds_H^{**}}{dt_e} + \frac{\partial \pi_i^{**}}{\partial s_L^{**}}\frac{ds_L^{**}}{dt_e} + \frac{\partial \pi_i^{**}}{\partial t_e}, i = H, L$$

Using equation (14) and $\frac{ds_H^{**}}{dt_e} = \frac{ds_L^{**}}{dt_e} = -\frac{\lambda}{b}$, we have

$$\frac{d\pi_H^{**}}{dt_e} = \frac{d\pi_L^{**}}{dt_e} = 0$$

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