Carbon emissions in a dual channel closed loop supply chain: the impact of consumer free riding behavior

Rongyao He, Yu Xiong, & Zhibin Lin

(Accepted 26 February 2016)

Citation:

He, R. Xiong, Y. & **Lin, Z.** (2016). Carbon emissions in the dual-channel closed-loop supply chain: the impact of consumer free-riding, *Journal of Cleaner Production*, 134 (Part A), 384-394. https://doi.org/10.1016/j.jclepro.2016.02.142

Abstract

Analyzing carbon emissions is critical for successfully managing sustainable production and consumption. In a dual channel supply chain that includes traditional retailers and online e-tailers, consumer free riding often occurs when consumers enjoy the services provided by a traditional retailer but make purchases at a lower price from an e-tailer. The specific aim of this paper, therefore, is to evaluate the impact of consumer free riding on a product's life cycle carbon emissions across a dual channel closed loop supply chain and to assess the effect of governmental e-commerce tax on carbon emissions. The study comprises a systematic comparison and numerical analysis of cases in which consumers do or do not free ride. Our results show that although manufacturers may gain economic benefits from consumer free riding behavior, total carbon emissions across the supply chain increase too, and a governmental tax on e-commerce can help reduce consumer free riding and total carbon emissions. But in consideration of social welfare maximization, a government may have to subsidize the e-tailer.

Key words: Life cycle carbon emissions; green supply chain; dual-channel; closed loop supply chain; free riding; e-commerce tax.

1. Introduction

Sustainable production and consumption requires effective “green” supply chain management to generate both economic and environmental benefits by reducing waste, minimizing pollution, saving energy, conserving natural resources, and reducing carbon emissions (Zhu, Sarkis, & Geng, 2005). Green supply chain management involves activities ranging from green product design to closed loop product return processing or recovery (Srivastava, 2007). However, the first step in controlling carbon footprints across a supply chain network is to analyze carbon emissions (Sundarakani, De Souza, Goh, Wagner, & Manikandan, 2010). Initial academic studies in this area have generated several useful insights (e.g. Cholette & Venkat, 2009; Lee, 2011; Sundarakani et al., 2010; Wu, Nagurney, Liu, & Stranlund, 2006). For instance, Cholette and Venkat (2009) provide estimates of carbon emissions associated with transportation links and warehousing activities in food and beverage supply chains, while Sundarakani et al. (2010) propose an initial analytical model that measures carbon emissions from both stationary and nonstationary supply chain processes. Yet with respect to modeling carbon emissions, the literature is still sparse, and much more investigation is needed (Lee, 2011).

At the same time, the rapid growth of broadband and the mobile Internet has greatly changed supply chain structures. Firms are now distributing their products through both offline retail stores and online e-tailers (Chiang, Chhajed, & Hess, 2003). For example, in 2014, China’s online shopping increased 48.7% over the previous year, which constitutes 10% of the total retail sales of consumer goods, and the e-commerce market is expected to continue this fast growth momentum (iResearch, 2015). In fact, e-commerce has been widely hailed as a revolution that is permanently transforming the landscape of consumer/supplier relationships. Not only is dual channel distribution becoming the new norm for managing closed loop supply chains, but the

Internet is providing consumers with a new way to interact with their supply chain (Ma, Zhao, & Ke, 2013). Today's consumers often go to a traditional brick-and-mortar store, enjoy the service provided by the retailer, find out about a product's function or even try it out but then make the final purchase of the same product from an e-tailer at a lower price, because online shoppers are not required to pay state and local sales tax (usually 5% to 10% of the selling price), which gives the e-tailers a pricing advantage. Worried retailers are getting more and more angry about consumers' free riding behavior and the unfair taxation and has been lobbying the government to tax on e-commerce for many years (Jopson, 2013).Yet although several prior studies have investigated how such consumer free riding may affect traditional retailers or e-tailers' decisions (e.g. Balakrishnan, Sundaresan, & Zhang, 2014b; Bernstein, Song, & Zheng, 2009; Perdikaki & Swaminathan, 2013), it is not yet clear how this phenomenon affects carbon emissions within the structure of a dual channel closed loop supply chain. This study therefore aims to fill this void in the literature by considering carbon emissions in a dual channel closed loop supply chain structure in which a manufacturer distributes products through both a traditional retailer channel and an e-tailer channel, and collects used products from consumers for remanufacturing.

One important aspect of a dual channel closed loop supply chain is the role played by government. For instance, whereas governmental subsidies help firms to optimize the operations of integrated logistics networks, the imposition of a general sales tax on e-commerce transactions may increase the price at which the e-tailer sells (Sheu, Chou, & Hu, 2005). In dual channel supply chain, the manufacturer and the retailer are beneficiaries of the governmental consumption subsidy towards CLSC(Ma et al., 2013). Looking from the perspective of product life cycle, the aggregate carbon emissions generated during a product's life consists of emissions in production, use by consumers, recovery process and end-of-life stage (Atasu et al. 2009; Atasu and Souza, 2013). As consumer free riding behavior will affect the total market demand quantity, that means the quantity of production, recycling, usage and landfill will be correspondingly affected. Not only that, with rapid growing of e-commerce, Internet retailers can often exploit nationwide markets with physical locations in only one or a few states and they have more locational flexibility than their traditional bricks and mortar counterparts. E-tailers can avoid establishing nexus in a state by ensuring that their degree of physical presence does not rise to the level determined to establish nexus by that state. This will cause tax evasion and annual e-commerce sales tax revenue losses grow rapidly (Bruce et al., 2015). Due to this unfair taxation situation, with some scholars and traditional retailers' lobbying, some governments are considering tax on e-commerce to prevent tax revenue losses, consumer free-riding and protect traditional retailers. Thus, a governmental tax on e-commerce will affect the decisions of consumers and supply chain members, which also affects the aggregate carbon emissions of a product's life cycle. This study thus seeks to answer the following research questions:

1. How does consumer free riding affect carbon emissions?
2. How does an e-commerce tax affect carbon emissions?

The analysis thus makes a valuable contribution to the literature assessing carbon emissions or the control of carbon footprints across a dual channel closed loop supply chain structure. In particular, our numerical modeling suggests that, compared with the no-free riding case, free riding may increase total carbon emissions and that a governmental tax on the e-tailer may help reduce them, thereby benefiting the environment.

The remainder of the paper is organized as follows. Section 2 reviews the related literature. Section 3 discusses the assumptions and notations. Section 4 describes the model formulation.

Section 5 provides the numerical examples for examining the propositions. Section 6 concludes the study and outlines directions for future research.

2. Literature review

This study is closely related to three streams of literature: closed loop supply chain considering carbon emissions, tax to e-commerce and consumer free riding in multichannel retailing context.

Closed loop supply chain considering carbon emissions

The closed loop supply chain allows firms to achieve both economic value and a reduced carbon footprint because it considers both the forward flow of material from suppliers to manufacturers to distributors to retailers to consumers and the reverse flow of used products back to the manufacturers for recovery closed loop(Souza, 2013). Such recovery recaptures the resources locked up in the product, which can be reclaimed with relatively low effort for collection, testing, disassembly, repair, recycling, and so forth (Krikke, 2011). It thus reduces the need for virgin resources by replacing part of the forward supply chain, thereby reducing carbon footprints. By using different research methods, some researchers study the CLSC operations under different carbon emission policy constraint (Fareeduddin et al.,2015;Garg et al., 2015;Mohajeri and Fallah,2015;Talaei et al., 2015;Tao et al.,2015). Specifically, Fareeduddin et al.(2015) find that carbon cap policy imposes a strict constraint on the amount of carbon emissions generated in CLSC supply chain operations. Garg et al.(2015) determine the optimal flow of parts and products in the CLSC network under low carbon logistics. By considering uncertainty on product demands and returns, Mohajeri and Fallah (2015) find that customer demand and the recovery rate were the main factors in an uncertain CLSC environment. Talaei et al.(2015) propose a mixed-integer linear programming model that capable of reducing the network total costs and the rate of carbon dioxide emission in the environment.Tao et al. (2015) find that carbon policies in CLSC network can restrict players' behaviors and when the total permitted carbon emissions are so low that the periodic carbon emission policies may be superior to the global carbon emission policies. In consideration of production,Low et al. (2015) demonstrate how the carbon footprint can be broken down based on the product structure and show that the implementation of the closed-loop production system can potentially result in an overall carbon footprint reduction of 39.91 million kg CO_2. While some other researchers study the CLSC and carbon emissions by using case study in practice. For example, taking copiers industry as example, Krikke (2011) find that compared with current and global-local CLSC network design, a regional CLSC network with combined forward and reverse facilities per continent proves most efficient and robust in view of uncertain exogenous variables. Based on companies and government in Australia, Fahimnia et al. (2013) evaluate the influences of CLSC on the carbon footprint and find that variations in environmental impacts occur over ranges of carbon pricing. Based on household plastic waste recycling, Bing et al. (2015) redesign the global reverse supply chain under the emission trading scheme and show that global relocation of re-processors leads to both a reduction of total costs and total transportation emission.Yet despite these initial efforts of modeling carbon emissions – an important phenomenon in today's Internet age – this literature neglects the issues of consumer free riding and e-commerce tax.

E-commerce tax

One of the characteristics electronic retailers differentiate from traditional retailers is that Internet retailers enjoy a clear and quite significant pricing advantage over traditional brick-and-mortar retailers: a consumer does not have to pay sales tax when purchasing from internet retailers who do not have a nexus (or physical presence) in her state. This will cause significant sales tax revenue losses to states and governments. Based on this, Hale and McNeal (2011) find that it may be the case that states begin to drop their political objections in order to participate in a cooperative, technological solution to streamline state sales tax systems in order to collect billions of dollars in revenue from taxes that are levied but unrealized. Bruce et al. (2015) find that firms are more likely to have nexus in large states, and that the effect of policy on nexus decisions appears to be relatively immediate and state efforts to either reduce sales tax rates or shrink sales tax bases to attract online retailers are not likely to be fruitful. With an expanding e-commerce volume, states enacted legislation to exercise its taxing power over remote vendors but such legislation was opposed and resisted by e-commerce vendors. Ward et al.(2012) point out that this controversy should be resolved within the next few years and if resolved, the tax playing field will be level for all retailers: those which are solely e-commerce businesses, those that are both brick-and-mortar and e-commerce businesses, and traditional Main Street businesses. Hu and Tang (2014) find that sales tax has a significant impact on consumers' purchase decisions, and such an impact varies across consumer segments, types of products, and channels. In China, the same problem also exists that the current tax system has not cover the Internet sales. Wei and Du (2009) uses the method of Principal-Agent mechanisms to propose that the Governments should take out countermeasures to prevent the loss of tax revenue.Jing (2015) suggests that government should consider tangible goods in accordance with the interim regulations on value-added Tax rules. If the individual consumers buy physical goods or goods via the Internet and take the traditional transport mode, and it is suitable to collect value-added Tax.

Consumer free riding in multichannel retailing context

Today, because of the growing use of information technology and multichannel retailing, consumer free riding phenomenon has become much more prominent (Balakrishnan, Sundaresan, & Zhang, 2014a). Consumers may, for instance, use a brick-and-mortar store to experience the product but purchase from an e-tailer and this offline-to-online free riding is referred to as "showrooming" (Balakrishnan et al., 2014a). It is also widely accepted that consumer free riding not only negatively affects retailers' profits but also those of the manufacturers who supply the retailers (!!! INVALID CITATION !!!). Thus, many studies focus on the strategies that manufacturers could use to avoid free riding; in particular, limiting distribution or imposing vertical restraints on the prices, locations, and sales of retail firms (!!! INVALID CITATION !!!). Xing and Liu (2012), for example, examine manufacturers and retailers' use of price matching and compensation rebate contracts to combat free riding. Several other studies, however (!!! INVALID CITATION !!!), suggest that free riding may improve supply chain profits by helping to create differentiation between competing retailers. Nevertheless, none of these studies considers free riding's implications for carbon emissions or explores how government taxes could influence the carbon emission associated with free riding. Hence, in this paper, when modeling carbon emissions across a closed loop supply chain, we incorporate consumer free riding and take into account government taxes aimed at restraining it.

3. Assumptions and Notations

Based on observations from current practice, we consider the model of a manufacturer with remanufacturing capability who sells its products (including re-manufactured products) through both a traditional retailer (hereafter retailer) and an online retailer (e-tailer). Government is also included. To encourage recycling, the government may provide subsidy for the manufacturer's recovery and to prevent tax evasion of e-commerce and consumer free riding behavior, the government may impose tax on the e-tailer (Fig.1).

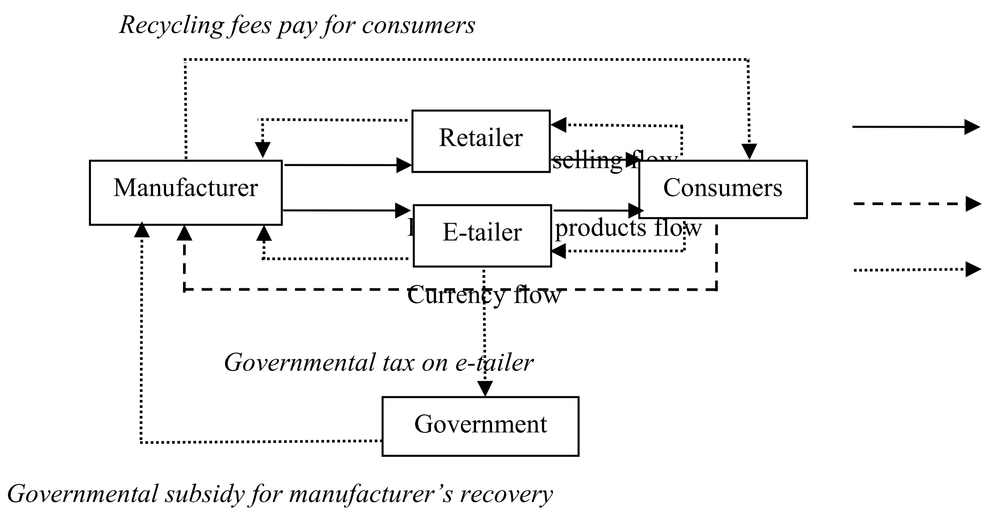

Fig.1 Dual channel closed loop supply chain

Table 1. Notations

Symbol	Definition
V	Consumers' initial valuation of the product
f	The degree of substitution between the retailer and the e-tailer
s	Service level of the retailer
λ	Scaling parameter of service investment
α	Consumer sensitivity to the retailer's service level
t	Consumers' misfit cost per unit distance
δ	Extent of valuation reduction through free riding
c	Unit production cost of the new product
c_0	Unit cost of remanufacturing a returned product into a new one
r_0	Per unit cost saving from recovery and reuse of components ($r_0 = c - c_0$)
n	The per unit benefit from recycling minus per unit recovery and processing cost
	$r = r_0$ if it is quality recovery and $r = n$ if it is material recovery
c_i	Unit selling costs of the sellers ($i = r, e$, $r =$ retailer, $e =$ e-tailer)
k	Scaling parameter of used product collection
τ	Recovery rate of used products
e_j	Unit carbon emissions of a product during life cycle ($j = p, u, r, eol$ where $p =$ production, $u =$ use, $r =$ recovery, $eol =$ end-of-life)
q_i	Market demand of retailer and e-tailer ($i = r, e$, $r =$ retailer, $e =$ e-tailer)
w	Wholesale price for the retailer and e-tailer
p_r	Retail price of the retailer
p_e	Retail price of the e-tailer
I	Total lifecycle carbon emissions of the dual channel closed loop supply chain
π_l	The profit function of firm l , $l = R, R_e, M$ where $R =$ retailer, $R_e =$ e-tailer, $M =$ manufacturer
CW	Consumer welfare
SW	Social welfare

As in most operational/economics/marketing literature from the seminal work of Hotelling (1929) to the dual channel model presented in Desai et al. (2010) and Xu et al. (2010), we conceptualize the end-product market as a straight line with exogenously specified locations for the retailer and e-tailer, who are f distance apart (see in Fig.2). The buyers of a commodity are assumed to be uniformly distributed along a virtual line, with those located to the left of the retailer loyal to the retailer and those located to the right of the e-tailer loyal to the e-tailer. Consumers located between the two are switchers.

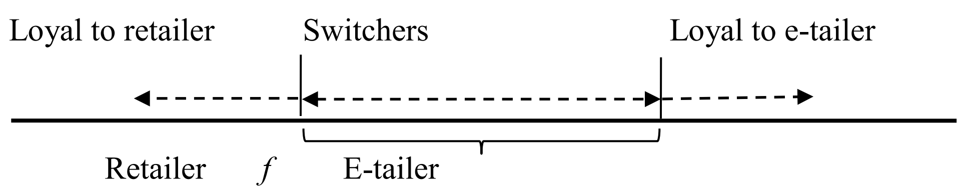

Fig. 2 End-product market characteristics

For the sake of simplicity, our assumptions about consumer preferences, channel members' costs, and the decision-making framework are as follows:

Assumption 1. The consumers' valuation of their ideal product is V, and the consumers are indifferent between the two kinds of retailers in product valuation. Their valuations for the retailer's service s are αs. When free riding occurs, consumers may first visit the retailer to enjoy the service and then go to the e-tailer to purchase the product. By doing so, however, they may be unable to take full advantage of the service the retailer provides. For example, when salesmen know that a consumer has come into the store simply to try out the commodity before purchasing more cheaply elsewhere, they will serve the consumer out of courtesy but will not make a one hundred percent effort. Thus, the benefit that these consumers can get from free riding is $\delta\alpha s$. Following the assumptions in Tsay and Agrawal (2000), Xia and Gilbert (2007), Desai et al. (2012), Wu (2012), among others, the cost of service is $\lambda s^2/2$, and for simplicity, we assume that $\lambda = 2$ [1]. The consumers' misfit costs (disutilities) along the straight line are t per unit, which represents the psychological costs of a store's layout and information delivery format being different from those at a given consumer's ideal store (cf. Pazgal and Soberman, 2008; Desai et al., 2010; Xu et al., 2010). The consumers' locations represent their preferences for a product, while a longer (shorter) distance between the location of consumer and store indicates that the consumer sees the store as less (more) than ideal. Like Pazgal and Soberman (2008), we simplify computation by normalizing t to 1.

We also assume, in line with Desai et al. (2010), that the firms' feature choices impose misfit costs on consumers who want a different combination of features. It is these consumer-borne misfit costs that enable a firm to segment a market and create a differentiated offering that better serves the requirements of the target segment (while being less valuable to other consumers). Consumers incur a loss of utility when they buy a commodity other than their ideal, a loss that depends on the misfit cost, which varies linearly with distance. Because the e-tailer provides no service, its coefficient is 0.

The retailer's sales effort is crucial for winning the market share. For instance, the retailer can stimulate demand by advertising the products' features and providing attractive shelf space and point-of-sale demonstrations by sales people. Because the sales effort also incurs significant

[1] In reality, the value of the coefficient would have no obvious influence on the firms' equilibrium results.

investment, it is vital that the retailer make the optimal sales effort decision and retail margin decision in the channel (Gao et al., 2016).

Assumption 2. All firms have access to the same information, and the decisions are considered in a single-period setting. Producing a new product from a used product is less costly than manufacturing a new one; that is, $c_0 < c$ and c_0 is the same for all re-manufactured products. The return rate of used products from the consumers is τ. As in Atasu and Souza (2013), we consider two type of recovery: the quality recovery of components that after some reprocessing can be reused in new production and the material recovery of components or materials that cannot be reused in new production but can be recycled to make a net profit (e.g., the often profitable recovery of precious metal from cell phones; see Geyer and Blass, 2010; Atasu and Souza, 2013). For quality recovery, the production cost of meeting demand q is $(c - r_0\tau)q$ where $r_0 = c - c_0$, while for material recovery, the production cost is cq. The collection investment effort is given by $k(\tau q)^2$, where k is assumed to be sufficiently large that $\tau < 1$, and more specifically, $k > 8r$ (cf. Savaskan et al., 2004; Gao et al., 2015). This latter assumption inherently means that collection is difficult and economically nonviable enough that the manufacturer does not try to recover all used products.

Assumption 3. The marginal operation cost of the retailer is c_r and that of the e-tailer is c_e. Because c_e is too small relative to c_r, for the sake of modeling simplicity, we normalize it to 0.

Assumption 4. As in Savaskan et al. (2004) and Savaskan and Wossenhove (2006), the sequence of the firm's decisions is as follows: the manufacturer decides on the return rate and announces the uniform wholesale price for both sellers. The sellers then simultaneously decide their retail prices and service level. In dealing with the retailer and e-tailer, the manufacturer always acts as a Stackelberg leader, so the research uses a Stackelberg game that can be either a complete information dynamic game and/or a simple leader-follower game. This game has a hierarchy consisting of an upper level decision maker who is the leader and lower level decision makers who are followers in a subordinate position. All players make their decisions successively, with those who decide later already knowing the decision of the player who decided first and this latter able to anticipate this consequence before the decision of the later decider. Hence, to solve the Stackelberg game, we use backward induction from the last game stage, analyze the decisions of the players at this stage and then at the previous stage, and finally stop at the first stage.

4. Model formulation

Before proceeding with the analysis, we need to first delineate the firms' demand functions. The point of market demand division between the two sellers lies in the marginal point at which a consumer is indifferent between buying from the retailer or the e-tailer. Consumers will choose the one that gives them greater utility. As in Desai et al. (2010) and Xu et al. (2010), in our model, a consumer's net utility from buying at any seller equals the consumer's valuation minus the costs related to this purchase (product price, psychological costs of buying process). For example, with the help of a retailer's service, a consumer's initial valuation V could be increased to $V+\alpha s$, so that a consumer located between the retailer and e-tailer would have a net utility of $V+\alpha s-p_r-x$ when buying from the retailer and a net utility of $V-p_e-(f-x)$ when buying from the e-tailer. Here, x [2] is the psychological distance between the consumer's location and the retailer's location. If consumers do not free ride on the retailer's service and only visit one seller, they constitute only two types: those that only purchase directly from the retailer and those that only purchase directly from the e-tailer. The distance x between the indifferent consumer's location from the retailer should then satisfy $V+\alpha s-p_r-x=V-p_e-(f-x)$; that is, $x=(\alpha s-p_r+p_e+f)/2$. If x represents the distance between the retailer and a consumer located on the retailer's left side or the distance between the e-tailer and a consumer located on the e-tailer's right side, then the consumer to the left will choose to purchase from the retailer if $V+\alpha s-p_r-x>0$ while the consumer located to the right will do so if $V-p_e-x>0$.

[2] When consumers choose their ideal product, there is a gap between the product a firm provides and the consumer' ideal product, which here is represented by x.

When consumer free riding occurs, however, as in Desai et al. (2010), consumers are of three types: those that only purchase directly from the retailer, those that only purchase directly from the e-tailer, and the free riding consumers who enjoy the retailer's service but make the final purchase from the e-tailer. In this case, our calculations of market demand should gear the amount of free riding consumers to the e-tailer's market demand. When the marginal consumer who is indifferent between purchasing directly from the retailer and consuming the retailers' service but makes the final purchase from the e-tailer is located x_1 distance from the retailer, x_1 satisfies $V+\alpha s-p_r-x_1=V+\alpha\delta s-p_e-f$ [3]; that is, $x_1=\alpha(1-\delta)s-p_r+p_e+f$. When the marginal consumer who is indifferent between consuming the retailer's service and directly purchasing from the e-tailer but who makes the final purchase from the e-tailer is located x_2 distance from the retailer, x_2 satisfies $V+\alpha\delta s-p_e-f=V-p_e-(f-x_2)$ and $x_2=\alpha\delta s$. Thus, the firms' demands can be expressed as

$$q_r=\begin{cases} V+\alpha s-p_r+(\alpha s-p_r+p_e+f)/2, & \text{if free riding is absent} \\ V+\alpha s-2p_r+\alpha(1-\delta)s+f+p_e, & \text{if free riding is present} \end{cases}$$

[3] We adopt the same assumption as in Desai et al. (2010) about a free riding consumer's traveling distance when visiting one store with a higher valuation level and making the final purchase at another store. Because the location and traveling costs along this distance represent only a psychological sensation disutility for the consumer (i.e., no physical travel is involved), the repeated computation of travel to the retailer and turn back to the e-tailer need not be considered. That is, the total traveling distance for free riding equals the distance between the consumer's location and one store plus the distance between the consumer's location and the other store.

$$q_e = \begin{cases} V - p_e + (f - \alpha s + p_r - p_e)/2\,, & \text{if free riding is absent} \\ V - 2p_e - \alpha(1-\delta)s + p_r\,, & \text{if free riding is present} \end{cases}$$

4.1. Firm decisions when free riding is absent or present

In deriving the manufacturers and retailers' decisions in different cases, we represent the problems of all the players as follows:

$$\max_{s,p_r} \pi_R = (p_r - w - c_r)q_r - s^2$$

$$\max_{p_e} \pi_{R_e} = (p_e - w)q_e$$

$$\max_{w,\tau} \pi_M = (w - c + r\tau)(q_r + q_e) - k(\tau(q_r + q_e))^2$$

where $r = r_0 + n$

Proposition 1. a) When free riding is absent, the equilibrium decisions of all players are

$$\tau = \frac{r(140-51\alpha^2)}{6k((28-6\alpha^2)(V-c)+(14-3\alpha^2)f-14c_r)}\,,\; w = \frac{(28-6\alpha^2)(V+c)+(14-3\alpha^2)f-14c_r}{4(14-3\alpha^2)}$$

$$p_r = \frac{(5488-2604\alpha^2+306\alpha^4)V+(2744-1302\alpha^2+153\alpha^4)f+(2352-1932\alpha^2+306\alpha^4)c+(2856-3006\alpha^2+612\alpha^4)c_r}{4(140-51\alpha^2)(14-3\alpha^2)}$$

$$s = \frac{3\alpha((196-42\alpha^2)(V-c)+(98-21\alpha^2)f-(378-102\alpha^2)c_r}{2(140-51\alpha^2)(14-3\alpha^2)}$$

$$p_e = \frac{(5488-3276\alpha^2+450\alpha^4)V+(2744-1638\alpha^2+225\alpha^4)f+(2352-1260\alpha^2+162\alpha^4)c-(504-234\alpha^2)c_r}{4(140-51\alpha^2)(14-3\alpha^2)}$$

b) When free riding occurs, the equilibrium decisions of all players are

$$\tau = \frac{r\left(30-\alpha^2(14-13\delta+3\delta^2)\right)}{2k((20-\alpha^2(6-7\delta+2\delta^2))(V-c)-(10+2\alpha^2\delta-\alpha^2\delta^2)c_r+(10-\alpha^2(2-3\delta+\delta^2))f)}$$

$$w = \frac{(20-\alpha^2(6-7\delta+2\delta^2))(V+c)-(10+2\alpha^2\delta-\alpha^2\delta^2)c_r+(10-\alpha^2(2-3\delta+\delta^2))f}{2(20-\alpha^2(6-7\delta+2\delta^2))}$$

$s = \dfrac{A_6(V-c)+A_7 f - A_8 c_r}{A_5}$, $p_r = \dfrac{A_1 V + A_2 c + A_3 f + A_4 c_r}{A_5}$, $p_e = \dfrac{A_9 V + A_{10} c + A_{11} f - A_{12} c_r}{A_5}$ where

$$A_1 = 800-\alpha^2(520-540\delta+140\delta^2)+\alpha^4(84-176\delta+137\delta^2-47\delta^3+6\delta^4)$$

$$A_2 = 400-\alpha^2(400-400\delta+100\delta^2)+\alpha^4(84-176\delta+137\delta^2-47\delta^3+6\delta^4)$$

$$A_3 = 520-\alpha^2(276-302\delta+82\delta^2)+\alpha^4(28-68\delta+59\delta^2-22\delta^3+3\delta^4)$$

$$A_4 = 440-\alpha^2(612-574\delta+134\delta^2)+\alpha^4(168-324\delta+234\delta^2-75\delta^3+9\delta^4)$$

$$A_5 = 2(20-\alpha^2(6-7\delta+2\delta^2))(30-\alpha^2(14-13\delta+3\delta^2))$$

$$A_6 = (200-100\delta-\alpha^2(60-100\delta+55\delta^2-10\delta^3))$$

$$A_7 = (220-110\delta-\alpha^2(76-120\delta+63\delta^2-11\delta^3))$$

$$A_8 = (460-230\delta-\alpha^2(168-260\delta+134\delta^2-23\delta^3))$$

$$A_9 = (800-\alpha^2(640-680\delta+180\delta^2)+\alpha^4(120-260\delta+210\delta^2-75\delta^3+10\delta^4))$$

$$A_{10} = (400-\alpha^2(280-260\delta+60\delta^2)+\alpha^4(48-92\delta+64\delta^2-19\delta^3+2\delta^4))$$

$$A_{11} = (280-\alpha^2(224-268\delta+78\delta^2)+\alpha^4(40-100\delta+90\delta^2-35\delta^3+5\delta^4))$$

$A_{12} = (40 - \alpha^2(32 - 124\delta + 54\delta^2) - \alpha^4(40\delta - 60\delta^2 + 30\delta^3 - 5\delta^4))$

For brevity, all proofs are provided in the appendix.

Corollary 1. In both cases, the return rate is higher (lower) with a lower (higher) f; the wholesale price, retail prices, and service level are higher (lower) with a higher (lower) f.

The profit from remanufacturing is the cost saving benefit $r_0\tau(q_r + q_e)$ minus the recovery cost $n\tau(q_r + q_e) + k(\tau(q_r + q_e))^2$. Solving the first- and second-order conditions of τ yields $\frac{\partial \pi_M}{\partial \tau} = r(q_r + q_e) - 2k\tau(q_r + q_e)^2$ and $\frac{\partial^2 \pi_M}{\partial \tau^2} = -2k(q_r + q_e)^2 < 0$. Then the optimal value of τ is $\tau^* = \frac{r}{2k(q_r + q_e)}$. Keeping all else unchanged, when f is larger, the total market share $(q_r + q_e)$ increases and the return rate decreases. This outcome is in line with the real-world dynamic that as market demand increases, recycling costs increase accordingly because it is much harder for manufacturers to manage returns efficiently.

When f represents the positioning difference of the retailer and e-tailer, the difference is lower (higher), competition/substitution intensifies, and sellers tend to set lower (higher) retail prices to attract switchers. Then, in anticipation of the sellers' competitive low prices, the manufacturer tends to set a lower wholesale price as competition/substitution intensifies. When f increases (decreases), some of the switchers' free riding utility decreases (increases) as their free riding misfit cost increases (decreases). In this condition, free riding is less attractive and the retailer increases the service level to attract more consumers.

Corollary 2. In both cases, the return rate increases with such supply chain cost factors as c, r, c_r. The wholesale price, e-tailer's price, and retailer's service level decrease with c_r.

Naturally, when production cost is high, the manufacturer transfers the cost pressure to sellers, a transfer that is reflected in pricing decisions and reduces market demand. This lower market demand combines with a higher return rate. On the other hand, when trying to relieve high cost pressure, the manufacturer also tends to take in more used products for remanufacturing because an increasing return rate lowers the average unit production cost, especially when the cost saving from remanufacturing increases. This observation, however, raises the question of why, all else being equal, an increase in the retailer's marginal operation cost increases the return rate. We propose the following answer: Because this cost increases the retailer's pricing level but decreases its service level, it decreases the market share that the manufacturer can earn from the retailer. Yet this cost increase also makes the retailer's price much less competitive than the e-tailer's price, which increases the market share that the manufacturer can earn from the e-tailer. At the same time, the total market share is lower because the e-tailer's price is less sensitive to the change in its competitor's cost increase. Thus, all else unchanged, a higher c_r reduces total market demand and increases the return rate.

Corollary 3. In this model, the cost saving from remanufacturing has no impact on prices and market demand.

As described in proposition 1, the cost saving r is only reflected in the return rate decision.

4.2. Environmental impact and governmental subsidy for remanufacturing

According to Atasu et al. (2009) and Atasu and Souza (2013), a product's lifecycle is composed of production, consumer use, recovery, and end-of-life in a landfill. The carbon emissions per unit of product during these processes can be denoted by e_p, e_u, e_r, e_{eol}, respectively (see Fig. 3).

Typically, only a fraction of the carbon emissions are actually emitted during production. For example, in the case of international toy maker Lego, only 10 percent of the total CO2 emission related to Lego products originate from production processes at the Lego factories. The remaining 90 percent stem from supply chain activities such as raw material extraction and refinement, indirect procurement, distribution from Lego factories to toy stores around the world, and end-of-life impact when the products are eventually scrapped (www.environmentalleader.com, 2013).

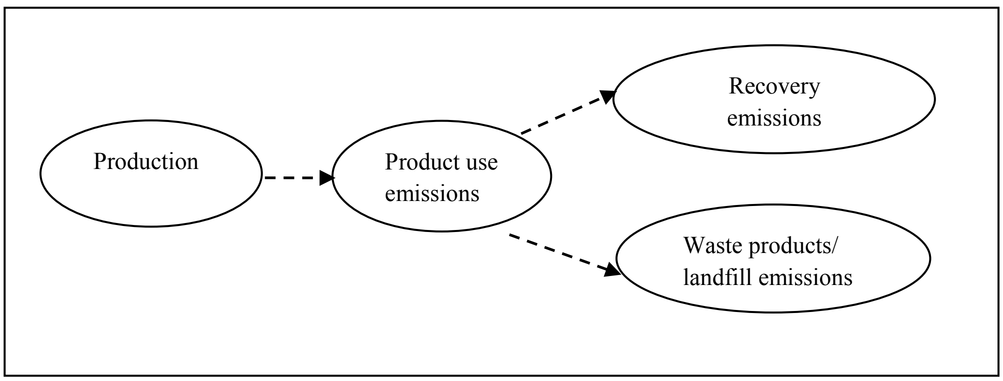

Figure 3. Life cycle carbon emissions of the dual channel supply chain

The total quantity of life cycle carbon emissions can thus be expressed as

$$I = (e_p(1-\tau) + e_r\tau + e_u + e_{eol}(1-\tau))(q_r + q_e)\,.$$ [4]

[4]Given the total market share quantity $q_r + q_e$, the recovery and remanufacturing quantity is $\tau(q_r + q_e)$ and the quantity of producing new products is $(1-\tau)(q_r + q_e)$. Thus the carbon emissions generated during recovery stage is $e_r\tau(q_r + q_e)$ and carbon emission generated during production of new products is $e_p(1-\tau)(q_r + q_e)$. The total carbon emissions generated during consumption stage is $e_u(q_r + q_e)$ and with the recovered products are not put in landfill, the carbon emissions generated during landfill stage is $e_{eol}(1-\tau)(q_r + q_e)$.

The equation can be simplified as $I = (E - e\tau)(q_r + q_e)$ where $e = e_p + e_{eol} - e_r$. According to this equation, $\tau < 1$ and $E > e$, meaning that $E - e\tau > 0$, so that, as lemma 1 shows, the total recovery amount $\tau(q_r + q_e)$ is unchanged by free riding. Hence, the total quantity of carbon emissions is always positively influenced by market demand, and how consumer free riding impacts the total environment depends strictly on whether this free riding increases or decreases market demand.

On the other hand, to promote remanufacturing activities, governments may pay subsidies to a manufacturer proportional to the remanufacturing volume (Mitra and Webster, 2008; Sheu and Chen, 2012). Assuming that the government provides subsidy h per remanufactured unit for the manufacturer, then the manufacturer's profit function is

$$\max_{w,\tau} \pi_M = (w - c + (r + h)\tau)(q_r + q_e) - k(\tau(q_r + q_e))^2$$

Hence, when free riding is absent, social welfare is

$$\max_{h} SW = \pi_M + \pi_R + \pi_{R_e} + CW - h\tau(q_r + q_e)$$

$$CW = \int_0^{V - p_e^*} (V - p_e^* - x)dx + \int_0^{\frac{f - \alpha s^* + p_r^* - p_e^*}{2}} (V - p_e^* - x)dx + \int_0^{V + \alpha s^* - p_r^*} (V + \alpha s^* - p_r^* - x)dx + \int_0^{\frac{f + \alpha s^* - p_r^* + p_e^*}{2}} (V + \alpha s^* - p_r^* - x)dx$$

and when free riding is present, social welfare is

$$\max_{h} SW = \pi_M + \pi_R + \pi_{R_e} + CW - h\tau(q_r + q_e)$$

$$CW = \int_0^{V - p_e^*} (V - p_e^* - x)dx + \int_0^{V + \alpha s^* - p_r^*} (V + \alpha s^* - p_r^* - x)dx + \int_0^{\alpha(1-\delta)s^* - p_r^* + p_e^* + f} (V + \alpha s^* - p_r^* - x)dx + \int_0^{f - \alpha\delta s^*} (V - p_e^* - x)dx +$$
$$\int_0^{\alpha s^*(2\delta - 1) + p_r^* - p_e^* - f} (V + \alpha\delta s^* - p_e^* - f)dx$$

Proposition 2. a) Whether free riding is present or absent, the government's optimal decision is always $h^* = e$. b) The subsidy reduces the total environmental impact. c) The subsidy increases the return rate but has no influence on prices, consumer welfare, or sellers' profits.

According to this proposition, consumer free riding behavior does not affect a government's subsidy decision. That is, if environmental impact depends on only two factors – market demand and return rate – then because the subsidy has no influence on prices and market demand remains unchanged, the return rate will be augmented and the environmental impact reduced. This proposition also reflects the fact that in this model, although free riding changes the firms' decisions and the quantity of market demand, it does not change the governmental subsidy. In fact, as regards the manufacturer's objective function, the subsidy plays a role in increasing the manufacturer's cost savings. As stated in lemmas 3 and 4, respectively, the change in cost savings r is not reflected in the manufacturer's wholesale price and the total recovery amount $\tau(q_r + q_e)$ does not change regardless of whether free riding is present or absent.

4.3. Governmental tax on the e-tailer

In the face of recent U.S. Senate legislation that ended tax-free shopping online (Jopson, 2013), we now consider whether governments should impose taxes on e-tailers and if so, what the impact might be not only on firms but also on consumers, the environment, and social welfare. Assuming that the government taxes the e-tailer g per unit of selling quantity to terminate consumer free riding behavior,[5] retailers can be expected to set their prices in anticipation that no consumer will free ride. Then the e-tailer's objective function is

$$\max_{p_e} \pi_{R_e} = (p_e - w - g)q_e$$

Proposition 3. The equilibrium of all firms is as follows.

$$\tau = \frac{(r+h)(140-51\alpha^2)}{6k((28-6\alpha^2)(V-c)-(14-6\alpha^2)g+(14-3\alpha^2)f-14c_r)}$$

$$w = \frac{(28-6\alpha^2)(V-c)-(14-6\alpha^2)g+(14-3\alpha^2)f-14c_r}{4(14-3\alpha^2)}$$

$$p_e = \frac{1}{4(140-51\alpha^2)(14-3\alpha^2)}((5488-3276\alpha^2+450\alpha^4)V+(2352-1260\alpha^2+162\alpha^4)c+(2744-1638\alpha^2+225\alpha^4)f$$
$$+(2856-1494\alpha^2+162\alpha^4)g-(504-234\alpha^2)c_r)$$

$$p_r = \frac{1}{4(140-51\alpha^2)(14-3\alpha^2)}((5488-2604\alpha^2+306\alpha^4)V+(2352-1932\alpha^2+306\alpha^4)c+(2744-1302\alpha^2+153\alpha^4)f$$
$$-(504-1074\alpha^2+306\alpha^4)g+(2856-3006\alpha^2+612\alpha^4)c_r)$$

$$s = \frac{3\alpha((196-42\alpha^2)(V-c)+(98-21\alpha^2)f-(378-102\alpha^2)c_r+(182-60\alpha^2)g)}{2(140-51\alpha^2)(14-3\alpha^2)}$$

According to this proposition, this tax has a positive impact on the return rate and e-tailer's price but a negative impact on the wholesale and retailer's price. In fact, the increase in g plays the same role as c_r on the recovery rate. At the same time, because this tax increases the e-tailer's price and decreases the retailer's price, it enhances the average retail price level and reduces total demand. Hence, under this condition, social welfare is

[5] Although in practice, consumer free riding behavior may not be completely terminated by government tax, in the model, we consider the ideal optimal condition. Specifically, we set the tax exactly large enough to compress the group of free riding consumers until it disappears so that only two groups of consumers exist in the market: those who only purchase from the retailer and those who only purchase from the e-tailer.

$$\max_{h,g} SW = \pi_M + \pi_R + \pi_{R_e} + CW - h\tau(q_r + q_e) + gq_e$$

where $CW = \int_0^{V-p_e^*}(V - p_e^* - x)dx + \int_0^{\frac{f-\alpha s^*+p_r^*-p_e^*}{2}}(V - p_e^* - x)dx + \int_0^{V+\alpha s^*-p_r^*}(V + \alpha s^* - p_r^* - x)dx + \int_0^{\frac{f+\alpha s^*-p_r^*+p_e^*}{2}}(V + \alpha s^* - p_r^* - x)dx$

Proposition 4. The optimal tax rate is $g^* = \dfrac{B_1V + B_2f + B_3c_r + B_4c}{6B_5}$ *where*

$B_1 = -(537824 - 727944\alpha^2 + 333144\alpha^4 - 62154\alpha^6 + 4050\alpha^8)$

$B_2 = -(268912 - 363972\alpha^2 + 166572\alpha^4 - 31077\alpha^6 + 2025\alpha^8)$

$B_3 = -(358288 - 197652\alpha^2 + 19602\alpha^4 + 2106\alpha^6)$

$B_4 = 537824 - 727944\alpha^2 + 333144\alpha^4 - 62154\alpha^6 + 4050\alpha^8$

$B_5 = 97608 - 110138\alpha^2 + 42555\alpha^4 - 6282\alpha^6 + 243\alpha^8$

From the above equations, it is impossible to determine whether g^* is positive or negative. When $g^* > 0$, it means the government should tax on the e-tailer. When $g^* < 0$, it means the government subsidize the e-tailer. Specifically, if the government provides subsidy to the e-tailer, although the consumer free-riding behavior may still stop, it may not benefit but hurt the traditional retailer. See from proposition 3, a negative g^*, which can be thought as a subsidy, will help enhance the status of the e-tailer's low pricing, increase the pricing of the retailer and reduce the service lelvel of the retailer, which will make the retailer's market share shrinks and the e-tailer's market share increases. This governmental subsidy enlarges consumers' utilities obtain from both sellers (consumers' utilities when purchasing from the e-tailer increase and when purchasing from the retailer decrease), the final result may be that the e-tailer's price is too low that consumers once free ride the traditional retailer's service will choose to directly purchasing from the e-tailer and some switchers once only choose to purchase from the retailer will turn to purchase from the e-tailer.

Corollary 4. This tax on e-tailer will reduce total carbon emissions and subsidy to e-tailer will increase total carbon emissions.

Hence, according to Propositions 1a and 4, if $g^* > 0$, the government will impose tax on the e-tailer and the tax will be treated as an additional cost increase to e-tailer which makes the e-tailer to enhance pricing level to transfer the cost to consumers. Hence the e-tailer's market share is reduced. Expecting this, the manufacturer will reduce wholesale pricing level to encourage retailer and e-tailer sales. Thus the retailer's service level is enhanced and its pricing level is decreased and its market share is increased. But compared with the e-tailer, its decisions change are less sensitive to the tax[6]. That is, being imposed only on the e-tailer, this tax has more impact on the decisions of e-tailer than the retailer. Hence, a tax on e-tailer will reduce total market demand.

Also if $g^* < 0$, a subsidy means a reduction of cost to e-tailer which will make the e-tailer lower its product's posted price to attract consumers. Expecting this potential trend of market expansion, the manufacturer will increase the wholesale price to reap profit. As the subsidy also has more impact on the decisions of e-tailer than the retailer, the total market demand will increase and the total carbon emissions also increase. It means if only from the perspective of protection to environment and traditional retailing, without considering social welfare, the government should impose tax on the e-tailer. But the role of a government is to consider the whole welfare of the

[6] As the equations in proposition 3 show, as α is not large because consumers will not fully sensitive to the retailer's service, p_r is less sensitive to g than p_e.

society and a government may sometimes choose to subsidize the e-tailer. The total change in carbon emissions can thus be expressed in the following function:

$$I_1 - I_2 = E(q_{r1} + q_{e1} - q_{r2} - q_{e2}) - e(\tau_1(q_{r1} + q_{e1}) - \tau_2(q_{r2} + q_{e2}))$$

1: The case when free riding is present   2: The case with a tax or subsidy on the e-tailer

As stated in corollary 1, $\tau_1(q_{r1} + q_{e1}) = \tau_2(q_{r2} + q_{e2}) = \frac{r}{2k}$, that is $I_1 - I_2 = E(q_{r1} + q_{e1} - q_{r2} - q_{e2}) > 0$ if $(q_{r1} + q_{e1}) - (q_{r2} + q_{e2}) > 0$. That is, the total amount of carbon emissions is positively impacted by the total market demand.

5. Numerical analysis and examples

Because some of the algebraic expressions are too complex to intuitively analyze and compare firms' decisions, profits, and the environmental impact engendered by consumer free riding, we assess the impact of free riding on the manufacturer using the numerical analysis adopted by most remanufacturing studies (e.g., Inderfurth 2005; Atasu et al. 2009; Toktay and Wei 2011; Wei and Zhao 2011; Xie et al. 2011; Atasu and Souza 2013; Atasu et al. 2013; Bae et al. 2010; Giovanni and Zaccour, 2014; Qiang 2015). We also adopt the parameters $f \in \{\frac{V}{30}, \frac{V}{25}, \frac{V}{20}\}$, $c \in \{\frac{V}{4}, \frac{V}{2}\}$, $c_r \in \{\frac{c}{20}, \frac{c}{15}, \frac{c}{10}\}$, $\alpha \in \{0.8, 0.9, 1\}$, $\delta \in \{0.8, 0.9, 1\}$. At the same time, because the parameters related to remanufacturing have no impact on firm prices or market demand, we set the basic parameters as $r_0 = \{\frac{c}{8}, \frac{c}{6}, \frac{c}{4}\}$, $n = \{\frac{c}{8}, \frac{c}{6}, \frac{c}{4}\}$, $k = 0.5$. In this comparison, however, we assign no value of V , e_o , e_t , E , or e because different products have different consumer valuations and may generate different carbon emissions during every stage of the life cycle.

Remark 1. The manufacturer's profit may be higher when free riding is present than when it is absent.

See in Table 2, consumer free riding behavior will increase manufacturer's profit. As some consumers always loyal to the retailer and e-tailer, the change of retailer and e-tailer's selling prices caused by consumer free riding may impact the change of the quantities of loyal consumers. Hence, this remark means that the increase in the e-tailer's market share induced by consumer free riding may exceed the decrease in the retailer's market share. Additionally, unlike the findings of Xing and Liu (2012), consumer free riding behavior may increase the manufacturer's profit.

Remark 2. Compared with the absence of consumer free riding, its presence may increase carbon emissions over the total life cycle, which may also increase when the government wants to tax on but actually subsidize the e-tailer.

Seeing from table 3, consumer free riding behavior increases total carbon emissions compared with no free riding case and the results mean that if only for the environment, it is better for the government to consider no matter tax or subsidize the e-tailer to stop consumer free riding behavior. The result may be because the quantity of consumers located between retailer and e-tailer unchanged, free riding behavior increases the total market demand and hence total carbon emission if the sum quantity of retailer and e-tailer's loyal consumers increases. Expecting consumers' free riding behavior, the retailer will lower its service and pricing level close to that of the e-tailer to avoid free riding as far as possible. But to consumers, pricing has more impact on purchasing than service. Hence, with the presence of consumer free riding, the quantity of retailer's loyal consumers increases. As the e-tailer could benefit from consumers' free riding and knows that its advantage to keep consumer free riding is its low pricing, the e-tailer will lower its price to fetch more free riding consumers. Thus the quantity of e-tailer's loyal consumers will also increase.

Seeing from Table 4 and 5, although the initial intention for the government is to tax on the e-tailer, as this policy is fair for traditional retailers and could solve the problem of tax evasion of e-commerce, the final choice for the government is subsidize the e-tailer ($g^* < 0$).

Remark 3. If a government subsidizes the e-tailer, the result may benefit both consumer and social welfare.

This benefit to both consumer and society may occur because the government tax on the e-tailer, although aimed at preventing consumer free riding, if it actually becomes a subsidy, may increase consumers' utilities , as given consumer valuation unchanged, the price of e-tailer is much lower. The profit of e-tailer will also be enhanced. In the whole society, in calculating social welfare, the governmental revenue (tax) or expenditure (subsidy) will not affect the total calculation. However, a higher demand is directly related to higher production, consumption, and recovery quantities and so might increase total carbon emissions.

Hence, the above results (remarks 2 and 3) mean that a government policy can have different impacts on different aspects. That is, although the original intention of the governmental tax on the e-tailer was to lessen the negative effects of consumer free riding behavior on offline retailers, in consideration of social welfare maximization, a tax policy would become a subsidy policy and the result may improve consumer and social welfare but hurt the environment. Thus, government actions should reflect government purpose. If without considering aggregate social welfare, to protect environment and traditional retailers, the government should impose tax on the e-tailer but if considering consumer and social welfare, the government should provide subsidy to the e-tailer.

6. Conclusions

In an effort to promote sustainable production and consumption, scholars have recently started to study models and designs of green or closed loop supply chains. However, the impact on carbon emissions of consumer free riding between traditional retailing and e-tailing channels has yet to be examined. To fill this research void, this study models and analyzes carbon emissions when a manufacturer sells through both a retailer and an e-tailer, allowing consumers to enjoy the services provided by the retailer but make their final purchase from the e-tailer.

Our results indicate that consumer free riding may increase carbon emissions in a dual channel closed loop-supply chain even while increasing manufacturer profits. They also show that imposing an e-commerce tax can improve environmental performance in the supply chain as a whole. But the government may choose to subsidize on e-commerce instead of tax. The practical implications of the study are thus twofold: first, manufacturers should be cautious about developing a dual channel distribution because of consumer free riding's negative impact on the environment; and second, governmental taxes on e-tailing transactions have the potential to improve sustainability in dual channel closed loop supply chains.

Admittedly, the study is subject to certain limitations, so the results should be interpreted cautiously. Nevertheless, the findings raise several interesting directions for further study. For example, future research might consider a scenario in which the retailer, e-tailer, or a third-party collects used products. It might also drop our assumption that all players make decisions under a condition of complete information to reflect the reality that in practice, information can be incomplete. Hence, no matter its shortcomings, the model developed here provides a useful starting point for additional investigation and validation.

References

Atasu, A., Souza,G.C.2013. How does product recovery affect quality choice? Production and Operations Management 22(4), 991-1010.

Atasu, A., Toktay, L.B., Van Wassenhove, L.N.2013.How collection cost structure drives a manufacturer's reverse channel choice. Production and Operations Management 22(5), 1089-1102.

Atasu, A., Van Wassenhove, L.N., and Sarvary, M. 2009. Efficient take-back legislation. Production and Operations Management 18(3), 243-258.

Bae, S.H., Yoo, C.S., and Sarkis, J. 2010. Outsourcing with quality competition: insights from a three-stage game-theoretic model. International Journal of Production Economics 48(2), 327-342.

Balakrishnan, A., Sundaresan, S., and Zhang, B. 2014. Browse-and-switch: Retail-online competition under value uncertainty. Production and Operations Management 23(7), 1129-1145.

Bernstein, F., Song, J.S., and Zheng, X. 2009. Free riding in a multi-channel supply chain. Naval Research Logistics 56(8), 745-765.

Browne, M., Rizet, C., Leonardi, J., and Allen, J. 2008. Analyzing energy use in supply chains: the case of fruits and vegetables and furniture. Proceedings of the Logistics Research Network Conference, Liverpool, September.

Carlton, D.W., Chevalier, J.A. 2001. Free riding and sales strategies for the Internet. Journal of Industrial Economics,49(4),441-461.

Chaabane, A., Ramudhin, A., and Paquet, M., 2012. Design of sustainable supply chains under the emission trading scheme. International Journal of Production Economics 135(1), 37-49.

Chiang, W.-y. K., Chhajed, D., and Hess, J. D., 2003. Direct marketing, indirect profits: A strategic analysis of dual channel supply-chain design. Management science 49(1), 1-20.

Cholette, S., and Venkat, K., 2009. The energy and carbon intensity of wine distribution: A study of logistical options for delivering wine to consumers. Journal of Cleaner Production, 17(16), 1401-1413.

De Benedetto, L., and Klemeš, J., 2009. The Environmental Performance Strategy Map: an integrated LCA approach to support the strategic decision-making process. Journal of Cleaner Production 17(10), 900-906.

de Haes, H. A. U., and Heijungs, R., 2007. Lifecycle assessment for energy analysis and management. Applied Energy84(7), 817-827.

Desai, P.S., Krishnamoorthy, A., and Sainam, P. 2010."Call for prices": Strategic implications of raising consumers' costs. Marketing Science 29(1), 158-174.

Elhedhli, S., and Merrick, R., 2012. Green supply chain network design to reduce carbon emissions. Transportation Research Part D: Transport and Environment 17(5), 370-379.

Edwards, J.B., McKinnon, A.C., and Cullinane, S.L. 2009. Comparative analysis of the carbon footprints of conventional and online retailing: A "last mile" perspective. International Journal of Physical Distribution and Logistics Management 40(1), 103-123.

Gao, J., Han, H., Hou, L., and Wang, H. 2016. Pricing and effort decisions in a closed loop supply chain under different channel power structures. Journal of Cleaner Production 112(20), 2043-2057.

Geyer, R., and Blass, D. 2010. The economics of cell phone reuse and recycling. International Journal of Advanced Manufacturing Technology 47(5), 515-525.

Giovanni, P.D., and Zaccour, G. 2014. A two-period game of a closed loop supply chain. European Journal of Operational Research 232, 22-40.

Govindan, K., Soleimani, H., and Kannan, D.2015. Reverse logistics and closed loop supply chain: A comprehensive review to explore the future. European Journal of Operational Research 240(3), 603-626.

Hotelling, H. 1929. Stability in competition. Economic Journal 39(153), 41-57.

Hugo, A., and Pistikopoulos, E., 2005. Environmentally conscious long-range planning and design of supply chain networks. Journal of Cleaner Production 13(15), 1471-1491.

Inderfurth, K. 2005. Impact of uncertainties on recovery behavior in a remanufacturing environment: A numerical analysis. International Journal of Physical Distribution and Logistics Managemen35(5), 318-336.

iResearch. (2015). China e-commerce market rises 21.3% in 2014. http://www.iresearchchina.com/views/6250.html

Jacobs, B.W., and Subramanian, R., 2012. Sharing responsibility for product recovery across the supply chain. Production and Operations Management 21 (1), 85-100.

Jopson, B.2013. Shoe stores sock it to online buyers. http://www.ft.com/cms/s/0/42893492-b385-11e2-b5a5-00144feabdc0.html.

Krikke, H., 2011. Impact of closed loop network configurations on carbon footprints: A case study in copiers. Resources, Conservation and Recycling 55(12), 1196-1205.

Kuksov, D., and Lin, Y. (2010). Information provision in a vertically differentiated competitive marketplace. Marketing Science 29(1), 122-138.

Lee, K.-H., 2011. Integrating carbon footprint into supply chain management: the case of Hyundai Motor Company (HMC) in the automobile industry. Journal of Cleaner Production 19(11), 1216-1223.

Ma, W.M., Zhao, Z., and Ke, H., 2013. Dual channel closed loop supply chain with government consumption-subsidy. European Journal of Operational Research 226 (2), 221-227.

Matthews, H.S., Hendrickson, C.T., and Soh, D.L. 2001. Environmental and economic effects of e-commerce: A case study of book publishing and retail logistics. Transportation Research Record 1763, 6-12.

Mitra, S., and Webster, S. 2008. Competition in remanufacturing and the effects of government subsidies. Son, International Journal of Production Economics 111, 287-298.

Pazgal, A., and Soberman, D. 2008. Behavior-based discrimination: Is it a winning play, and if so, when? Marketing Science 27(6), 977-994.

Perdikaki, O., and Swaminathan, J. 2013. Improving valuation under consumer search: Implications for pricing and profits. Production and Operations Management 22(4), 857-874.

Qiang, Q. 2015. The closed loop supply chain network with competition and design for remanufactureability. Journal of Cleaner Production 105(15), 348-356.

Ramudhin, A., Chaabane, A., and Paquet, M., 2010. Carbon market sensitive sustainable supply chain network design. International Journal of Management Science and Engineering Management 5(1), 30-38.

Savaskan, R.C., Bhattacharya, S., and Van Wassenhove, L.N. 2004. Closed loop supply chain models with product remanufacturing. Management Science 50(2), 239-252.

Savaskan, R. C., and Van Wassenhove, L. N. 2006. Reverse channel design: The case of competing retailers. Management Science 52 (1), 1-14.

Sheu, J.-B., Chou, Y.-H., and Hu, C.-C., 2005. An integrated logistics operational model for green-supply chain management. Transportation Research Part E: Logistics and Transportation Review 41(4), 287-313.

Sheu J.B., and Chen Y.J. 2012. Impact of government financial intervention on competition among green supply chains. International Journal of Production Economics 138(1), 201-213.

Shin, J. 2007. How does free riding on customer service affect competition? Marketing Science 26(4), 488-503.

Souza, G. C., 2013. Closed loop supply chains: A critical review, and future research. Decision Sciences 44(1), 7-38.

Srivastava, S. K., 2007. Green supply-chain management: A state-of-the-art literature review. International Journal of Management Review, 9(1), 53-80.

Sundarakani, B., De Souza, R., Goh, M., Wagner, S. M., and Manikandan, S., 2010. Modeling carbon footprints across the supply chain. International Journal of Production Economics 128(1), 43-50.

Toktay, L.B., and Wei, D. 2011. Cost allocation in manufacturing-remanufacturing operations. Production and Operations Management 20(6), 841-847.

Tsay, A.A., and Agrawal, N., 2000. Channel dynamics under price and service competition. Manufacturing and Service Operations Management 2(4), 372-391.

Wei, J., and Zhao, J.2011. Pricing decisions with retail competition in a fuzzy closed loop supply chain. Expert Systems with Applications 38, 11209-11216.

Wu, C.H., 2012. Price and service competition between new and remanufactured products in a two-echelon supply chain. International Journal of Production Economics 140(1), 496-507.

Wu, K., Nagurney, A., Liu, Z., and Stranlund, J. K., 2006. Modeling generator power plant portfolios and pollution taxes in electric power supply chain networks: A transportation network equilibrium transformation. Transportation Research Part D: Transport and Environmen, 11(3), 171-190.

Wu, D., Ray, G., Geng, X., and Whinston, A. 2004. Implications of reduced search cost and free riding in E-commerce. Marketing Science 23(2), 255-262.

www.environmentalleader.com.2013. Lego pledges supply chain CO2 cuts, joins climate savers http://www.environmentalleader.com/2013/11/27/lego-pledges-supply-chain-co2-cuts-joins-climate-savers/.

www.sciencedaily.com. 2010. Working from home and online shopping can increase carbon emissions, UK report claims. http://www.sciencedaily.com/releases/2010/09/100921085524.htm.

Xia, Y., and Gilbert, S.M., 2007. Strategic interactions between channel structure and demand enhancing services. European Journal of Operational Research 181(1), 252-265.

Xie, G., Wang, S., and Lai, K.K.2011. Quality improvement in competing supply chains. International Journal of Production Economics 134(1), 262-270.

Xing, D., and Liu, T. 2012. Sales effort free riding and coordination with price match and channel rebate. European Journal of Operational Research 219, 264-271.

Xu, Y., Gurnani, H., and Desiraju, R. 2010. Strategic supply chain structure design for a proprietary component manufacturer. Production and Operations Management 19(4), 371-389.

Zhu, Q., Sarkis, J., and Geng, Y., 2005. Green supply chain management in China: Pressures, practices and performance. International Journal of Operations and Production Management 25(5), 449-468.

Tao, Z.G., Guang, Z.Y., Hao, S., Song, H.J., Xin, D.G.2015. Multi-period closed-loop supply chain network equilibrium with carbon emission constraints.Resources, Conservation and Recycling, 104(B),354-365.

Talaei, M., Moghaddam, B.F., Pishvaee, M.S., Amiri, A.B.,Gholamnejad, S.2015.A robust fuzzy optimization model for carbon-efficient closed-loop supply chain network design problem: a numerical illustration in electronics industry.Journal of Cleaner Production, in Press.

Fareeduddin, M.,Hassan, A., Syed, M.N., Selim,S.Z.2015.The Impact of Carbon Policies on Closed-loop Supply Chain Network Design.Procedia CIRP,26,335-340.

Garg, K., Kannan,D.,Diabat, A.,Jha,P.C.2015.A multi-criteria optimization approach to manage environmental issues in closed loop supply chain network design.Journal of Cleaner Production,100(1),297-314.

Mohajeri,A., Fallah,M.2015.A carbon footprint-based closed-loop supply chain model under uncertainty with risk analysis: A case study. Transportation Research Part D: Transport and Environment,in Press.

Fahimnia, B.,Sarkis, J., Dehghanian, F., Banihashemi,N., Rahman, S. 2013.The impact of carbon pricing on a closed-loop supply chain: an Australian case study.Journal of Cleaner Production,59(15),210-225.

Low,J.S.C., Tjandra, T.B., Lu, W.F., Lee, H.M.2015.Adaptation of the Product Structure-based Integrated Life cycle Analysis (PSILA) technique for carbon footprint modelling and analysis of closed-loop production systems.Journal of Cleaner Production, in Press.

Bing, X., Ruwaard, J.B.,Chaabane, A., van der Vorst, J. 2015.Global reverse supply chain redesign for household plastic waste under the emission trading scheme.Journal of Cleaner Production,103(15),28-39.

Krikke, H.2011.Impact of closed-loop network configurations on carbon footprints: A case study in copiers. Resources, Conservation and Recycling,55(12),1196-1205.

Bruce, D., Fox, W.F., luna, L.A.2015. E-tailer sales tax nexus and state tax policies. National Tax Journal,68(3s),735-766.

Hale, K., McNeal, R.2011.Technology, politics, and e-commerce: Internet sales tax and interstate cooperation.Government Information Quarterly,28(2),262-270.

Jing,C.2015.Taxation of e-commerce in China: applying US experience.International Conference on Social Science and Technology Education.

Ward,B.T., Sipior, J.C., MacGabhann, L.2012.The E-Commerce Sales and Use Tax Controversy: Is the End Near? Information Systems Management,29(4),331-337.

Wei, L., Du, C. 2009. Research on China's E-Commerce Taxation Based on the Principal-Agent Mechanism. International Conference on E-business & Information System Security.

Hu, Y.J., Tang, Z. 2014.The impact of sales tax on internet and catalog sales: Evidence from a natural experiment. International Journal of Industrial Organization,32(C),84-90.

Appendix A.

Proof of proposition 1.

In the second decision stage, the sellers find their optimal prices and service level given a previous first stage choice of return rate τ and wholesale price w. The first-order conditions of sellers when free riding is absent are given by

$$\frac{\partial \pi_R}{\partial p_r} = V + \frac{3}{2}(\alpha s + w + c_r) + \frac{1}{2}(p_e + f) - 3p_r \,,\ \frac{\partial \pi_R}{\partial s} = \frac{3}{2}\alpha(p_r - w - c_r) - 2s \,,\ \frac{\partial \pi_R}{\partial p_e} = V + \frac{3}{2}w + \frac{1}{2}(p_r + f - \alpha s) - 3p_e$$

The determinant of the Hessian Matrix for the retailer is $\begin{vmatrix} \frac{\partial^2 \pi_R}{\partial p_r^2} & \frac{\partial^2 \pi_R}{\partial p_r \partial s} \\ \frac{\partial^2 \pi_R}{\partial s \partial p_r} & \frac{\partial^2 \pi_R}{\partial s^2} \end{vmatrix}$, which equals $\begin{vmatrix} -3 & \frac{3}{2}\alpha \\ \frac{3}{2}\alpha & -2 \end{vmatrix}$>0. The first-order conditions then result in $p_r^*(w) = \frac{56V + (84 - 51\alpha^2)w + (72 - 51\alpha^2)c_r + 28f}{140 - 51\alpha^2}$, $s^*(w) = \frac{3\alpha(14(V - w) - 17c_r + 7f)}{140 - 51\alpha^2}$,

$$p_e^*(w) = \frac{(56 - 24\alpha^2)V + (84 - 27\alpha^2)w + 12c_r + (28 - 12\alpha^2)f}{140 - 51\alpha^2}.$$

By substituting the sellers' optimal reactions into the manufacturer's objective function, the first-order condition of w yields

$$\frac{\partial \pi_M}{\partial w} = \frac{6}{(140 - 51\alpha^2)^2}((3920 - 2268\alpha^2 + 306\alpha^4 + k\tau^2(9408 - 4032\alpha^2 + 432\alpha^4))V + (3920 - 2268\alpha^2 + 306\alpha^4)c - (1960 - 714\alpha^2 +$$
$$k\tau^2(4704 - 1008\alpha^2))c_r + (1960 - 1134\alpha^2 + 153\alpha^4 + k\tau^2(4704 - 2016\alpha^2 + 216\alpha^4))f - (7840 - 4536\alpha^2 + 612\alpha^4 + k\tau^2(9408 - 4032\alpha^2 + 432\alpha^4))w$$

Because $\frac{\partial^2 \pi_M}{\partial w^2} < 0$, the optimal wholesale price is

$$w^*(\tau) = \frac{1}{4(1960 - 1134\alpha^2 + 153\alpha^4 + k\tau^2(2352 - 1008\alpha^2 + 108\alpha^4))}((3920 - 2268\alpha^2 + 306\alpha^4 + k\tau^2(9408 - 4032\alpha^2 + 432\alpha^4))V$$
$$+ (3920 - 2268\alpha^2 + 306\alpha^4)c - (1960 - 714\alpha^2 + k\tau^2(4704 - 1008\alpha^2))c_r + (1960 - 1134\alpha^2 + 153\alpha^4 + k\tau^2(4704 - 2016\alpha^2 + 216\alpha^4))f)$$

By substituting the wholesale price into the manufacturer's function, the first-order condition of τ yields

$$\frac{\partial \pi_M}{\partial \tau} = -\frac{3}{(140-51\alpha^2+k\tau^2(168-36\alpha^2))^2}(l_1t^2+l_2t+l_3)$$, where

$$l_1 = 2016rc\alpha^2k + 504k\alpha^2c_r r - 1008k\alpha^2 fr + 108k\alpha^4 fr - 2016kV\alpha^2 r - 216rc\alpha^4k + 216kV\alpha^4 r - 4704rck - 2352rkc_r + 4704kVr + 2352kfr$$

$$\begin{aligned} l_2 = {} & -432kV\alpha^4c - 2016kV\alpha^2 f + 4032kV\alpha^2c + 1008kV\alpha^2cr + 216kV\alpha^4 f - 2016kc^2\alpha^2 + 216kc^2\alpha^4 - 4704kfc - 2352kfc_r + 4704kc_rc + \\ & 54k\alpha^4 f^2 - 504k\alpha^2 f^2 - 3920r^2 + 4704kV^2 - 216k\alpha^4 fc + 2016k\alpha^2 fc + 504k\alpha^2 fc_r - 1008k\alpha^2c_rc - 4704kVc_r - 9408kVc + 4704kVf + \\ & 216kV^2\alpha^4 - 2016kV^2\alpha^2 + 4704kc^2 + 1176kc_r^2 - 306r^2\alpha^4 + 1176kf^2 + 2268r^2\alpha^2 \end{aligned}$$

$$l_3 = 1134r\alpha^2 f + 2268rV\alpha^2 - 306rV\alpha^4 - 2268rc\alpha^2 + 1960rc_r - 1960rf + 3920rc - 3920rV + 306rc\alpha^4 - 153r\alpha^4 f - 714r\alpha^2c_r$$

Solving $\frac{\partial \pi_M}{\partial \tau} = 0$ yields $\tau_1 = -\frac{2(V-c)-f}{r} < 0$, $\tau_2 = \frac{r(140-51\alpha^2)}{6k((28-6\alpha^2)(V-c)+(14-3\alpha^2)f-14c_r)}$

Here, only τ_2 is a feasible solution, whose substitution into the second-order expression yields $\frac{\partial^2 \pi_M}{\partial \tau^2} < 0$. Thus, τ_2 is the unique equilibrium solution to the game. Even if the first-order conditions of w and τ are solved and the Hessian Matrix derived simultaneously, the equilibrium solutions do not change.

The solutions when free riding is present are similarly derived.

Proof of proposition 2.

Given the manufacturer's profit function, similarly solving the first- and second-order conditions yields the following manufacturer decisions:

When free riding is absent, the return rate and wholesale price are

$$\tau = \frac{(r+h)(140-51\alpha^2)}{6k((28-6\alpha^2)(V-c)+(14-3\alpha^2)f-14c_r)}, \quad w = \frac{(28-6\alpha^2)(V+c)+(14-3\alpha^2)f-14c_r}{4(14-3\alpha^2)}$$

When free riding is present, the return rate and wholesale price are

$$\tau = \frac{(r+h)\left(30-\alpha^2(14-13\delta+3\delta^2)\right)}{2k((20-\alpha^2(6-7\delta+2\delta^2))(V-c)-(10+2\alpha^2\delta-\alpha^2\delta^2)c_r+(10-\alpha^2(2-3\delta+\delta^2))f)}$$

$$w = \frac{(20-\alpha^2(6-7\delta+2\delta^2))(V+c)-(10+2\alpha^2\delta-\alpha^2\delta^2)c_r+(10-\alpha^2(2-3\delta+\delta^2))f}{2(20-\alpha^2(6-7\delta+2\delta^2))}$$

Equilibrium can then be derived by substituting all the reactions into the government's social welfare function and solving the first- and second-order conditions of h.

Appendix B.

Table 2. Manufacturer's profit difference between consumer's is present and absent

$\alpha = 0.8$, $\delta = 0.8$, $k = 0.5$

f	c	c_r	r	$\Delta\pi_M$
$\frac{V}{30}$	$\frac{V}{4}$	$\frac{c}{20}$	$\frac{c}{8}$	$0.0120V^2$
$\frac{V}{30}$	$\frac{V}{4}$	$\frac{c}{20}$	$\frac{c}{6}$	$0.0120V^2$
$\frac{V}{30}$	$\frac{V}{4}$	$\frac{c}{20}$	$\frac{c}{4}$	$0.0120V^2$
$\frac{V}{30}$	$\frac{V}{4}$	$\frac{c}{15}$	$\frac{c}{8}$	$0.0119V^2$
$\frac{V}{30}$	$\frac{V}{4}$	$\frac{c}{15}$	$\frac{c}{6}$	$0.0119V^2$

$\frac{V}{30}$	$\frac{V}{4}$	$\frac{c}{15}$	$\frac{c}{4}$	$0.0119V^2$
$\frac{V}{30}$	$\frac{V}{4}$	$\frac{c}{10}$	$\frac{c}{8}$	$0.0119V^2$
$\frac{V}{30}$	$\frac{V}{4}$	$\frac{c}{10}$	$\frac{c}{6}$	$0.0119V^2$
$\frac{V}{30}$	$\frac{V}{4}$	$\frac{c}{10}$	$\frac{c}{4}$	$0.0119V^2$
$\frac{V}{30}$	$\frac{V}{2}$	$\frac{c}{20}$	$\frac{c}{8}$	$0.0054V^2$
$\frac{V}{30}$	$\frac{V}{2}$	$\frac{c}{20}$	$\frac{c}{6}$	$0.0054V^2$
$\frac{V}{30}$	$\frac{V}{2}$	$\frac{c}{20}$	$\frac{c}{4}$	$0.0054V^2$
$\frac{V}{30}$	$\frac{V}{2}$	$\frac{c}{15}$	$\frac{c}{8}$	$0.0053V^2$
$\frac{V}{30}$	$\frac{V}{2}$	$\frac{c}{15}$	$\frac{c}{6}$	$0.0053V^2$
$\frac{V}{30}$	$\frac{V}{2}$	$\frac{c}{15}$	$\frac{c}{4}$	$0.0053V^2$
$\frac{V}{30}$	$\frac{V}{2}$	$\frac{c}{10}$	$\frac{c}{8}$	$0.0053V^2$
$\frac{V}{30}$	$\frac{V}{2}$	$\frac{c}{10}$	$\frac{c}{6}$	$0.0053V^2$
$\frac{V}{30}$	$\frac{V}{2}$	$\frac{c}{10}$	$\frac{c}{4}$	$0.0053V^2$

$\frac{V}{25}$	$\frac{V}{4}$	$\frac{c}{20}$	$\frac{c}{8}$	$0.0122V^2$
$\frac{V}{25}$	$\frac{V}{4}$	$\frac{c}{20}$	$\frac{c}{6}$	$0.0122V^2$
$\frac{V}{25}$	$\frac{V}{4}$	$\frac{c}{20}$	$\frac{c}{4}$	$0.0122V^2$
$\frac{V}{25}$	$\frac{V}{4}$	$\frac{c}{15}$	$\frac{c}{8}$	$0.0121V^2$
$\frac{V}{25}$	$\frac{V}{4}$	$\frac{c}{15}$	$\frac{c}{6}$	$0.0121V^2$
$\frac{V}{25}$	$\frac{V}{4}$	$\frac{c}{15}$	$\frac{c}{4}$	$0.0121V^2$
$\frac{V}{25}$	$\frac{V}{4}$	$\frac{c}{10}$	$\frac{c}{8}$	$0.0120V^2$
$\frac{V}{25}$	$\frac{V}{4}$	$\frac{c}{10}$	$\frac{c}{6}$	$0.0120V^2$
$\frac{V}{25}$	$\frac{V}{4}$	$\frac{c}{10}$	$\frac{c}{4}$	$0.0120V^2$
$\frac{V}{25}$	$\frac{V}{2}$	$\frac{c}{20}$	$\frac{c}{8}$	$0.0056V^2$
$\frac{V}{25}$	$\frac{V}{2}$	$\frac{c}{20}$	$\frac{c}{6}$	$0.0056V^2$
$\frac{V}{25}$	$\frac{V}{2}$	$\frac{c}{20}$	$\frac{c}{4}$	$0.0056V^2$
$\frac{V}{25}$	$\frac{V}{2}$	$\frac{c}{15}$	$\frac{c}{8}$	$0.0055V^2$

$\frac{V}{25}$	$\frac{V}{2}$	$\frac{c}{15}$	$\frac{c}{6}$	$0.0055V^2$
$\frac{V}{25}$	$\frac{V}{2}$	$\frac{c}{15}$	$\frac{c}{4}$	$0.0055V^2$
$\frac{V}{25}$	$\frac{V}{2}$	$\frac{c}{10}$	$\frac{c}{8}$	$0.0054V^2$
$\frac{V}{25}$	$\frac{V}{2}$	$\frac{c}{10}$	$\frac{c}{6}$	$0.0054V^2$
$\frac{V}{25}$	$\frac{V}{2}$	$\frac{c}{10}$	$\frac{c}{4}$	$0.0054V^2$
$\frac{V}{20}$	$\frac{V}{4}$	$\frac{c}{20}$	$\frac{c}{8}$	$0.0124V^2$
$\frac{V}{20}$	$\frac{V}{4}$	$\frac{c}{20}$	$\frac{c}{6}$	$0.0124V^2$
$\frac{V}{20}$	$\frac{V}{4}$	$\frac{c}{20}$	$\frac{c}{4}$	$0.0124V^2$
$\frac{V}{20}$	$\frac{V}{4}$	$\frac{c}{15}$	$\frac{c}{8}$	$0.0124V^2$
$\frac{V}{20}$	$\frac{V}{4}$	$\frac{c}{15}$	$\frac{c}{6}$	$0.0124V^2$
$\frac{V}{20}$	$\frac{V}{4}$	$\frac{c}{15}$	$\frac{c}{4}$	$0.0124V^2$
$\frac{V}{20}$	$\frac{V}{4}$	$\frac{c}{10}$	$\frac{c}{8}$	$0.0123V^2$
$\frac{V}{20}$	$\frac{V}{4}$	$\frac{c}{10}$	$\frac{c}{6}$	$0.0123V^2$

$\frac{V}{20}$	$\frac{V}{4}$	$\frac{c}{10}$	$\frac{c}{4}$	$0.0123V^2$
$\frac{V}{20}$	$\frac{V}{2}$	$\frac{c}{20}$	$\frac{c}{8}$	$0.0057V^2$
$\frac{V}{20}$	$\frac{V}{2}$	$\frac{c}{20}$	$\frac{c}{6}$	$0.0057V^2$
$\frac{V}{20}$	$\frac{V}{2}$	$\frac{c}{20}$	$\frac{c}{4}$	$0.0057V^2$
$\frac{V}{20}$	$\frac{V}{2}$	$\frac{c}{15}$	$\frac{c}{8}$	$0.0056V^2$
$\frac{V}{20}$	$\frac{V}{2}$	$\frac{c}{15}$	$\frac{c}{6}$	$0.0056V^2$
$\frac{V}{20}$	$\frac{V}{2}$	$\frac{c}{15}$	$\frac{c}{4}$	$0.0056V^2$
$\frac{V}{20}$	$\frac{V}{2}$	$\frac{c}{10}$	$\frac{c}{8}$	$0.0056V^2$
$\frac{V}{20}$	$\frac{V}{2}$	$\frac{c}{10}$	$\frac{c}{6}$	$0.0056V^2$
$\frac{V}{20}$	$\frac{V}{2}$	$\frac{c}{10}$	$\frac{c}{4}$	$0.0056V^2$

$\Delta\pi_M = \pi_M$ (the government taxes the e-tailer to stop consumer free riding) - π_M (consumer free riding behavior is present)

Table 3. Total life cycle carbon emissions difference between situations when consumer free riding is present and absent

$\alpha = 0.8$, $\delta = 0.8$, $k = 0.5$

f	c	c_r	r	ΔI
$\frac{V}{30}$	$\frac{V}{4}$	$\frac{c}{20}$	$\frac{c}{8}$	$0.0310V^2$
$\frac{V}{30}$	$\frac{V}{4}$	$\frac{c}{20}$	$\frac{c}{6}$	$0.0310V^2$
$\frac{V}{30}$	$\frac{V}{4}$	$\frac{c}{20}$	$\frac{c}{4}$	$0.0310V^2$
$\frac{V}{30}$	$\frac{V}{4}$	$\frac{c}{15}$	$\frac{c}{8}$	$0.0309V^2$
$\frac{V}{30}$	$\frac{V}{4}$	$\frac{c}{15}$	$\frac{c}{6}$	$0.0309V^2$
$\frac{V}{30}$	$\frac{V}{4}$	$\frac{c}{15}$	$\frac{c}{4}$	$0.0309V^2$
$\frac{V}{30}$	$\frac{V}{4}$	$\frac{c}{10}$	$\frac{c}{8}$	$0.0308V^2$
$\frac{V}{30}$	$\frac{V}{4}$	$\frac{c}{10}$	$\frac{c}{6}$	$0.0308V^2$
$\frac{V}{30}$	$\frac{V}{4}$	$\frac{c}{10}$	$\frac{c}{4}$	$0.0308V^2$
$\frac{V}{30}$	$\frac{V}{2}$	$\frac{c}{20}$	$\frac{c}{8}$	$0.0209V^2$

$\frac{V}{30}$	$\frac{V}{2}$	$\frac{c}{20}$	$\frac{c}{6}$	$0.0209V^2$
$\frac{V}{30}$	$\frac{V}{2}$	$\frac{c}{20}$	$\frac{c}{4}$	$0.0209V^2$
$\frac{V}{30}$	$\frac{V}{2}$	$\frac{c}{15}$	$\frac{c}{8}$	$0.0208V^2$
$\frac{V}{30}$	$\frac{V}{2}$	$\frac{c}{15}$	$\frac{c}{6}$	$0.0208V^2$
$\frac{V}{30}$	$\frac{V}{2}$	$\frac{c}{15}$	$\frac{c}{4}$	$0.0208V^2$
$\frac{V}{30}$	$\frac{V}{2}$	$\frac{c}{10}$	$\frac{c}{8}$	$0.0206V^2$
$\frac{V}{30}$	$\frac{V}{2}$	$\frac{c}{10}$	$\frac{c}{6}$	$0.0206V^2$
$\frac{V}{30}$	$\frac{V}{2}$	$\frac{c}{10}$	$\frac{c}{4}$	$0.0206V^2$
$\frac{V}{25}$	$\frac{V}{4}$	$\frac{c}{20}$	$\frac{c}{8}$	$0.0312V^2$
$\frac{V}{25}$	$\frac{V}{4}$	$\frac{c}{20}$	$\frac{c}{6}$	$0.0312V^2$
$\frac{V}{25}$	$\frac{V}{4}$	$\frac{c}{20}$	$\frac{c}{4}$	$0.0312V^2$
$\frac{V}{25}$	$\frac{V}{4}$	$\frac{c}{15}$	$\frac{c}{8}$	$0.0312V^2$
$\frac{V}{25}$	$\frac{V}{4}$	$\frac{c}{15}$	$\frac{c}{6}$	$0.0312V^2$

$\frac{V}{25}$	$\frac{V}{4}$	$\frac{c}{15}$	$\frac{c}{4}$	$0.0312V^2$
$\frac{V}{25}$	$\frac{V}{4}$	$\frac{c}{10}$	$\frac{c}{8}$	$0.0311V^2$
$\frac{V}{25}$	$\frac{V}{4}$	$\frac{c}{10}$	$\frac{c}{6}$	$0.0311V^2$
$\frac{V}{25}$	$\frac{V}{4}$	$\frac{c}{10}$	$\frac{c}{4}$	$0.0311V^2$
$\frac{V}{25}$	$\frac{V}{2}$	$\frac{c}{20}$	$\frac{c}{8}$	$0.0211V^2$
$\frac{V}{25}$	$\frac{V}{2}$	$\frac{c}{20}$	$\frac{c}{6}$	$0.0211V^2$
$\frac{V}{25}$	$\frac{V}{2}$	$\frac{c}{20}$	$\frac{c}{4}$	$0.0211V^2$
$\frac{V}{25}$	$\frac{V}{2}$	$\frac{c}{15}$	$\frac{c}{8}$	$0.0210V^2$
$\frac{V}{25}$	$\frac{V}{2}$	$\frac{c}{15}$	$\frac{c}{6}$	$0.0210V^2$
$\frac{V}{25}$	$\frac{V}{2}$	$\frac{c}{15}$	$\frac{c}{4}$	$0.0210V^2$
$\frac{V}{25}$	$\frac{V}{2}$	$\frac{c}{10}$	$\frac{c}{8}$	$0.0208V^2$
$\frac{V}{25}$	$\frac{V}{2}$	$\frac{c}{10}$	$\frac{c}{6}$	$0.0208V^2$
$\frac{V}{25}$	$\frac{V}{2}$	$\frac{c}{10}$	$\frac{c}{4}$	$0.0208V^2$

$\frac{V}{20}$	$\frac{V}{4}$	$\frac{c}{20}$	$\frac{c}{8}$	$0.0315V^2$
$\frac{V}{20}$	$\frac{V}{4}$	$\frac{c}{20}$	$\frac{c}{6}$	$0.0315V^2$
$\frac{V}{20}$	$\frac{V}{4}$	$\frac{c}{20}$	$\frac{c}{4}$	$0.0315V^2$
$\frac{V}{20}$	$\frac{V}{4}$	$\frac{c}{15}$	$\frac{c}{8}$	$0.0315V^2$
$\frac{V}{20}$	$\frac{V}{4}$	$\frac{c}{15}$	$\frac{c}{6}$	$0.0315V^2$
$\frac{V}{20}$	$\frac{V}{4}$	$\frac{c}{15}$	$\frac{c}{4}$	$0.0315V^2$
$\frac{V}{20}$	$\frac{V}{4}$	$\frac{c}{10}$	$\frac{c}{8}$	$0.0314V^2$
$\frac{V}{20}$	$\frac{V}{4}$	$\frac{c}{10}$	$\frac{c}{6}$	$0.0314V^2$
$\frac{V}{20}$	$\frac{V}{4}$	$\frac{c}{10}$	$\frac{c}{4}$	$0.0314V^2$
$\frac{V}{20}$	$\frac{V}{2}$	$\frac{c}{20}$	$\frac{c}{8}$	$0.0214V^2$
$\frac{V}{20}$	$\frac{V}{2}$	$\frac{c}{20}$	$\frac{c}{6}$	$0.0214V^2$
$\frac{V}{20}$	$\frac{V}{2}$	$\frac{c}{20}$	$\frac{c}{4}$	$0.0214V^2$
$\frac{V}{20}$	$\frac{V}{2}$	$\frac{c}{15}$	$\frac{c}{8}$	$0.0214V^2$

$\frac{V}{20}$	$\frac{V}{2}$	$\frac{c}{15}$	$\frac{c}{6}$	$0.0214V^2$
$\frac{V}{20}$	$\frac{V}{2}$	$\frac{c}{15}$	$\frac{c}{4}$	$0.0214V^2$
$\frac{V}{20}$	$\frac{V}{2}$	$\frac{c}{10}$	$\frac{c}{8}$	$0.0212V^2$
$\frac{V}{20}$	$\frac{V}{2}$	$\frac{c}{10}$	$\frac{c}{6}$	$0.0212V^2$
$\frac{V}{20}$	$\frac{V}{2}$	$\frac{c}{10}$	$\frac{c}{4}$	$0.0212V^2$

$\Delta I = I$ (consumer free riding is present)- I (consumer free riding is absent)

Table 4. Optimal governmental tax on e-tailer

$\alpha = 0.8$, $\delta = 0.8$, $k = 0.5$

f	c	c_r	r	g^*
$\frac{V}{30}$	$\frac{V}{4}$	$\frac{c}{20}$	$\frac{c}{8}$	$-0.5853V$
$\frac{V}{30}$	$\frac{V}{4}$	$\frac{c}{20}$	$\frac{c}{6}$	$-0.5853V$
$\frac{V}{30}$	$\frac{V}{4}$	$\frac{c}{20}$	$\frac{c}{4}$	$-0.5853V$
$\frac{V}{30}$	$\frac{V}{4}$	$\frac{c}{15}$	$\frac{c}{8}$	$-0.5892V$
$\frac{V}{30}$	$\frac{V}{4}$	$\frac{c}{15}$	$\frac{c}{6}$	$-0.5892V$

$\frac{V}{30}$	$\frac{V}{4}$	$\frac{c}{15}$	$\frac{c}{4}$	$-0.5892V$
$\frac{V}{30}$	$\frac{V}{4}$	$\frac{c}{10}$	$\frac{c}{8}$	$-0.5969V$
$\frac{V}{30}$	$\frac{V}{4}$	$\frac{c}{10}$	$\frac{c}{6}$	$-0.5969V$
$\frac{V}{30}$	$\frac{V}{4}$	$\frac{c}{10}$	$\frac{c}{4}$	$-0.5969V$
$\frac{V}{30}$	$\frac{V}{2}$	$\frac{c}{20}$	$\frac{c}{8}$	$-0.4099V$
$\frac{V}{30}$	$\frac{V}{2}$	$\frac{c}{20}$	$\frac{c}{6}$	$-0.4099V$
$\frac{V}{30}$	$\frac{V}{2}$	$\frac{c}{20}$	$\frac{c}{4}$	$-0.4099V$
$\frac{V}{30}$	$\frac{V}{2}$	$\frac{c}{15}$	$\frac{c}{8}$	$-0.4177V$
$\frac{V}{30}$	$\frac{V}{2}$	$\frac{c}{15}$	$\frac{c}{6}$	$-0.4177V$
$\frac{V}{30}$	$\frac{V}{2}$	$\frac{c}{15}$	$\frac{c}{4}$	$-0.4177V$
$\frac{V}{30}$	$\frac{V}{2}$	$\frac{c}{10}$	$\frac{c}{8}$	$-0.4332V$
$\frac{V}{30}$	$\frac{V}{2}$	$\frac{c}{10}$	$\frac{c}{6}$	$-0.4332V$
$\frac{V}{30}$	$\frac{V}{2}$	$\frac{c}{10}$	$\frac{c}{4}$	$-0.4332V$

$\frac{V}{25}$	$\frac{V}{4}$	$\frac{c}{20}$	$\frac{c}{8}$	$-0.5878V$
$\frac{V}{25}$	$\frac{V}{4}$	$\frac{c}{20}$	$\frac{c}{6}$	$-0.5878V$
$\frac{V}{25}$	$\frac{V}{4}$	$\frac{c}{20}$	$\frac{c}{4}$	$-0.5878V$
$\frac{V}{25}$	$\frac{V}{4}$	$\frac{c}{15}$	$\frac{c}{8}$	$-0.5917V$
$\frac{V}{25}$	$\frac{V}{4}$	$\frac{c}{15}$	$\frac{c}{6}$	$-0.5917V$
$\frac{V}{25}$	$\frac{V}{4}$	$\frac{c}{15}$	$\frac{c}{4}$	$-0.5917V$
$\frac{V}{25}$	$\frac{V}{4}$	$\frac{c}{10}$	$\frac{c}{8}$	$-0.5994V$
$\frac{V}{25}$	$\frac{V}{4}$	$\frac{c}{10}$	$\frac{c}{6}$	$-0.5994V$
$\frac{V}{25}$	$\frac{V}{4}$	$\frac{c}{10}$	$\frac{c}{4}$	$-0.5994V$
$\frac{V}{25}$	$\frac{V}{2}$	$\frac{c}{20}$	$\frac{c}{8}$	$-0.4124V$
$\frac{V}{25}$	$\frac{V}{2}$	$\frac{c}{20}$	$\frac{c}{6}$	$-0.4124V$
$\frac{V}{25}$	$\frac{V}{2}$	$\frac{c}{20}$	$\frac{c}{4}$	$-0.4124V$
$\frac{V}{25}$	$\frac{V}{2}$	$\frac{c}{15}$	$\frac{c}{8}$	$-0.4202V$

$\frac{V}{25}$	$\frac{V}{2}$	$\frac{c}{15}$	$\frac{c}{6}$	$-0.4202V$
$\frac{V}{25}$	$\frac{V}{2}$	$\frac{c}{15}$	$\frac{c}{4}$	$-0.4202V$
$\frac{V}{25}$	$\frac{V}{2}$	$\frac{c}{10}$	$\frac{c}{8}$	$-0.4357V$
$\frac{V}{25}$	$\frac{V}{2}$	$\frac{c}{10}$	$\frac{c}{6}$	$-0.4357V$
$\frac{V}{25}$	$\frac{V}{2}$	$\frac{c}{10}$	$\frac{c}{4}$	$-0.4357V$
$\frac{V}{20}$	$\frac{V}{4}$	$\frac{c}{20}$	$\frac{c}{8}$	$-0.5915V$
$\frac{V}{20}$	$\frac{V}{4}$	$\frac{c}{20}$	$\frac{c}{6}$	$-0.5915V$
$\frac{V}{20}$	$\frac{V}{4}$	$\frac{c}{20}$	$\frac{c}{4}$	$-0.5915V$
$\frac{V}{20}$	$\frac{V}{4}$	$\frac{c}{15}$	$\frac{c}{8}$	$-0.5954V$
$\frac{V}{20}$	$\frac{V}{4}$	$\frac{c}{15}$	$\frac{c}{6}$	$-0.5954V$
$\frac{V}{20}$	$\frac{V}{4}$	$\frac{c}{15}$	$\frac{c}{4}$	$-0.5954V$
$\frac{V}{20}$	$\frac{V}{4}$	$\frac{c}{10}$	$\frac{c}{8}$	$-0.6032V$
$\frac{V}{20}$	$\frac{V}{4}$	$\frac{c}{10}$	$\frac{c}{6}$	$-0.6032V$

$\frac{V}{20}$	$\frac{V}{4}$	$\frac{c}{10}$	$\frac{c}{4}$	$-0.6032V$
$\frac{V}{20}$	$\frac{V}{2}$	$\frac{c}{20}$	$\frac{c}{8}$	$-0.4161V$
$\frac{V}{20}$	$\frac{V}{2}$	$\frac{c}{20}$	$\frac{c}{6}$	$-0.4161V$
$\frac{V}{20}$	$\frac{V}{2}$	$\frac{c}{20}$	$\frac{c}{4}$	$-0.4161V$
$\frac{V}{20}$	$\frac{V}{2}$	$\frac{c}{15}$	$\frac{c}{8}$	$-0.4239V$
$\frac{V}{20}$	$\frac{V}{2}$	$\frac{c}{15}$	$\frac{c}{6}$	$-0.4239V$
$\frac{V}{20}$	$\frac{V}{2}$	$\frac{c}{15}$	$\frac{c}{4}$	$-0.4239V$
$\frac{V}{20}$	$\frac{V}{2}$	$\frac{c}{10}$	$\frac{c}{8}$	$-0.4394V$
$\frac{V}{20}$	$\frac{V}{2}$	$\frac{c}{10}$	$\frac{c}{6}$	$-0.4394V$
$\frac{V}{20}$	$\frac{V}{2}$	$\frac{c}{10}$	$\frac{c}{4}$	$-0.4394V$

Table 5. Total life cycle carbon emissions change when the government wants to impose tax on the e-tailer

$\alpha = 0.8$, $\delta = 0.8$, $k = 0.5$

f	c	c_r	r	ΔI
$\frac{V}{30}$	$\frac{V}{4}$	$\frac{c}{20}$	$\frac{c}{8}$	$0.1352V^2$
$\frac{V}{30}$	$\frac{V}{4}$	$\frac{c}{20}$	$\frac{c}{6}$	$0.1352V^2$
$\frac{V}{30}$	$\frac{V}{4}$	$\frac{c}{20}$	$\frac{c}{4}$	$0.1352V^2$
$\frac{V}{30}$	$\frac{V}{4}$	$\frac{c}{15}$	$\frac{c}{8}$	$0.1363V^2$
$\frac{V}{30}$	$\frac{V}{4}$	$\frac{c}{15}$	$\frac{c}{6}$	$0.1363V^2$
$\frac{V}{30}$	$\frac{V}{4}$	$\frac{c}{15}$	$\frac{c}{4}$	$0.1363V^2$
$\frac{V}{30}$	$\frac{V}{4}$	$\frac{c}{10}$	$\frac{c}{8}$	$0.1386V^2$
$\frac{V}{30}$	$\frac{V}{4}$	$\frac{c}{10}$	$\frac{c}{6}$	$0.1386V^2$
$\frac{V}{30}$	$\frac{V}{4}$	$\frac{c}{10}$	$\frac{c}{4}$	$0.1386V^2$

$\frac{V}{30}$	$\frac{V}{2}$	$\frac{c}{20}$	$\frac{c}{8}$	$0.0955V^2$
$\frac{V}{30}$	$\frac{V}{2}$	$\frac{c}{20}$	$\frac{c}{6}$	$0.0955V^2$
$\frac{V}{30}$	$\frac{V}{2}$	$\frac{c}{20}$	$\frac{c}{4}$	$0.0955V^2$
$\frac{V}{30}$	$\frac{V}{2}$	$\frac{c}{15}$	$\frac{c}{8}$	$0.0978V^2$
$\frac{V}{30}$	$\frac{V}{2}$	$\frac{c}{15}$	$\frac{c}{6}$	$0.0978V^2$
$\frac{V}{30}$	$\frac{V}{2}$	$\frac{c}{15}$	$\frac{c}{4}$	$0.0978V^2$
$\frac{V}{30}$	$\frac{V}{2}$	$\frac{c}{10}$	$\frac{c}{8}$	$0.1024V^2$
$\frac{V}{30}$	$\frac{V}{2}$	$\frac{c}{10}$	$\frac{c}{6}$	$0.1024V^2$
$\frac{V}{30}$	$\frac{V}{2}$	$\frac{c}{10}$	$\frac{c}{4}$	$0.1024V^2$
$\frac{V}{25}$	$\frac{V}{4}$	$\frac{c}{20}$	$\frac{c}{8}$	$0.1357V^2$
$\frac{V}{25}$	$\frac{V}{4}$	$\frac{c}{20}$	$\frac{c}{6}$	$0.1357V^2$
$\frac{V}{25}$	$\frac{V}{4}$	$\frac{c}{20}$	$\frac{c}{4}$	$0.1357V^2$
$\frac{V}{25}$	$\frac{V}{4}$	$\frac{c}{15}$	$\frac{c}{8}$	$0.1368V^2$

$\frac{V}{25}$	$\frac{V}{4}$	$\frac{c}{15}$	$\frac{c}{6}$	$0.1368V^2$
$\frac{V}{25}$	$\frac{V}{4}$	$\frac{c}{15}$	$\frac{c}{4}$	$0.1368V^2$
$\frac{V}{25}$	$\frac{V}{4}$	$\frac{c}{10}$	$\frac{c}{8}$	$0.1391V^2$
$\frac{V}{25}$	$\frac{V}{4}$	$\frac{c}{10}$	$\frac{c}{6}$	$0.1391V^2$
$\frac{V}{25}$	$\frac{V}{4}$	$\frac{c}{10}$	$\frac{c}{4}$	$0.1391V^2$
$\frac{V}{25}$	$\frac{V}{2}$	$\frac{c}{20}$	$\frac{c}{8}$	$0.0960V^2$
$\frac{V}{25}$	$\frac{V}{2}$	$\frac{c}{20}$	$\frac{c}{6}$	$0.0960V^2$
$\frac{V}{25}$	$\frac{V}{2}$	$\frac{c}{20}$	$\frac{c}{4}$	$0.0960V^2$
$\frac{V}{25}$	$\frac{V}{2}$	$\frac{c}{15}$	$\frac{c}{8}$	$0.0983V^2$
$\frac{V}{25}$	$\frac{V}{2}$	$\frac{c}{15}$	$\frac{c}{6}$	$0.0983V^2$
$\frac{V}{25}$	$\frac{V}{2}$	$\frac{c}{15}$	$\frac{c}{4}$	$0.0983V^2$
$\frac{V}{25}$	$\frac{V}{2}$	$\frac{c}{10}$	$\frac{c}{8}$	$0.1029V^2$
$\frac{V}{25}$	$\frac{V}{2}$	$\frac{c}{10}$	$\frac{c}{6}$	$0.1029V^2$

$\frac{V}{25}$	$\frac{V}{2}$	$\frac{c}{10}$	$\frac{c}{4}$	$0.1029V^2$
$\frac{V}{20}$	$\frac{V}{4}$	$\frac{c}{20}$	$\frac{c}{8}$	$0.1364V^2$
$\frac{V}{20}$	$\frac{V}{4}$	$\frac{c}{20}$	$\frac{c}{6}$	$0.1364V^2$
$\frac{V}{20}$	$\frac{V}{4}$	$\frac{c}{20}$	$\frac{c}{4}$	$0.1364V^2$
$\frac{V}{20}$	$\frac{V}{4}$	$\frac{c}{15}$	$\frac{c}{8}$	$0.1375V^2$
$\frac{V}{20}$	$\frac{V}{4}$	$\frac{c}{15}$	$\frac{c}{6}$	$0.1375V^2$
$\frac{V}{20}$	$\frac{V}{4}$	$\frac{c}{15}$	$\frac{c}{4}$	$0.1375V^2$
$\frac{V}{20}$	$\frac{V}{4}$	$\frac{c}{10}$	$\frac{c}{8}$	$0.1398V^2$
$\frac{V}{20}$	$\frac{V}{4}$	$\frac{c}{10}$	$\frac{c}{6}$	$0.1398V^2$
$\frac{V}{20}$	$\frac{V}{4}$	$\frac{c}{10}$	$\frac{c}{4}$	$0.1398V^2$
$\frac{V}{20}$	$\frac{V}{2}$	$\frac{c}{20}$	$\frac{c}{8}$	$0.0967V^2$
$\frac{V}{20}$	$\frac{V}{2}$	$\frac{c}{20}$	$\frac{c}{6}$	$0.0967V^2$
$\frac{V}{20}$	$\frac{V}{2}$	$\frac{c}{20}$	$\frac{c}{4}$	$0.0967V^2$

$\frac{V}{20}$	$\frac{V}{2}$	$\frac{c}{15}$	$\frac{c}{8}$	$0.0990V^2$
$\frac{V}{20}$	$\frac{V}{2}$	$\frac{c}{15}$	$\frac{c}{6}$	$0.0990V^2$
$\frac{V}{20}$	$\frac{V}{2}$	$\frac{c}{15}$	$\frac{c}{4}$	$0.0990V^2$
$\frac{V}{20}$	$\frac{V}{2}$	$\frac{c}{10}$	$\frac{c}{8}$	$0.1036V^2$
$\frac{V}{20}$	$\frac{V}{2}$	$\frac{c}{10}$	$\frac{c}{6}$	$0.1036V^2$
$\frac{V}{20}$	$\frac{V}{2}$	$\frac{c}{10}$	$\frac{c}{4}$	$0.1036V^2$

$\Delta I = I$ (the government taxes the e-tailer to stop consumer free riding) – I (consumer free riding is present)

Table 6. Consumer welfare difference

$\alpha = 0.8$, $\delta = 0.8$, $k = 0.5$

f	c	c_r	r	ΔCW
$\frac{V}{30}$	$\frac{V}{4}$	$\frac{c}{20}$	$\frac{c}{8}$	$0.0703V^2$
$\frac{V}{30}$	$\frac{V}{4}$	$\frac{c}{20}$	$\frac{c}{6}$	$0.0703V^2$

$\frac{V}{30}$	$\frac{V}{4}$	$\frac{c}{20}$	$\frac{c}{4}$	$0.0703V^2$
$\frac{V}{30}$	$\frac{V}{4}$	$\frac{c}{15}$	$\frac{c}{8}$	$0.0716V^2$
$\frac{V}{30}$	$\frac{V}{4}$	$\frac{c}{15}$	$\frac{c}{6}$	$0.0716V^2$
$\frac{V}{30}$	$\frac{V}{4}$	$\frac{c}{15}$	$\frac{c}{4}$	$0.0716V^2$
$\frac{V}{30}$	$\frac{V}{4}$	$\frac{c}{10}$	$\frac{c}{8}$	$0.0742V^2$
$\frac{V}{30}$	$\frac{V}{4}$	$\frac{c}{10}$	$\frac{c}{6}$	$0.0742V^2$
$\frac{V}{30}$	$\frac{V}{4}$	$\frac{c}{10}$	$\frac{c}{4}$	$0.0742V^2$
$\frac{V}{30}$	$\frac{V}{2}$	$\frac{c}{20}$	$\frac{c}{8}$	$0.0355V^2$
$\frac{V}{30}$	$\frac{V}{2}$	$\frac{c}{20}$	$\frac{c}{6}$	$0.0355V^2$
$\frac{V}{30}$	$\frac{V}{2}$	$\frac{c}{20}$	$\frac{c}{4}$	$0.0355V^2$
$\frac{V}{30}$	$\frac{V}{2}$	$\frac{c}{15}$	$\frac{c}{8}$	$0.0374V^2$
$\frac{V}{30}$	$\frac{V}{2}$	$\frac{c}{15}$	$\frac{c}{6}$	$0.0374V^2$
$\frac{V}{30}$	$\frac{V}{2}$	$\frac{c}{15}$	$\frac{c}{4}$	$0.0374V^2$

$\frac{V}{30}$	$\frac{V}{2}$	$\frac{c}{10}$	$\frac{c}{8}$	$0.0412V^2$
$\frac{V}{30}$	$\frac{V}{2}$	$\frac{c}{10}$	$\frac{c}{6}$	$0.0412V^2$
$\frac{V}{30}$	$\frac{V}{2}$	$\frac{c}{10}$	$\frac{c}{4}$	$0.0412V^2$
$\frac{V}{25}$	$\frac{V}{4}$	$\frac{c}{20}$	$\frac{c}{8}$	$0.0709V^2$
$\frac{V}{25}$	$\frac{V}{4}$	$\frac{c}{20}$	$\frac{c}{6}$	$0.0709V^2$
$\frac{V}{25}$	$\frac{V}{4}$	$\frac{c}{20}$	$\frac{c}{4}$	$0.0709V^2$
$\frac{V}{25}$	$\frac{V}{4}$	$\frac{c}{15}$	$\frac{c}{8}$	$0.0722V^2$
$\frac{V}{25}$	$\frac{V}{4}$	$\frac{c}{15}$	$\frac{c}{6}$	$0.0722V^2$
$\frac{V}{25}$	$\frac{V}{4}$	$\frac{c}{15}$	$\frac{c}{4}$	$0.0722V^2$
$\frac{V}{25}$	$\frac{V}{4}$	$\frac{c}{10}$	$\frac{c}{8}$	$0.0749V^2$
$\frac{V}{25}$	$\frac{V}{4}$	$\frac{c}{10}$	$\frac{c}{6}$	$0.0749V^2$
$\frac{V}{25}$	$\frac{V}{4}$	$\frac{c}{10}$	$\frac{c}{4}$	$0.0749V^2$
$\frac{V}{25}$	$\frac{V}{2}$	$\frac{c}{20}$	$\frac{c}{8}$	$0.0360V^2$

$\frac{V}{25}$	$\frac{V}{2}$	$\frac{c}{20}$	$\frac{c}{6}$	$0.0360V^2$
$\frac{V}{25}$	$\frac{V}{2}$	$\frac{c}{20}$	$\frac{c}{4}$	$0.0360V^2$
$\frac{V}{25}$	$\frac{V}{2}$	$\frac{c}{15}$	$\frac{c}{8}$	$0.0379V^2$
$\frac{V}{25}$	$\frac{V}{2}$	$\frac{c}{15}$	$\frac{c}{6}$	$0.0379V^2$
$\frac{V}{25}$	$\frac{V}{2}$	$\frac{c}{15}$	$\frac{c}{4}$	$0.0379V^2$
$\frac{V}{25}$	$\frac{V}{2}$	$\frac{c}{10}$	$\frac{c}{8}$	$0.0417V^2$
$\frac{V}{25}$	$\frac{V}{2}$	$\frac{c}{10}$	$\frac{c}{6}$	$0.0417V^2$
$\frac{V}{25}$	$\frac{V}{2}$	$\frac{c}{10}$	$\frac{c}{4}$	$0.0417V^2$
$\frac{V}{20}$	$\frac{V}{4}$	$\frac{c}{20}$	$\frac{c}{8}$	$0.0719V^2$
$\frac{V}{20}$	$\frac{V}{4}$	$\frac{c}{20}$	$\frac{c}{6}$	$0.0719V^2$
$\frac{V}{20}$	$\frac{V}{4}$	$\frac{c}{20}$	$\frac{c}{4}$	$0.0719V^2$
$\frac{V}{20}$	$\frac{V}{4}$	$\frac{c}{15}$	$\frac{c}{8}$	$0.0732V^2$
$\frac{V}{20}$	$\frac{V}{4}$	$\frac{c}{15}$	$\frac{c}{6}$	$0.0732V^2$

$\frac{V}{20}$	$\frac{V}{4}$	$\frac{c}{15}$	$\frac{c}{4}$	$0.0732V^2$
$\frac{V}{20}$	$\frac{V}{4}$	$\frac{c}{10}$	$\frac{c}{8}$	$0.0759V^2$
$\frac{V}{20}$	$\frac{V}{4}$	$\frac{c}{10}$	$\frac{c}{6}$	$0.0759V^2$
$\frac{V}{20}$	$\frac{V}{4}$	$\frac{c}{10}$	$\frac{c}{4}$	$0.0759V^2$
$\frac{V}{20}$	$\frac{V}{2}$	$\frac{c}{20}$	$\frac{c}{8}$	$0.0366V^2$
$\frac{V}{20}$	$\frac{V}{2}$	$\frac{c}{20}$	$\frac{c}{6}$	$0.0366V^2$
$\frac{V}{20}$	$\frac{V}{2}$	$\frac{c}{20}$	$\frac{c}{4}$	$0.0366V^2$
$\frac{V}{20}$	$\frac{V}{2}$	$\frac{c}{15}$	$\frac{c}{8}$	$0.0385V^2$
$\frac{V}{20}$	$\frac{V}{2}$	$\frac{c}{15}$	$\frac{c}{6}$	$0.0385V^2$
$\frac{V}{20}$	$\frac{V}{2}$	$\frac{c}{15}$	$\frac{c}{4}$	$0.0385V^2$
$\frac{V}{20}$	$\frac{V}{2}$	$\frac{c}{10}$	$\frac{c}{8}$	$0.0424V^2$
$\frac{V}{20}$	$\frac{V}{2}$	$\frac{c}{10}$	$\frac{c}{6}$	$0.0424V^2$
$\frac{V}{20}$	$\frac{V}{2}$	$\frac{c}{10}$	$\frac{c}{4}$	$0.0424V^2$

$\Delta CW = CW$ (the government taxes the e-tailer to stop consumer free riding) – CW (consumer free riding is present)

Table 7. Social welfare difference

$\alpha = 0.8$, $\delta = 0.8$, $k = 0.5$

f	c	c_r	r	ΔSW
$\frac{V}{30}$	$\frac{V}{4}$	$\frac{c}{20}$	$\frac{c}{8}$	$0.0255V^2$
$\frac{V}{30}$	$\frac{V}{4}$	$\frac{c}{20}$	$\frac{c}{6}$	$0.0255V^2$
$\frac{V}{30}$	$\frac{V}{4}$	$\frac{c}{20}$	$\frac{c}{4}$	$0.0255V^2$
$\frac{V}{30}$	$\frac{V}{4}$	$\frac{c}{15}$	$\frac{c}{8}$	$0.0260V^2$
$\frac{V}{30}$	$\frac{V}{4}$	$\frac{c}{15}$	$\frac{c}{6}$	$0.0260V^2$
$\frac{V}{30}$	$\frac{V}{4}$	$\frac{c}{15}$	$\frac{c}{4}$	$0.0260V^2$

$\frac{V}{30}$	$\frac{V}{4}$	$\frac{c}{10}$	$\frac{c}{8}$	$0.0270V^2$
$\frac{V}{30}$	$\frac{V}{4}$	$\frac{c}{10}$	$\frac{c}{6}$	$0.0270V^2$
$\frac{V}{30}$	$\frac{V}{4}$	$\frac{c}{10}$	$\frac{c}{4}$	$0.0270V^2$
$\frac{V}{30}$	$\frac{V}{2}$	$\frac{c}{20}$	$\frac{c}{8}$	$0.0129V^2$
$\frac{V}{30}$	$\frac{V}{2}$	$\frac{c}{20}$	$\frac{c}{6}$	$0.0129V^2$
$\frac{V}{30}$	$\frac{V}{2}$	$\frac{c}{20}$	$\frac{c}{4}$	$0.0129V^2$
$\frac{V}{30}$	$\frac{V}{2}$	$\frac{c}{15}$	$\frac{c}{8}$	$0.0136V^2$
$\frac{V}{30}$	$\frac{V}{2}$	$\frac{c}{15}$	$\frac{c}{6}$	$0.0136V^2$
$\frac{V}{30}$	$\frac{V}{2}$	$\frac{c}{15}$	$\frac{c}{4}$	$0.0136V^2$
$\frac{V}{30}$	$\frac{V}{2}$	$\frac{c}{10}$	$\frac{c}{8}$	$0.0150V^2$
$\frac{V}{30}$	$\frac{V}{2}$	$\frac{c}{10}$	$\frac{c}{6}$	$0.0150V^2$
$\frac{V}{30}$	$\frac{V}{2}$	$\frac{c}{10}$	$\frac{c}{4}$	$0.0150V^2$
$\frac{V}{25}$	$\frac{V}{4}$	$\frac{c}{20}$	$\frac{c}{8}$	$0.0257V^2$

$\frac{V}{25}$	$\frac{V}{4}$	$\frac{c}{20}$	$\frac{c}{6}$	$0.0257V^2$
$\frac{V}{25}$	$\frac{V}{4}$	$\frac{c}{20}$	$\frac{c}{4}$	$0.0257V^2$
$\frac{V}{25}$	$\frac{V}{4}$	$\frac{c}{15}$	$\frac{c}{8}$	$0.0262V^2$
$\frac{V}{25}$	$\frac{V}{4}$	$\frac{c}{15}$	$\frac{c}{6}$	$0.0262V^2$
$\frac{V}{25}$	$\frac{V}{4}$	$\frac{c}{15}$	$\frac{c}{4}$	$0.0262V^2$
$\frac{V}{25}$	$\frac{V}{4}$	$\frac{c}{10}$	$\frac{c}{8}$	$0.0272V^2$
$\frac{V}{25}$	$\frac{V}{4}$	$\frac{c}{10}$	$\frac{c}{6}$	$0.0272V^2$
$\frac{V}{25}$	$\frac{V}{4}$	$\frac{c}{10}$	$\frac{c}{4}$	$0.0272V^2$
$\frac{V}{25}$	$\frac{V}{2}$	$\frac{c}{20}$	$\frac{c}{8}$	$0.0131V^2$
$\frac{V}{25}$	$\frac{V}{2}$	$\frac{c}{20}$	$\frac{c}{6}$	$0.0131V^2$
$\frac{V}{25}$	$\frac{V}{2}$	$\frac{c}{20}$	$\frac{c}{4}$	$0.0131V^2$
$\frac{V}{25}$	$\frac{V}{2}$	$\frac{c}{15}$	$\frac{c}{8}$	$0.0138V^2$
$\frac{V}{25}$	$\frac{V}{2}$	$\frac{c}{15}$	$\frac{c}{6}$	$0.0138V^2$

$\frac{V}{25}$	$\frac{V}{2}$	$\frac{c}{15}$	$\frac{c}{4}$	$0.0138V^2$
$\frac{V}{25}$	$\frac{V}{2}$	$\frac{c}{10}$	$\frac{c}{8}$	$0.0152V^2$
$\frac{V}{25}$	$\frac{V}{2}$	$\frac{c}{10}$	$\frac{c}{6}$	$0.0152V^2$
$\frac{V}{25}$	$\frac{V}{2}$	$\frac{c}{10}$	$\frac{c}{4}$	$0.0152V^2$
$\frac{V}{20}$	$\frac{V}{4}$	$\frac{c}{20}$	$\frac{c}{8}$	$0.0259V^2$
$\frac{V}{20}$	$\frac{V}{4}$	$\frac{c}{20}$	$\frac{c}{6}$	$0.0259V^2$
$\frac{V}{20}$	$\frac{V}{4}$	$\frac{c}{20}$	$\frac{c}{4}$	$0.0259V^2$
$\frac{V}{20}$	$\frac{V}{4}$	$\frac{c}{15}$	$\frac{c}{8}$	$0.0265V^2$
$\frac{V}{20}$	$\frac{V}{4}$	$\frac{c}{15}$	$\frac{c}{6}$	$0.0265V^2$
$\frac{V}{20}$	$\frac{V}{4}$	$\frac{c}{15}$	$\frac{c}{4}$	$0.0265V^2$
$\frac{V}{20}$	$\frac{V}{4}$	$\frac{c}{10}$	$\frac{c}{8}$	$0.0275V^2$
$\frac{V}{20}$	$\frac{V}{4}$	$\frac{c}{10}$	$\frac{c}{6}$	$0.0275V^2$
$\frac{V}{20}$	$\frac{V}{4}$	$\frac{c}{10}$	$\frac{c}{4}$	$0.0275V^2$

$\frac{V}{20}$	$\frac{V}{2}$	$\frac{c}{20}$	$\frac{c}{8}$	$0.0132V^2$
$\frac{V}{20}$	$\frac{V}{2}$	$\frac{c}{20}$	$\frac{c}{6}$	$0.0132V^2$
$\frac{V}{20}$	$\frac{V}{2}$	$\frac{c}{20}$	$\frac{c}{4}$	$0.0132V^2$
$\frac{V}{20}$	$\frac{V}{2}$	$\frac{c}{15}$	$\frac{c}{8}$	$0.0140V^2$
$\frac{V}{20}$	$\frac{V}{2}$	$\frac{c}{15}$	$\frac{c}{6}$	$0.0140V^2$
$\frac{V}{20}$	$\frac{V}{2}$	$\frac{c}{15}$	$\frac{c}{4}$	$0.0140V^2$
$\frac{V}{20}$	$\frac{V}{2}$	$\frac{c}{10}$	$\frac{c}{8}$	$0.0155V^2$
$\frac{V}{20}$	$\frac{V}{2}$	$\frac{c}{10}$	$\frac{c}{6}$	$0.0155V^2$
$\frac{V}{20}$	$\frac{V}{2}$	$\frac{c}{10}$	$\frac{c}{4}$	$0.0155V^2$

$\Delta SW = SW$ (the government taxes the e-tailer to stop consumer free riding) – SW (consumer free riding is present)