Environmental implications for online retailing

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Abstract

Recent press has highlighted the environmental benefits associated with online shopping, such as emissions savings from individual drivers, economies of scale in package delivery, and decreased inventories. We formulate a dual channel model for a retailer who has access to both online and traditional market outlets to analyze the impact of customer environmental sensitivity on its supply. In particular, we analyze stocking decisions for each channel incorporating price dependent demand, customer preference/utility for online channels, and channel related costs. We compare and contrast results from both deterministic and stochastic models, and utilize numerical examples to illustrate the implications of industry specific factors on these decisions. Finally, we compare and contrast the findings for disparate industries, such as electronics, books and groceries.

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1. Motivation

The environmental benefits associated with online shopping, such as emissions savings from individual drivers, economies of scale in package delivery, and decreased inventories, are well documented. Weber et al. (2008) performed a case study for buy.com comparing the environmental impact of e-commerce vs. a traditional retailer for the purchase and delivery of a flash drive. A key finding of this study is that the total energy usage for a traditional retailer is higher than that typically associated with e-commerce delivery. The main factors driving this result are the distance that the customer has to drive to buy the item via a traditional retailer (on average they drive 14 miles for a round trip), and the consumer fuel economy (assumed to be 22 miles/gallon from the US EPA). The authors also note the limitations of these results. For instance, if express air shipping is chosen as the delivery method by the customer, then the carbon emissions for both modes (i.e. e-commerce and traditional retailer) are roughly comparable.

Moreover, consumer awareness concerning the environmental impact associated with particular product choices is growing. A 2010 article appearing in the Wall Street Journal summarizes the results of a poll which finds that 17% of U.S. consumers and 23% of European consumers are willing to pay more for environmentally friendly products (O'Connell, 2010). These numbers have increased significantly over the past year. Consequently, major retailers such as Wal Mart are undertaking initiatives to include environmental information on labels along with pricing information. To start the process of gathering more environmental information from suppliers, Wal Mart will require its suppliers to answer questions concerning energy costs and emissions, material efficiency, natural resources, and ethical workforce concerns (Bustillo, 2009). According to O’Connell (2010), the percentage of advertisements in major magazines making “green claims” has also grown. However, many vendors have overstated the environmental properties of their goods (a practice commonly referred to as “greenwashing”) such that the Federal Trade Commission has taken actions against these claims.

Internet companies are undertaking initiatives to highlight the environmental choices to consumers when they purchase goods via the internet. For example, Amazon.com has received a patent on “environmentally conscious electronic transactions,” (Engleman, 2010). Their goal is to distinguish the environmental impact between different shipping methods, and to specifically market this service to consumers who are willing to pay more for delivery methods which have a lower environmental impact. Engleman (2010) also notes that, “These shipping options could cost more, and entail a longer wait for a package, but presumably Amazon sees a potential market for this.” Examples of such environmental shipping practices include the use of hybrid vehicles, minimization of packaging materials, and efficient truck utilization techniques.

Many retail firms are grappling with the issue of how to best manage dual distribution channels for their goods as demand via internet channel grows. To illustrate, the U.K. retailer Tesco
established a home delivery service in 2000 and advertised their new internet channel with the slogan, “You shop. We drop.” (Anonymous, 2006). While other retailers may fear that there is a conflict between these two important channels, Tesco embraced the complementarities between the new and old channels while concurrently continuing to expand its traditional bricks-and-mortar stores. In contrast, Webvan tried to establish a single online channel to deliver groceries by investing in large warehouses and inventory management systems (Spurgeon, 2001). Unfortunately, they went bankrupt due to a lack of customers willing to pay a higher premium for their service. Therefore, primary concerns of dual channel distribution include supply chain costs, customer service, and pricing.

In this paper, we introduce a stylized single firm model focusing on marketing choices for a dual channel strategy. We explicitly address the environmental implications of each channel to determine appropriate pricing and stocking decisions. Through our analysis, we address the following key research questions:

1. If a retailer has both traditional and online sales channels, how should he/she manage the split between these?
2. Are there circumstances under which a retailer should focus only on online and/or traditional channels?
3. How will consumer behavior evolve in response to these environmental channel concerns?
4. Which factors associated with e-commerce have the most significant impact on the environment?
5. How will policy issues such as a carbon tax impact on the retailer’s decision?

The paper is organized as follows. In Section 2, we further discuss the existing body of literature as it relates to our key research questions. In Section 3.1, we introduce and analyze a deterministic model based on price dependent demand functions to determine when a dual strategy is appropriate. We extend this model in Section 3.2 to incorporate demand uncertainty via a newsvendor framework. A numerical analysis that analyzes the impact of various environmental factors on the optimal solutions and profits is included in Section 4. Conclusions and directions for future research are discussed in Section 5.

2. Literature review

2.1. e-Commerce and the environment: empirical literature

Several notable case-based and empirical studies have been published which analyze the environmental effects of e-commerce for specific industries, including electronics, groceries and books. For a more complete description of this literature, see Carrillo, Vakharia, and Wang (2010). As previously mentioned, Weber et al. (2008) utilize monte-carlo simulation techniques to analyze key factors involved in the delivery of a flash drive for buy.com. Fernie, Pfab, and Marchant (2000) survey senior executives currently working in grocery supply chain companies and conclude that some of the top issues that these executives are concerned about for the future included both e-commerce and environmental factors. Siikavirta, Punakivi, Krkkinen, and Linnanen (2002) employ simulation methodologies to analyze green house gas emissions associated with home delivery grocery services. They identify scenarios under which the home delivery service can cut green house gases by up to 87%. Matthews, Hendrickson, and Soh (2001) perform a study of the online book industry to directly analyze the environmental impact of online vs. traditional book retailers. They find that, when there are no returns, both modes have a comparable environmental impact. However, when the remainder rates are significant (they are typically 35% for best-selling books that are not sold at the end of the selling season from the retailer), the environmental impact of the traditional retailer is much worse, as they must stock higher inventories. Our model utilizes the evidence from this body of empirical studies to motivate certain relationships which link environmental factors to consumer decisions concerning channel choice.

2.2. Literature on e-commerce

Agatz, Fleischmann, and van Nunen (2008) offer a detailed overview of both the empirical and analytic literature which addresses e-fulfillment in a multi-channel environment. These authors note that, “One recurrent pattern is the combination of ‘bricks-and-clicks’, the integration of online sales into a portfolio of multiple alternative distribution channels.” They offer numerous examples of retail firms where (a) traditional retailers are adding an online channel and (b) internet retailers are opening physical stores. One of the conclusions that these authors reach is that, “Pricing models for a multi-channel setting appear to be scarce as of yet.” Our model directly addresses this shortcoming in the literature. Specifically, we develop optimal pricing and stocking strategies for a multi-channel retailer based on factors such as (a) the consumer’s propensity to buy from the online channel, (b) the environmental costs associated with both channels, (c) price sensitivity to demand in both channels, and (c) cross price substitution effects between the channels.

2.2.1. Empirical literature on e-commerce

In his seminal paper, Bakos (2001) offers an overview of the impact of e-commerce on the retailing landscape and summarizes several key issues associated with e-commerce. Factors relevant in our context include increased price competition and differentiation via pricing for goods ordered online. Brynjolfsson and Smith (2000) explore the impact of internet commerce on price by analyzing data from book and CD industries for both traditional and e-commerce channels. These authors find that prices on the internet are significantly lower than those in a traditional retailer even when accounting for taxes, shipping, shopping and transportation costs. Brynjolfsson, Hu, and Rhaman (2009) further characterize the nature of competition between traditional bricks-and-mortar stores and an internet retailer. Their empirical study shows that the competition between these two channels is strongest when the goods are mainstream products that are typically associated with lower search costs. We utilize this literature in motivating our model by incorporating a cross price sensitivity parameter between the channels which reflects the competition between the two channels. Consequently, we can analyze the circumstances under which prices may be lower in a particular channel.

2.2.2. Analytic dual channel models

A body of literature within the operations management area addresses supply chain issues typically associated with dual channel models of distribution. For an overview of these models, see Agatz et al. (2008) and also Cattani, Gilland, Heese, and Svaninathan (2006). In particular, many of these analytic models address the manufacturer’s decision concerning the addition of a direct retail channel (i.e. online sales) and sales via a traditional established independent retailer (i.e. bricks-and-mortar). The key decision variables in these models classically include both the wholesale/transfer price between the manufacturer and the retailer and the price offered to customers in both of the channels (Cattani et al., 2006; Chiang, Chhajed, & Hess, 2003; Chiang & Monahan, 2005; Dumrongsriri, Fan, Jain, & Moinzadeh, 2008; Tsay & Agrawal, 2004; Yue & Liu, 2006). These game theoretic models directly address the problem of double marginalization and characterize the circumstances under which the traditional retailer
may actually benefit from the second online channel. In addition, Tsay and Agrawal (2004) explicitly consider investments in sales activities, while Chen, Kaya, and Ozer (2008a) consider investments in activities which improve product availability (for the traditional retailer) or leadtime (for the online channel). Cattani et al. (2006) and Chen et al. (2008a) take into account the relative “inconvenience” of shopping in a traditional retailer vs. an online retailer via channel cost differentials. Boyaci (2005) addresses stocking decisions for both channels and explicitly models substitution effects for the situation where there is a stockout in one of the channels. Finally, Tsay and Agrawal (2000) consider competition between two retailers via price and service mechanisms when selling a single product procured from a single manufacturer.

Our model is focused on a single stage channel for a single product. In contrast, other authors including Cattani et al. (2006), Chiang et al. (2003), Chiang and Monahan (2005), Dumrongsiri et al. (2008), Tsay and Agrawal (2004), and Yue and Liu (2006) all explicitly address a dual stage situation where the retailer negotiates with the manufacturer in addition to setting prices for the traditional retail channel. Compared with these dual channel models, our model is unique as it addresses the situation where both channels (online and traditional) are owned by a single retailer. Consequently, we do not explicitly include the manufacturer in this problem. The Tsay and Agrawal (2000) model is closest to ours as it utilizes similar demand functions to ours and it considers two competing retailers. In addition, we also incorporate environmental factors into the retailer’s decision.

2.3. Operations/demand related literature

Several papers utilize price dependent demand models to analyze various stocking and pricing decisions for a duopoly where there are two substitute products in the marketplace. Singh and Vives (1984) derive linear demand functions with substitution from quadratic utility functions. Specifically, they characterize demand for each product as (a) a decreasing function of the product’s own price and (b) an increasing function of the substitute product’s price. Lus and Muriel (2009) also consider different forms of price linear demand functions and conclude that this form of the function may lead to “unrealistically high prices and profits as products become more substitutable.” Tsay and Agrawal (2000) utilize a price-quantity linear demand structure when developing optimal wholesaler and retailer pricing policies for two competing retailers selling the same product. Under a different context, Chen, Vakharia, and Alptekinoglu (2008b) also use price-quantity linear demand functions to analyze the situation under which a firm should introduce a “fusion” product which combines products currently selling in different markets into a single product.

Stochastic demand and pricing models typically utilize a news-vendor approach to determine optimal stocking policies. For a complete review of these papers, see Qin, Wang, Vakharia, Chen, and Serfet (2011). One such paper is particularly relevant to our model. Petruzzi and Dada (1999) analyze pricing decisions for different variations of the newsvendor model for a single product. One case that they consider utilizes a price linear additive function of demand which is similar in nature to those shown in the deterministic demand literature. These authors derive mathematical conditions under which an optimal solution for both price and quantity can be determined for the situation when there is demand uncertainty. Specifically, they show that when the probability distribution function which characterizes demand uncertainty has certain properties, then the optimal solution within a pre-specified range is unique. We utilize several elements from this body of operations/demand related literature to motivate our choice for specific functional forms in the model.

2.4. Contribution to the literature

While several authors have addressed the environmental impact of e-commerce via case-based and empirical methodologies, we contribute to this literature by developing an analytical model which offers managerial guidance concerning this important area of inquiry. Our model links the empirical literature on environmental issues in e-commerce with classic marketing and operations models. Specifically, we formulate a dual channel model of a single retailer which has access to both online and traditional market outlets to analyze the impact of environmental factors on its demand. We also analyze optimal pricing and stocking decisions for each channel incorporating price linear demand, customer preference for online shopping, and channel related costs. We develop analytic solutions for both deterministic and stochastic versions of the dual channel models, and utilize numerical examples to illustrate the implications of industry specific factors on these decisions. The insights that we derive are particularly relevant for a single retail firm deciding whether or not to complement its traditional sales with an online sales channel, in industries, such as electronics, books and groceries.

3. Modeling framework

3.1. Preliminaries

In this section, we outline the key parameters and variables utilized in our model. A summary of the model notation is included in Table 1. Our stylized modeling scenario focuses on examining a single retailer’s channel choice decision for a single product. The three choices for the retailer we investigate are to offer its product through: (a) the traditional retail (“bricks and mortar”) channel or RC indexed as $j = 1$; or (b) the online channel or OC indexed as $j = 2$; and (c) both the RC and OC or a DC (Dual Channel) and indexed as $j = 3$. The RC represents the established configuration where the firm stocks its product and customers are required to travel to the location to purchase the product. These types of structures are well established in practice and the cost per unit to process a product through this channel is assumed to be $c_1$.

An “online” channel (OC) could be introduced as a replacement for the current channel or as an additional channel for serving the market demand and in this setting the retailer incurs a per unit

Table 1

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$i$</td>
<td>Index for channel structures</td>
</tr>
<tr>
<td>$c_j$</td>
<td>Unit cost for channel $i$ $(i = 1, 2)$</td>
</tr>
<tr>
<td>$e$</td>
<td>Environmental unit cost savings/premium for OC channel</td>
</tr>
<tr>
<td>$p_i$</td>
<td>Unit price for channel $i$ $(i = 1, 2)$</td>
</tr>
<tr>
<td>$q_i$</td>
<td>Quantity offered through channel $i$ $(i = 1, 2)$</td>
</tr>
<tr>
<td>$a_i$</td>
<td>Maximum market size for channel $i$ $(i = 1, 2)$</td>
</tr>
<tr>
<td>$a$</td>
<td>Total market size</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>Propensity of customers for OC $(0 &lt; \lambda &lt; 1)$</td>
</tr>
<tr>
<td>$h$</td>
<td>Price elasticity of demand for channel $i$ $(i = 1, 2)$</td>
</tr>
<tr>
<td>$s$</td>
<td>Symmetric price substitution parameter</td>
</tr>
<tr>
<td>$f_1()$</td>
<td>Probability density function for $e_1$</td>
</tr>
<tr>
<td>$F_1()$</td>
<td>Cumulative density function for $e_1$</td>
</tr>
<tr>
<td>$[-d, d]$</td>
<td>Minimum and maximum values for $e_1$</td>
</tr>
<tr>
<td>$h$</td>
<td>Salvage value for an unsold unit</td>
</tr>
<tr>
<td>$I_{i1}$</td>
<td>Firm profit associated with channel structure $i$ $(i = 1, 2, 3)$</td>
</tr>
</tbody>
</table>
cost $c_2$ for processing the product through this channel. In order to investigate the impact of environmental aspects, we assume that the cost differential between the RC and the OC is $c_2 - c_1 = \epsilon + \beta$ where the parameter $\epsilon$ represents the environmental cost/savings of the OC as compared to the RC, and $\beta$ represents cost differences between channels due to other factors. We allow $\epsilon$ to be either positive or negative, and note that the differential in these costs is partially driven by environmental issues associated with channel costs. To illustrate, $\epsilon < 0$ implies that the OC provides environmental economies as compared to the RC while the reverse is true when $\epsilon > 0$. For example, when considering the OC for non-perishable products (e.g., books), it is highly likely that there would be a reduction of total inventories due to pooling effects. This would be reflected in environmental savings associated with using less paper since fewer books would need to be printed for the OC (i.e., $\epsilon < 0$).

On the other hand, for perishable (or short shelf life) grocery items, an OC would require the use of delivery vehicles with freezers. Such vehicles may increase the “carbon footprint” associated with the OC and hence, would result in a negative value of $\epsilon$.

On the demand side, we assume that for $j = 1, 2$, the market demand ($x_j$) is linear in price ($p_j$). We let $a_j$ and $b_j$ represent the maximum potential market for the RC and OC respectively. Similarly, $b_j$ represents the price elasticity of demand for channel $j$ whereby an increase by a dollar of the price in channel $j$ will lead to a decrease of $b_j$ in the demand. For the case where the retailer has the possibility of operating in both channels simultaneously, we also incorporate a symmetric cross-price based substitution effects parameter $s$. Consequently, if the price of the item sold in one channel increases by a unit, then some consumers may switch their channel choice. Specifically, the demand in the channel will increase by an amount of $s$ for a dollar increase in the price in the alternate channel. This cross-price substitution effect also captures the competitive intensity between the two channels for consumer demand. Note that Tsay and Agrawal (2000) choose similar demand forms for a situation where two independent retailers are selling the same product procured from a single manufacturer. When analyzing the channel choice decision under demand uncertainty, we also use a random term $c_j$ for each channel's demand function where $c_j$ is a continuous random variable with probability density function $f(\cdot)$ and distribution function $F(\cdot)$ defined in the interval $[-d, d]$.

We also define the following additional notation. Let $q_j(p_j)$ represent the quantity stocked by channel $j$ under demand certainty (uncertainty) when the retailer chooses either single channel strategy RC ($j = 1$) or OC ($j = 2$); $q_j(p_j')$ represent the quantity stocked by channel $j$ ($j = 1, 2$) under demand certainty (uncertainty) when the retailer chooses the DC strategy and hence, offers the product through both channels simultaneously; $p_j(p_j')$ represent the market price for channel $j$ under demand certainty (uncertainty) when the retailer chooses either single channel strategy RC ($j = 1$) or OC ($j = 2$); $p_j(p_j')$ represent the market price for channel $j$ under demand certainty (uncertainty) when the retailer chooses the Dual Channel (SC) strategy; and $\Pi_j(P_j')$ represent the firm profits for channel $j$ under demand certainty (uncertainty) for $j = 1, 2, 3$.

The primary focus of our analysis is on analyzing the channel selection decision for the retailer in the presence of the environmental related savings/costs on the supply side and consumer preferences on the demand side. We start by focusing on the case where the firm demand is deterministic and follow this up with analyzing the stochastic demand scenario.

### 3.2. Deterministic demand

Under this setting, the optimal stocking quantity for the retailer for each channel setting is analogous to the market demand satisfied. Hence, the demand functions for each strategy choice are:

- For strategy choice RC: $q_1(p_1) = a_1 - b_1p_1$;
- For strategy choice OC: $q_2(p_2) = a_2 - b_2p_2$; and
- For strategy choice DC: $q_{31}(p_{31}, p_{32}) = a_1 - b_1p_{31} + sp_{32}$ and $q_{32}(p_{31}, p_{32}) = a_2 - b_2p_{31} + sp_{32}$.

Under each strategy choice, the retailer solves the following profit maximization problems:

- For strategy choice RC
  \[ \text{Maximize}_{p_1 > 0} \Pi_1 = [p_1 - c_1]q_1(p_1) \] (1)
- For strategy choice OC
  \[ \text{Maximize}_{p_2 > 0} \Pi_2 = [p_2 - c_1 - \epsilon]q_2(p_2) \] (2)
- For strategy choice DC
  \[ \text{Maximize}_{p_{31}, p_{32} > 0} \Pi_3 = [p_{31} - c_1]q_{31}(p_{31}, p_{32}) + [p_{32} - c_1 - \beta]q_{32}(p_{31}, p_{32}) \] (3)

For each setting, it is easy to show that the profit functions are strictly concave in the decision variables.\(^1\) Based on this, the optimal prices, quantities and firm profits under each strategy choice are shown in Table 2 (with all proofs shown in Appendix A).

To further delineate the impact of demand on our optimal solution, we utilize a change of variables. Specifically, we replace the variables $a_1$ and $a_2$ which reflect the maximum market size for the RC and the OC with two alternate variables. We let $a$ represent the maximum total market size such that $\bar{a} = a_1 + a_2$. We also integrate a propensity of customers for the OC by a parameter $\lambda = \frac{a_2}{\bar{a}}$ which represents the proportion of the total number of customers who would prefer the online channel ($0 \leq \lambda \leq 1$). For the variable substitution, we let $a_2 = \alpha a$ represent the maximum demand for channel OC and $a_1 = \alpha(1-\lambda)$ represent the maximum demand for channel RC. Hence, a higher value of $\lambda$ is associated with a higher total potential market for the OC and vice versa.

In examining Table 2, it is quite obvious that the retailer's choice of channel strategies is parameter dependent. However, as

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\(^1\) In case of strategy DC, the profit function is strictly and jointly concave in the decision variables provided $b_1 > s$ and $b_2 > s$.

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### Table 2

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Prices</th>
<th>Quantity</th>
<th>Profits</th>
</tr>
</thead>
<tbody>
<tr>
<td>RC</td>
<td>$p_1 = \frac{a_1 + b_1 \epsilon}{b_1}$</td>
<td>$q_1 = \frac{a_1 - b_1}{b_1}$</td>
<td>$\Pi_1 = \frac{(a_1 - b_1)^2}{b_1^2}$</td>
</tr>
<tr>
<td>OC</td>
<td>$p_2 = \frac{a_2 + b_2 \epsilon}{b_2}$</td>
<td>$q_2 = \frac{a_2 - b_2}{b_2}$</td>
<td>$\Pi_2 = \frac{(a_2 - b_2)^2}{b_2^2}$</td>
</tr>
<tr>
<td>DC</td>
<td>$p_{31} = \frac{a_1 + b_1 \epsilon}{b_1}$</td>
<td>$q_{31} = \frac{a_1 - b_1}{b_1}$</td>
<td>$\Pi_{31} = \frac{(a_1 - b_1)^2}{b_1^2}$</td>
</tr>
<tr>
<td></td>
<td>$p_{32} = \frac{a_2 + b_2 \epsilon}{b_2}$</td>
<td>$q_{32} = \frac{a_2 - b_2}{b_2}$</td>
<td>$\Pi_{32} = \frac{(a_2 - b_2)^2}{b_2^2}$</td>
</tr>
</tbody>
</table>

In this table, $a_1 = (1 - \lambda)a$; $a_2 = \lambda a$; and $x = 4(b_1 b_2 - s^2)$.
stated in Theorem 1 below, these can be structurally characterized based on the \( \lambda \) parameter. First, we define the following additional notation:

- for the lowest value breakpoint: \( \lambda_1 = \frac{(s_1 b_1 + \beta_1)(s_2 b_2 + \beta_2)}{b_1 + b_2 + \beta_1 + \beta_2} \)
- for the highest value breakpoint: \( \lambda_2 = 1 - \frac{\beta_1}{b_2} \) and \( \lambda_2 = 1 - \frac{\beta_2}{b_1} \), and
- for the difference in the breakpoints: \( \Delta \lambda = 1 - \frac{(s_1 b_1 + \beta_1)(s_2 b_2 + \beta_2)}{b_1 + b_2 + \beta_1 + \beta_2} \)

**Theorem 1.** Assuming that all three strategies are feasible, the optimal strategy choice for the retailer is as follows:

1. If \( 0 < \lambda < \lambda_1 \), the retailer should choose strategy RC (i.e., only offer the product through the retail bricks and mortar channel);
2. If \( \lambda_1 < \lambda < \lambda_2 \), the retailer should choose strategy DC (i.e., offer the product through dual channels); and
3. If \( \lambda_2 \leq \lambda \leq 1 \), the retailer’s choice is the OC strategy (i.e., only offer the product through the online channel).

**Proof.** See Appendix B.

From Theorem 1, it is clear that \( \lambda \) (which reflects the channel choice propensity) is a key factors driving the retailer’s optimal channel strategy choice. Recall that \( \lambda \) can also be interpreted as a proxy for customer utility for goods sold through a particular channel, and is influenced by factors such as convenience, distance to the traditional store, the type of product (i.e. mainstream or niche), and customer service.

A second key result concerns the impact of the environmental costs/savings. As would be expected, as the value of the \( \epsilon \) increases the region of dominance of the RC strategy grows (i.e. \( \lambda_1 \) increases). Similarly, the region of dominance for the OC strategy shrinks (i.e. \( \lambda_2 \) increases), and the region of dominance for the differential for the two channels shrinks (i.e. \( \Delta \lambda \) decreases). In particular, if the unit cost for the traditional channel increases, or if the unit cost for the online channel decreases, then it’s less likely that the bricks-and-mortar channel strategy will be optimal. Suppose the cost of stocking online is lower due to risk pooling, then the retailer should use an online or dual channel strategy. To illustrate, consider online book stores such as Amazon which sell solely through an online channel and reap the benefits of lower costs due to inventory centralization (see Matthews et al., 2001). In contrast, in the grocery industry, the environmental costs for the online channel may come at a premium due to the investment in trucks refrigerator capabilities.

It seems clear that market related parameters also help to determine the firm’s optimal strategy. The impact of the customer’s price sensitivity on demand for the individual channels is significant in driving a single channel strategy. When the price elasticity of demand \( b_i \) for channel \( i \) decreases, then \( (1) \) a single channel solution for channel \( i \) is more likely to be optimal, \( (2) \) the optimal price decreases for the single channel, and \( (3) \) the optimal quantity increases for the single channel. Conversely, if there is an increase in the total market for the product as represented by the variable \( \alpha \) or if there is an increase in the demand substitution parameter \( \gamma \), then it’s more likely that a dual channel solution will be optimal. Indeed, the grocery/retail firm Tesco has introduced an online channel in addition to their traditional channel to reap the benefits from this unique channel with their slogan “You shop. We drop” (Anonymous, 2006).

### 3.3. Stochastic demand

Similar to the previous section on deterministic demand, we start this section by characterizing the retailer’s optimal decision for a single channel setting and follow with an analysis of the case where the retailer chooses to operate both channels simultaneously.

#### 3.3.1. Single channel setting

For each single channel setting, the process of obtaining an optimal solution to the retailer’s profit maximization problem is similar. Thus, in this section, we present the general procedure which applies to each channel setting (recall that the index \( i = 1 \) is used for the “bricks and mortar” channel while the index \( i = 2 \) is for the online channel). Considering either channel individually, it is assumed that the market demand is characterized by the following linear demand function:
where \( \varepsilon_i \) is a random variable with probability density function \( f(\cdot) \) and distribution function \( F(\cdot) \) and defined in the interval \([-d_I, d_I]\) such that \(-d_I > -a_I\) and \( \mu_I \) is the mean for \( \varepsilon_i \). In this setting, we allow for the possibility that the retailer could have leftover inventory (if \( q^U > x^U \)) and we assume that this is sold at a markdown price per unit unit.\(^2\) Hence, the retailer makes the market pricing and stocking quantity decision using a newsupplier framework. Based on this, to maximize expected end-of-season firm profits, the firm solves the following problem:

\[
\text{Maximize } E[I^U(z, p^U)] = \left\{ \int_{z_1}^{z_2} p^U_i(a_i - b_i p^U_j + \varepsilon_i) + h(z_i - \varepsilon_i) f(e_i) \, de_i \right\} \\
+ \left\{ \int_{z_1}^{z_2} p^U_i(a_i - b_i p^U_j + z_i) f(e_i) \, de_i \right\} \\
- \left( (c_i - h) z_i - (p_i^U - h) \int_{z_1}^{z_2} (e_i - z_i) f(e_i) \, de_i - \mu_i \right) \tag{6}
\]

where \( z_i = q_i^U - a_i - b_i p_i^U \) (similar transformations were proposed by Ernst (1970) and Thoson (1975)). The first-order conditions for this problem are:

\[
\frac{\partial E[I^U(z, p^U)]}{\partial z_i} = -c_i + h + (p_i^U - h) [1 - F(z_i)] \tag{7}
\]

\[
\frac{\partial E[I^U(z, p^U)]}{\partial p_i^U} = 2b_i \left[ a_i + b_i c_i - \frac{p_i^U - h}{2b_i} \right] - \int_{z_1}^{z_2} (e_i - z_i) f(e_i) \, de_i + \mu_i \tag{8}
\]

and the second-order conditions are:

\[
\frac{\partial^2 E[I^U(z, p^U)]}{\partial z_i^2} = -(p_i^U - h) f(z_i) \tag{9}
\]

\[
\frac{\partial^2 E[I^U(z, p^U)]}{\partial p_i^U \partial p_j^U} = 0 \tag{10}
\]

\[
\frac{\partial^2 E[I^U(z, p^U)]}{\partial z_i \partial p_j^U} = -2b_i \tag{11}
\]

For strict concavity of Eq. (6) to hold, it is necessary to assume that \( |b_{i2}| = 2b_i (p_{i0} - h f(z_i) - [1 - F(z_i)]) > 0 \). Other technical conditions for the uniqueness of the solution to the problem stated in Eq. (6) have been specified by Petruzzi and Dada (1999). Regardless of whether either of these conditions are met, it is relatively straightforward to note that for a given \( z_i \), Eq. (10) indicates that Eq. (6) is strictly concave in \( p_i^U \). Hence, for a given value of \( z_i \), the optimal \( p_i^U \) is obtained from the first order condition in Eq. (8) as:

\[
p_i^U(z_i) = \frac{a_i + b_i c_i - \int_{z_1}^{z_2} (e_i - z_i) f(e_i) \, de_i + \mu_i}{2b_i} \tag{12}
\]

Based on this, the following search algorithm can be used to identify the optimal market price, the optimal stocking quantity, and the corresponding optimal profit for the retailer.

1. Set \( z_i = -d_i - 0.01 \). Profit = 0; \( v = 0; \) \( P_{\text{temp}} = p_i^U = 0; \) and \( z_{\text{temp}} = 0 \).
2. \( z_i = z_i + 0.01 \). If \( z_i > d_i \), goto 5.
3. Compute \( p_i^U(z_i) \) using Eq. (12). Set \( P_{\text{temp}} = p_i^U(z_i) \).
4. Compute \( E[I^U(z_i, P_{\text{temp}})] \) using Eq. (6). If Profit > \( E[I^U(z_i, P_{\text{temp}})] \), goto 2, else set Profit = \( E[I^U(z_i, P_{\text{temp}})] \), \( z_i \), \( v \), \( P_{\text{temp}} \) and goto 2.
5. The optimal market price is \( v \), the optimal stocking quantity is \( q_i^U = a_i - b_i v + z_{\text{temp}} \), and associated optimal profit is Profit.

We now turn our attention to determining the optimal solution to the retailer’s profit maximization problem in a multiple channel setting.

3.3.2. Both channels

In this setting, the market demand functions for each channel are assumed to be characterized by the following linear demand functions:

\[
x_{31}^U = a_1 - b_1 p_{31}^U + s p_{31}^U + \varepsilon_1 \tag{13}
\]

\[
x_{32}^U = a_2 - b_2 p_{32}^U + s p_{32}^U + \varepsilon_2 \tag{14}
\]

where as defined earlier \( \varepsilon_1 \) and \( \varepsilon_2 \) are random variables defined in the interval \([-d_1, d_1]\) and \([-d_2, d_2]\) with means \( \mu_1 \) and \( \mu_2 \), respectively. In order to maximize end-of-season profits, the retailer solves the following problem:

Maximize

\[
E[I^U(z, p^U)] = \left\{ \int_{z_1}^{z_2} p^U_i(a_i - b_i p^U_j + s p^U_i + \varepsilon_i) + h(z_i - \varepsilon_i) f(e_i) \, de_i \right\} \\
+ \left\{ \int_{z_1}^{z_2} p^U_i(a_i - b_i p^U_j + s p^U_i + z_i) f(e_i) \, de_i \right\} \\
- \left( (c_i - h) z_i - (p_i^U - h) \int_{z_1}^{z_2} (e_i - z_i) f(e_i) \, de_i - \mu_i \right) \tag{15}
\]

where \( z_i = q_i^U - a_i - b_i p_i^U \) (similar transformations were proposed by Ernst (1970) and Thoson (1975)). The first-order conditions for this problem are:

\[
\frac{\partial E[I^U(z, p^U)]}{\partial z_i} = -c_i + h + (p_i^U - h) [1 - F(z_i)] \tag{16}
\]

\[
\frac{\partial E[I^U(z, p^U)]}{\partial p_i^U} = 2b_i \left[ a_i + b_i c_i - \frac{p_i^U - h}{2b_i} \right] - \int_{z_1}^{z_2} (e_i - z_i) f(e_i) \, de_i + \mu_i \tag{17}
\]

\[
\frac{\partial E[I^U(z, p^U)]}{\partial p_{i3}^U} = 2b_i \left[ a_i + b_i c_i - \frac{p_{i3}^U - h}{2b_i} \right] - \int_{z_1}^{z_2} (e_i - z_i) f(e_i) \, de_i + 2s p_{i3}^U - s c_i + \mu_i \tag{18}
\]

and the second-order conditions are:

\[
\frac{\partial^2 E[I^U]}{\partial z_i^2} = -(p_i^U - h) f(z_i) \tag{20}
\]

\[
\frac{\partial^2 E[I^U]}{\partial p_i^U^2} = -2b_i \tag{21}
\]

\[
\frac{\partial^2 E[I^U]}{\partial z_i \partial p_{i3}^U} = 1 - F(z_i) \tag{22}
\]

\[
\frac{\partial^2 E[I^U]}{\partial p_i^U \partial p_{i3}^U} = 0 \tag{23}
\]

\[
\frac{\partial^2 E[I^U]}{\partial z_i \partial p_{i3}^U} = 1 - F(z_2) \tag{24}
\]

\[
\frac{\partial^2 E[I^U]}{\partial p_i^U \partial p_{i3}^U} = 0 \tag{25}
\]

\[
\frac{\partial^2 E[I^U]}{\partial p_{i3}^U^2} = 2s \tag{26}
\]

As in the single channel setting, we can see that for specific values of \( z_1 \) and \( z_2 \), Eq. (19) is strictly and jointly concave in \( p_i^U \) and \( p_{i3}^U \). Thus, for given values of \( z_1 \) and \( z_2 \), the optimal prices can be

\(^2\) Similar to Petruzzi and Dada, 1999, we do not consider a “lost-sales” cost in our analysis and also assume that the markdown price is not channel specific.

\(^3\) This is a result of the fact that Eqs. (21) and (26) indicate that \( |b_{i2}| < 0 \) and \( |b_{i2}| - 4b_i b_{i3} - s^2 > 0 \) since it was assumed that \( b_i > s \) for \( i = 1, 2 \).
determined by solving the following simultaneous equations (obtained by setting the first order conditions in Eqs. (18) and (19) equal to 0):

$$2b_1p_{11}^{\mu} - 2sp_{32}^{\mu} = \int_{z_1}^{d_1} (\epsilon - z_1)f(\epsilon) d\epsilon + sc_2 - (a_1 + b_1c_1)$$

(27)

$$- 2sp_{31}^{\mu} + 2b_2p_{32}^{\mu} = \int_{z_2}^{d_2} (\epsilon - z_2)f(\epsilon) d\epsilon + sc_1 - (a_2 + b_2c_2)$$

(28)

The solution to this set of equations is:

$$p_{11}^{\mu}(z_1, z_2) = \frac{b_2u_1 + su_2}{2(b_1b_2 - s^2)}$$

(29)

$$p_{32}^{\mu}(z_1, z_2) = \frac{b_1u_2 + su_1}{2(b_1b_2 - s^2)}$$

(30)

where

$$u_1 = -(a_1 + b_1c_1) + \int_{z_1}^{d_1} (\epsilon - z_1)f(\epsilon) d\epsilon + sc_3 + \mu_1$$

and

$$u_2 = -(a_2 + b_2c_2) + \int_{z_2}^{d_2} (\epsilon - z_2)f(\epsilon) d\epsilon + sc_1 + \mu_2.$$ Based on this, the following search algorithm can be used to identify the optimal market prices, the optimal stocking quantities, and the corresponding optimal profit for the retailer.

1. Set

$$z_1 = -d_1 - 0.01; z_2 = -d_2 - 0.01; Profit = 0; \; v_1 = v_2 = 0;$$

$$p_{11} = p_{32} = 0; p_{22} = p_{12} = 0$$ and $z_{11} = z_{22} = 0$.

2. $z_1 = z_1 + 0.01$. If $z_1 > d_1$, goto 6.

3. $z_2 = z_2 + 0.01$. If $z_2 > d_2$, goto 2.

4. Compute $p_{11}^{\mu}(z_1, z_2)$ using Eq. (29) and $p_{32}^{\mu}(z_1, z_2)$ using Eq. (30).

5. Compute

$$E[Profit(z_1, z_2, P_{11}, P_{22})]$$

using Eq. (15). If

$$Profit > E[Profit(z_1, z_2, P_{11}, P_{22})],$$

go to 3, else set

$$Profit = E[Profit(z_1, z_2, P_{11}, P_{22})]; z_{11} = z_1; z_{22} = z_2; v_1 = P_{11}; v_2 = P_{22}$$ and goto 3.

6. The optimal market prices are: $v_1$ and $v_2$; the optimal stocking quantities are:

$$q_{11}^{\mu} = a_1 - b_1v_1 + sv_2 + z_{11},$$

and

$$q_{22}^{\mu} = a_2 - b_2v_2 + sv_1 + z_{22}$$

and associated optimal profit is $Profit$.

3.3.3. Sensitivity analysis for the stochastic model

While we do not have explicit expressions for the optimal values for the stochastic models, the separable nature of the price functions as shown Eqs. (29) and (30) facilitates sensitivity analysis on key parameters.

**Corollary 1.** Assuming a dual channel (DC) strategy is optimal, then the optimal price for RC ($p_{11}^{\mu}$) will increase in response to the following:

1. An increase in the maximum market size $a$.
2. A decrease in the propensity of customers for the OC channel $\lambda$.
3. A decrease in the price sensitivity to demand for the RC channel $b_1$.
4. A decrease in the price sensitivity to demand for the OC channel $b_2$.
5. An increase in the symmetric price based substitution effects parameter $s$.
6. An increase in the unit cost premium for the OC channel $\beta$.
7. An increase in the environmental cost premium for the OC channel $e$.

**Proof.** See Appendix D.

**Corollary 2.** Assuming a dual channel (DC) strategy is optimal, then the optimal price for OC ($p_{32}^{\mu}$) will increase in response to the following:

1. An increase in the maximum market size $a$.
2. An increase in the propensity of customers for the OC channel $\lambda$.
3. A decrease in the price sensitivity to demand for the RC channel $b_1$.
4. A decrease in the price sensitivity to demand for the OC channel $b_2$.

**Proof.** See Appendix C. □

**4. Numerical analysis**

In this section, we outline the results of numerical examples intended to complement the analysis for the stochastic demand case shown in the previous section. Because we cannot derive explicit solutions for the optimal values of the quantity and price variables for the stochastic dual channel model, we turn to numerical examples to illustrate the impact of key factors on these variables and the overall firm profit. The numerical examples were written in the JAVA programming language, and utilize the search algorithms outlined in the previous section.

The specific parameter values used in the numerical base case example are as follows: (a) the unit cost for the RC ($c_1$) is set to $20$. In order to focus on the impact of environmental costs/savings for the OC, we set the value of $\beta = 0$. Hence, the unit cost for the online channel is $e = 10 + e$; and (b) the maximum market size $(a)$ is set equal to 2500. Both channels are assumed to have an equal price elasticity (i.e., $b_1 = b_2$) and this value is set equal to 30. The symmetric price substitution parameter $(s)$ which applies only to channel structure DC is set at 10. The minimum and maximum values of $\lambda_i$ are equal across both channel structures and is assumed to be uniformly distributed. Finally, we vary the value of $\lambda$ between $[0, 1]$ by increments of .01 and calculate the optimal prices, quantities and profits for both single channel and the dual channel solutions and this is used to identify the range of values over which single and/or dual channel solutions are optimal.

Consider a base case example where $h = \$10, d = 10, and e = 0$. For values of $\lambda \leq .23$, the retailer optimally sells only via the traditional channel and makes a fairly low profit. For values of $\lambda$ between .24 and .75, the retailer optimally sells via both channels and reaps the benefits of higher profit. For values of $\lambda > .76$, the retailer optimally sells via the online channel only and earns a fairly low profit. A graph of the profit for this case as a function of $\lambda$ is shown in Fig. 1 – Panel A. Note that the profit values are symmetric around the value $\lambda = .5$, because the base case demand and cost parameters are similar for both channels. When $\lambda$ is extremely high or low and a single channel solution is optimal, then the dual channel solution is infeasible and the total profit in these tails is fairly low. When a dual channel solution is feasible and optimal (i.e. in the center of the graph), the profit is much higher due to the synergy between the two channels in terms of the demand substitution parameter. Therefore, the retailer should plan for single channel distribution if environmental and/or consumer related factors drive the demand to be extremely high for one of the single channels.
In addition to the base case scenario, we also investigated the impact of the salvage value \((h)\) and demand variability \((d_1, d_2)\) on the optimal channel choice. Table 3 summarizes the results of these examples for salvage values \((h)\) of 10 and 20, and also for demand variability (i.e. \(d_1\) and \(d_2\)) values of 10, 375, 675 and 1250. These levels of demand variability correspond to 4%, 15%, 25% and 50% of the total demand \((a = 2500)\) for the product among both channels. We also set the demand variability for both channels to be equivalent for each example (i.e. \(d_1 = d_2\)). Finally, note that the previously discussed base case scenario is shown in the upper left hand corner of Table 3 with values of \(h = 10\) and \(d = 10\).

The results shown in Table 3 illustrate that increasing levels of demand uncertainty for both channels decreases the range under which a dual channel solution is optimal. For example, focusing on the top row of the results where \(h = 10\) and comparing the values where \(d = 10\) and \(d = 375\), we see that the range of customer preference \((\lambda)\) where the dual channel strategy is optimal shrinks from between \([0.24, 0.75]\) to between \([0.32, 0.68]\). For these situations, increasing demand uncertainty increases the risk of stocking both channels.

### Table 3: Numerical results for sensitivity to salvage value and demand uncertainty.

<table>
<thead>
<tr>
<th>(d = 10)</th>
<th>(d = 375)</th>
<th>(d = 675)</th>
<th>(d = 1250)</th>
<th>Strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>(h = 10)</td>
<td>(0 \leq \lambda \leq 24)</td>
<td>(0 \leq \lambda \leq 31)</td>
<td>(0 \leq \lambda \leq 41)</td>
<td>(0 \leq \lambda \leq 18)</td>
</tr>
<tr>
<td>25 \leq \lambda \leq 75</td>
<td>32 \leq \lambda \leq 68</td>
<td>42 \leq \lambda \leq 58</td>
<td>None</td>
<td>DC</td>
</tr>
<tr>
<td>76 \leq \lambda \leq 1</td>
<td>69 \leq \lambda \leq 1</td>
<td>59 \leq \lambda \leq 1</td>
<td>82 \leq \lambda \leq 1</td>
<td>OC</td>
</tr>
<tr>
<td>(h = 20)</td>
<td>(0 \leq \lambda \leq 23)</td>
<td>(0 \leq \lambda \leq 26)</td>
<td>(0 \leq \lambda \leq 33)</td>
<td>(0 \leq \lambda \leq 24)</td>
</tr>
<tr>
<td>24 \leq \lambda \leq 76</td>
<td>27 \leq \lambda \leq 73</td>
<td>34 \leq \lambda \leq 66</td>
<td>None</td>
<td>DC</td>
</tr>
<tr>
<td>77 \leq \lambda \leq 1</td>
<td>74 \leq \lambda \leq 1</td>
<td>67 \leq \lambda \leq 1</td>
<td>76 \leq \lambda \leq 1</td>
<td>OC</td>
</tr>
</tbody>
</table>

The results shown in Fig. 1 illustrate the impact of environmental costs/savings on channel choice. For example, focusing on the left most column of Table 3, we find that for values of \(d = 1250\), the region where a dual channel solution is optimal (and feasible) disappears. Instead, it is optimal for the retailer to operate with a single channel only if demand for that channel is extremely high. When the customer preference is somewhat indifferent between the two channels (i.e. \(\lambda\) is between \(0.19\) and \(0.81\)), then it is actually optimal for the retailer to stay out of the market in this situation. We denote this situation as “No Channel” or NC. Apparently, the demand uncertainty is too high such that stocking for these intermediate scenarios is excessively costly. Additional numerical experiments show that when \(d\) is greater than approximately 685, then the dual channel optimal solution disappears.

Next, we focus on the impact of the salvage value \(h\) on the optimal channel strategy. When a dual channel strategy is optimal, increasing the salvage value also increases the range of optimality for a dual channel strategy. To illustrate, focusing on the left most column of Table 3, we see that the range of customer preference \((\lambda)\) where the dual channel strategy is optimal grows from between \([0.24, 0.75]\) for a salvage value of \(h = 10\) to \([0.23, 0.77]\) for a salvage value of \(h = 20\). Recall that a higher salvage value corresponds to an increased value for the leftover inventory. Therefore, the retailer can absorb more risk in stocking two individual channels when the salvage value is higher. To illustrate, consider the book industry. While stocking is risky at the traditional retailer, the salvage value for books is relatively high due to well developed secondary wholesale markets for remainder books. In contrast, in the grocery industry, salvage values are very low due to the perishability of the fresh products. Consequently, the range for which a dual channel solution exists may be smaller.

However, when the demand uncertainty is extremely high, a dual channel solution is no longer optimal. Focusing on the right most column of Table 3, we find that for values of \(d = 1250\), the region where a dual channel solution is optimal (and feasible) disappears. Instead, it is optimal for the retailer to operate with a single channel only if demand for that channel is extremely high. When the customer preference is somewhat indifferent between the two channels (i.e. \(\lambda\) is between \(0.19\) and \(0.81\)), then it is actually optimal for the retailer to stay out of the market in this situation. We denote this situation as “No Channel” or NC. Apparently, the demand uncertainty is too high such that stocking for these intermediate scenarios is excessively costly. Additional numerical experiments show that when \(d\) is greater than approximately 685, then the dual channel optimal solution disappears.

We also investigate the impact of the environmental cost differential effects on the optimal strategy for the retailer. For these examples, we set the salvage value \(h = 10\) and the demand uncertainty \(d = 375\). The results for these examples (summarized in Table 4) show that when the online channel is less costly and/or the environmental impact is lower, then the optimal range for the dual channel strategy (DC) and the online channel strategy (OC) are more viable. Similarly, Panels B and C in Fig. 1 also illustrate the impact of environmental costs/savings on channel choice. For example, in Panel B of Fig. 1, we see that when \(e = 10\) (i.e., the OC provides environmental savings as compared to the RC), the break point \(\lambda_1\) decreases and the difference \(\Delta\lambda\) increases. In Panel C of Fig. 1, we see that when \(e = 10\) (i.e., the OC is more costly than the RC due to environmental effects), the break point \(\lambda_2\) increases and the difference \(\Delta\lambda\) decreases. To summarize, if one channel has higher costs, then the optimal range for that channel shrinks.
In the previous sections, we have investigated a retailer's channel strategy decision as driven by factors including customer preferences, demand uncertainty, and cost differentials. In this section, we investigate the impact of several policy issues on this important decision. First, firms should consider the rising costs associated with carbon emissions in the delivery of their goods. To illustrate, many countries have levied energy related taxes based on the carbon content of the goods. In July 2011, Australia implemented a carbon tax whereby firms are charged 23 Australian dollars per ton, and this tax will eventually be replaced with a carbon trading scheme (Curran (2011)). While many countries currently have not undertaken such taxation measures, many companies are voluntarily purchasing carbon credits to justify the emissions of carbon dioxide in their company.

The numerical examples shown in Section 4 also highlight the logistics/delivery arrangements for the retailer. Consider the book industry where more carbon taxes are incurred for delivering the goods to the store. Consequently, the prices will increase for the book via the traditional channel. Suppose also that the delivery of the goods for the retailer's online sales channel is outsourced to a third party logistics provider, and that the customer pays an additional charge for the delivery. In this scenario, the third party logistics provider will incur a large portion of the carbon tax, presumably which will be passed on to the customer. The retailer will likely favor the internet channel in this situation, as it is penalized proportionately more for its traditional channel. Consider also the company Amazon, which is an OC retailer that sales books via an online channel only. Amazon has invested heavily in logistics assets such as warehouses and utilizes a practice of postal injection to deliver products to the mail carrier associated with the customer's city of origin (Hammond, 2005). Amazon charges the customer an additional fee for the transportation portion of the item. Presumably, these fees will increase if a carbon tax is implemented. As previously mentioned, Amazon has recently received a patent on “environmentally conscious electronic transactions”, which will allow them to distinguish different delivery options based on the carbon usage. If such a carbon tax occurs, then customers will be able to choose whether they want a high carbon delivery option with additional taxes (such as air delivery) or a low carbon option without additional taxes. However, further research is necessary to verify the specific impact of the carbon tax on the different parties (i.e. retailer, 3PL, and consumer) in this situation.

5. Policy issues

In this section, we investigate the impact of several policy issues on this important decision. First, firms should consider the rising costs associated with carbon emissions in the delivery of their goods. While many countries currently have not undertaken such taxation measures, many companies are voluntarily purchasing carbon credits to justify the emissions of carbon dioxide in their company. One such company is Dell, which purchases renewable energy certificates which reflect investments in wind power energy projects to offset the carbon emissions from its facilities (Ball, 2008).

In terms of our model, the net effect of these schemes is to amplify the cost differential associated with environmental factors as captured in the variable $e$. Recent studies have shown that the total energy usage for a traditional retailer is higher than that typically associated with e-commerce delivery in the delivery of certain electronic goods (Weber et al., 2008). For such industries, $e < 0$ and the impact of a carbon tax or voluntary carbon credit program is to amplify the magnitude of the value of $e$, such that the differential between the costs for the two channel choices is even greater. From Table 2, a retailer using an OC only strategy should price the goods lower and to increase the total quantity sold via the more environmentally efficient online sales channel. For a DC company in an industry where $e < 0$, the retailer should lower the price for the online channel, raise the quantity of goods sold via the online channel, and lower the quantity of goods sold via the traditional channel. Note also that the region of optimality for the DC and OC grow, whereas the region of optimality for the RC shrinks in this situation. Conversely, for an industry where $e > 0$ (such as groceries), the following occurs when the environmental differential increases: (1) the RC and DC regions grow, (2) the OC region shrinks, (3) the price of the online channel for a DC increases, (4) the quantity of goods sold via the online channel for a DC decreases, and (5) the quantity of goods sold via the traditional channel for a DC increases. A key issue associated with carbon tax schemes is how to apply it to different industry sectors. From our analysis, the outcome of such a tax can yield quite different results depending on the industry under consideration.

With regards to the carbon tax, another complicating factor concerns the logistics/delivery arrangements for the retailer. Consider the book industry where $e < 0$, and customers typically pay an additional charge for the delivery of their goods. Suppose the retailer is currently utilizing a dual strategy arrangement. Then the retailer will pay proportionately more for the traditional retail center where more carbon taxes are incurred for delivering the goods to the store. Consequently, the prices will increase for the book via the traditional channel. Suppose also that the delivery of the goods for the retailer's online sales channel is outsourced to a third party logistics provider, and that the customer pays an additional charge for the delivery. In this scenario, the third party logistics provider will incur a large portion of the carbon tax, presumably which will be passed on to the customer. The retailer will likely favor the internet channel in this situation, as it is penalized proportionately more for its traditional channel. Consider also the company Amazon, which is an OC retailer that sales books via an online channel only. Amazon has invested heavily in logistics assets such as warehouses and utilizes a practice of postal injection to deliver products to the mail carrier associated with the customer's city of origin (Hammond, 2005). Amazon charges the customer an additional fee for the transportation portion of the item. Presumably, these fees will increase if a carbon tax is implemented. As previously mentioned, Amazon has recently received a patent on “environmentally conscious electronic transactions”, which will allow them to distinguish different delivery options based on the carbon usage. If such a carbon tax occurs, then customers will be able to choose whether they want a high carbon delivery option with additional taxes (such as air delivery) or a low carbon option without additional taxes. However, further research is necessary to verify the specific impact of the carbon tax on the different parties (i.e. retailer, 3PL, and consumer) in this situation.

6. Conclusions

In this paper, we analyze a dual channel model for a retailer who has access to both online and traditional market outlets to answer several key research questions regarding the environmental impact of the dual channel strategy for retail. The first question we address is, “If a retailer has both traditional and online sales channels, how should he/she manage the split between these?” In particular, we analyze three potential strategies for the retailer: the traditional retail channel only (RC), the online channel only (OC), and the dual channel which combines both (DC). Utilizing the results from Theorem 1 concerning the optimal channel choice for the case with deterministic demand, we find that all three of these strategies can be optimal depending on the customer's propensity ($\lambda$) to buy from the online channel. This propensity is driven partially by customer awareness concerning the environmental impact of their product choice. When the customer's propensity is extremely low, then the retailer should focus on their traditional retail channel (RC). When the customer's propensity is extremely high, then the retailer should focus on their online retail channel (OC). When the customer's propensity is of medium strength, then the retailer should focus on the dual channel strategy (DC) and can reap the benefits of higher profits due to synergy between the two channels. Furthermore, the break points which determine the optimal strategy choice are driven by the following factors: the unit costs for each channel, the environmental cost savings/premium for the online channel, the price elasticity of demand for each channel, the maximum market size, and the price substitution effects.

The second question we address is, “Are there circumstances under which a retailer should focus only on online and/or traditional channels?” As mentioned in the previous paragraph, analysis in Theorem 1 from the deterministic model shows that the customer's propensity to buy from the online channel ($\lambda$) is a crucial factor in this decision. In particular, if this parameter is extremely high or extremely low, then a single channel strategy is optimal. The numerical examples shown in Section 4 also highlight the impact of stochastic elements on this important decision. In particular, we find that a single channel strategy is more likely to be optimal when the salvage value ($h$) of the item sold is relatively low. In this situation, there is an increased risk associated with leftover items and consequently the region of optimality associated with the single channel strategy is slightly greater. Interestingly, we also show via the numerical results that when demand uncertainty is extremely high, then the region where a dual channel solution is
optimal actually disappears. Under extreme demand uncertainty, the retailer should focus on a single channel strategy or stay out of the market altogether.

The third question we address is, "How will consumer behavior evolve in response to these environmental channel concerns?" In our model, we capture consumer behavior chiefly through the variable \( \lambda \), which represents the customer's propensity to buy from the online channel. As listed in Sections 1 and 2 of our paper, evidence exists which links the consumer's channel choice with environmental concerns. As firms start to promote the environmental impact of this alternative and as consumers become increasingly aware of the implications of this choice, then it's likely that the consumer propensity will increase over time. Consequently, some retailers which had previously focused only on a traditional retail outlet (RC) will need to plan for a dual channel (DC) strategy. There are some notable exceptions, however, based on factors such as the population of the particular region where the traditional retailer is located and also the service levels associated with the potential online retailer (OC) channel. For example, Matthews, Williams, Tagami, and Hendrickson (2002) show that in Japan, a traditional book retailer can be more energy efficient due to the highly concentrated population.

The next question posed earlier was, "Which factors associated with e-commerce have the most significant impact on the environment?" From the deterministic analysis, two main factors relevant to our model influence the environmental impact of e-commerce, including the customer propensity to buy online (\( \lambda \)) and the cost differential associated with each channel (\( \epsilon \)). From the numerical section, the analysis of the cost differential (\( \epsilon \)) shows that environmental cost differences can significantly shift the ranges of optimality such that the dual channel (DC) option is more prevalent. In addition, if the online channel has a smaller environmental impact such that (\( \epsilon < 0 \)), then the retailer should prepare for a dual channel (DC) or strictly online sales (OC) in the future. From the Numerical analysis in Section 4, we also show that the salvage value and demand uncertainty are significant determinants of the firm's strategy.

Industry specific characteristics are also important when answering the question concerning which factors have the most significant impact on the environment. Three e-commerce industries which have been studied in the past include groceries, electronics, and books. For the grocery industry, the environmental cost differential between the two channels could actually be positive (\( \epsilon > 0 \)) due to the refrigeration capabilities necessary for delivery. Also, the high perishability of these items is such that the salvage value (\( h \)) is fairly low. For the electronics industry, consider the study by Weber et al. (2008) which shows that the environmental impact of e-commerce is lower such that \( e < 0 \). Obsolescence rates are also high in this industry due to the decrease in the price of these items and the shorter product life cycles (i.e. low \( h \)). For the book industry, the existence of secondary markets is such that the salvage value is fairly high (\( h \)). In addition, the costs of dealing with returns or remainders may actually drive the environmental differential costs (\( \epsilon \)) to favor the online channel. However, further empirical analysis is needed in each of these industries to verify the relative magnitude of these environmental factors on the channel choice.

The last question posed in the introduction is, "How will policy issues such as a carbon tax impact the retailer's decision?" From the previous section, carbon taxes and voluntary carbon credit schemes will have the effect of amplifying the environmental differences between the two different retail channels. The industry specific characteristic relevant in this context is the environmental cost differential, as reflected via the variable \( \epsilon \). Therefore, policy makers need consider the disparate impact on different industries for carbon tax schemes.

Future topics of inquiry on e-commerce and the associated environmental impact are numerous. Our model focuses on a specific firm level decision, in particular trading off the environmental impact of online vs. traditional retail sales. While the focus of this model is on single firm decision making, there is an opportunity to consider social policy issues in the future. For example, a holistic objective which incorporates both consumer utility and firm profit could yield insights concerning the implications of these firm decisions on broader societal goals. To illustrate, both Fichter (2002) and Sui and Rejeski (2002) discuss the possibility that sales via the internet may lead to excessive consumer consumption, thereby negating some of the environmental improvements offered by this channel. Second, the model here takes into account customers who will potentially buy a single product either via a specific retailer's traditional channel or that same retailer's online channel. While our results still hold when the customer is buying multiple products from distinct groups, it would be interesting to analyze the impact of a budget constraint or product complimentarities on this decision. Also, the topic of showrooming has the potential to show additional synergies between the two channels. Finally, a model which explicitly addresses the impact of competition on this decision also has the potential to make an important contribution to this field. For example, how does the relative size and bargaining power of the competitive retailers influence channel distribution decisions?

### Appendix A. Optimal pricing for the dual channel (DC) strategy

**Claim 1.** For the following profit maximization problem:

\[
\text{Maximize}_{p_{31}, p_{32}, q_{31}, q_{32}} \Pi = (p_{31} - c_1)q_{31} + (p_{32} - c_2)q_{32}
\]

where \( q_{31} = (1 - \lambda)a - b_1p_{31} + sp_{32} \) and \( q_{32} = \lambda a - b_2p_{32} + sp_{31} \), the optimal prices are:

\[
p_{31}^* = \frac{b_1(1 + c_1) + s(a_2 - sc_1)}{2(b_1b_2 - s^2)}
\]

\[
p_{32}^* = \frac{b_1(1 + c_2) + s(a_1 - sc_2)}{2(b_1b_2 - s^2)}
\]

where \( a_1 = (1 - \lambda)a; \ a_2 = \lambda a; \ \text{and} \ c_2 = c_1 + e + \beta \).

**Proof.** The first-order conditions (FOCs) for the problem stated in Eq. (31) are:

\[
\frac{\partial \Pi}{\partial p_{31}} = a_1 - b_1p_{31} + sp_{32} - b_1(p_{31} - c_1) + s(p_{32} - c_2)
\]

\[
\frac{\partial \Pi}{\partial p_{32}} = a_2 - b_2p_{32} + sp_{31} - b_1(p_{32} - c_2) + s(p_{31} - c_1)
\]

and the second-order conditions are:

\[
\frac{\partial^2 \Pi}{\partial p_{31}^2} = -2b_1
\]

\[
\frac{\partial^2 \Pi}{\partial p_{32}^2} = -2b_2
\]

\[
\frac{\partial^2 \Pi}{\partial p_{31} \partial p_{32}} = 2s
\]

These second-order conditions indicate that \( \Pi \) is strictly and jointly concave in \( p_{31} \) and \( p_{32} \). Hence, we can set the FOC's in Eqs. (34) and (35) equal to 0 and determine the optimal prices by solving the following two simultaneous equations:

\[\text{This is based on observing that } |H_1| < 0 \text{ and } |H_2| - 4(b_1b_2 - s^2) > 0 \text{ since it is assumed that } b_1 > s \text{ and } b_2 > s.\]
Appendix B. Proof of Theorem 1

Theorem 1. Assuming that all three strategies are feasible, the optimal strategy choice for the firm is as follows:

1. If $0 \leq \lambda < \frac{(c_1b_1 - s)c_2}{2(b_1 + s) - c_1}$, the firm should choose Strategy RC (i.e., only offer the product through the retail bricks and mortar channel);
2. If $\frac{(c_1b_1 - s)c_2}{2(b_1 + s) - c_1} \leq \lambda < 1 - \frac{(c_1b_1 - s)c_2}{2(b_2 - s) + s(e + \beta)}$, the firm should choose Strategy DC (i.e., offer the product through dual channels); and
3. If $1 - \frac{(c_1b_1 - s)c_2}{2(b_2 - s) + s(e + \beta)} \leq \lambda \leq 1$, the firm’s choice is the OC strategy (i.e., only offer the product through the online channel).

Proof. Our proof is based on the assumption that the firm will always choose to adopt at least one of the three strategies: RC, DC, or OC. To start with, we make the following observations:

- Observation 1: If both $p_{31}$ and $p_{11}$ as defined in Table 2 are positive then $p_{31} - p_{11} = \frac{a_1 + c_1b_1 + s(a_2 - sc_1)}{2(b_1 + s) - c_1} > 0$.
- Observation 2: If both $p_{32}$ and $p_{12}$ as defined in Table 2 are positive then $p_{32} - p_{12} = \frac{a_2 + b_2c_2 - sc_1}{2(b_2 - s) - c_1} > 0$.
- Observation 3: If both $q_{31}$ and $q_{11}$ as defined in Table 2 are positive then $q_{31} - q_{11} = \frac{a_1 + c_1b_1}{2(b_1 + s)} > 0$.
- Observation 4: If both $q_{32}$ and $q_{12}$ as defined in Table 2 are positive then $q_{32} - q_{12} = \frac{a_2 + b_2c_2}{2(b_2 - s)} > 0$.
- Observation 5: Strategy RC is feasible if $0 \leq \lambda < 1 - \frac{\Theta}{\alpha}$ since this implies that $q_{31}$ is non-negative.
- Observation 6: Strategy DC is feasible if $\frac{(c_1b_1 - s)c_2}{2(b_1 + s) - c_1} \leq \lambda \leq 1 - \frac{\Theta}{\alpha}$ since this implies both $q_{31}$ and $q_{32}$ are non-negative.
- Observation 7: Strategy OC is feasible if $\frac{(c_1b_1 - s)c_2}{2(b_2 - s) + s(e + \beta)} \leq \lambda \leq 1$ since this implies that $q_{32}$ is non-negative.

Case 1: $0 \leq \lambda < \frac{(c_1b_1 - s)c_2}{2(b_1 + s) - c_1}$.
We start by assuming that this is a feasible range (i.e., $\frac{(c_1b_1 - s)c_2}{2(b_1 + s) - c_1} > 0$). Then, we observe that in this range: (a) strategy DC is infeasible (Observation 6); and (b) strategy RC is feasible (Observation 7). For the OC strategy to be feasible in this range, we need to show that $\frac{(c_1b_1 - s)c_2}{2(b_1 + s) - c_1} \leq \lambda \leq 1 - \frac{\Theta}{\alpha}$. This is true provided $a \geq (b_1 + b_2 - s)c_1 + (b_2 - s)(e + \beta)$ which obviously holds since $a \geq (b_1 + b_2)c_1 + b_2(e + \beta)$. Hence, in this range the OC is the optimal strategy.

Case 3: $1 - \frac{\Theta}{\alpha} \leq \lambda < \lambda \leq 1$.
We start by assuming that this is a feasible range (i.e., $1 - \frac{\Theta}{\alpha} < \lambda < 1$). Then, we observe that in this range: (a) strategy DC is feasible (Observation 6); and (b) strategy RC is infeasible (Observation 5). For the OC strategy to be feasible in this range, we need to show that $\frac{(c_1b_1 - s)c_2}{2(b_1 + s) - c_1} \leq \lambda \leq 1 - \frac{\Theta}{\alpha}$. This is true provided $a \geq (b_1 + b_2 - s)c_1 + (b_2 - s)(e + \beta)$ which obviously holds since $a \geq (b_1 + b_2)c_1 + b_2(e + \beta)$. Hence, in this range the OC is the optimal strategy.

This concludes our proof of Theorem 1.

Appendix C. Multi-product group model

Under this setting, the optimal stocking quantity for the firm for each channel setting is analogous to the market demand satisfied. Hence, the demand functions for each strategy choice (where the subscript $k$ is product group specific) are:

- For channel strategy RC: $q_1^k(p_1^k) = a_1^k - b_1^k p_1^k$;
- For channel strategy OC: $q_1^k(p_2^k) = a_2^k - b_2^k p_2^k$; and
- For channel strategy DC: $q_1^k(p_3^k, p_{32}^k) = a_1^k - b_1^k p_3^k + s^1 p_{32}^k$ and $q_1^k(p_3^k, p_{32}^k) = a_2^k - b_2^k p_{32}^k + s^2 p_{32}^k$.

Under each strategy choice, the firm solves the following profit maximization problems:

- For strategy choice RC
  \[
  \text{Maximize}_{p_1^k > 0} \Pi_1 = \sum_{k=1}^{2} p_1^k(p_1^k) - c_1^k |q_1^k(p_1^k)|
  \]
- For strategy choice OC
  \[
  \text{Maximize}_{p_2^k > 0} \Pi_2 = \sum_{k=1}^{2} p_2^k(p_2^k) - c_1^k - e^k - \beta^k |q_2^k(p_2^k)|
  \]
- For strategy choice DC
  \[
  \text{Maximize}_{p_3^k, p_{32}^k > 0} \Pi_3 = \sum_{k=1}^{2} \left[ p_3^k - c_1 |q_{31}^k(p_3^k, p_{32}^k) - q_{31}^k(p_3^k, p_{32}^k) \right]
  + \left[ p_{32}^k - c_2 - e^k - \beta^k |q_{32}^k(p_3^k, p_{32}^k)| \right]
  \]

Appendix D. Proof for Corollary 1 and 2

Claim 2. Assuming that a dual channel (DC) strategy is optimal, then the optimal price for RC ($p_{32}^k$) will increase in response to the following:

1. An increase in the maximum market size $a$.
2. A decrease in the environmental propensity of customers $\lambda$.
3. A decrease in the price sensitivity to demand for the RC channel $b_1$.
4. A decrease in the price sensitivity to demand for the OC channel $b_2$.
5. An increase in the symmetric price basis substitution effects parameter $s$.
6. An increase in the unit cost for the RC channel $c_1$. and
Claim 3. Assuming that a dual channel (DC) strategy is optimal, then the optimal price for OC \((p_{OC}^{DC})\) will increase in response to the following:

1. An increase in the maximum market size \(a\).
2. An increase in the environmental propensity of customers \(\lambda\).
3. A decrease in the price sensitivity to demand for the RC channel \(b_1\).
4. A decrease in the price sensitivity to demand for the OC channel \(b_2\).
5. An increase in the symmetric price based substitution effects parameter \(s\).
6. An increase in the cost premium for the OC channel \(e\).

**Proof.** The optimal prices for the dual channel stochastic model are as follows:

\[
p_{OC}^{DC}(z_1, z_2) = \frac{b_2 u_1 + s u_2}{2(b_2 b_2 - s^2)}
\]

\[
p_{RC}^{DC}(z_1, z_2) = \frac{b_1 u_1 + s u_1}{2(b_2 b_2 - s^2)}
\]

where \(u_1 = (a_1 + b_1 z_1) - g(z_1, d_1) - s c_2 + \mu_1\), \(u_2 = (a_2 + b_2 z_2) - g(z_2, d_2) - s c_1 + \mu_2\), \(g(z_1, d_1) = \int_0^1 \left(1-f(e_1)\right)de_1\) and \(g(z_2, d_2) = \int_0^1 \left(1-f(e_2)\right)de_2\).

Analyzing \(g(z_1, d_1)\) further, we find that \(g(z_1, d_1) = \int_0^1 \left(1-f(e_1)\right)de_1 = \int_0^1 \left(1-f(e_1)\right)de_1 - \int_0^1 z_1 f(e_1)de_1\). In this expression, we find that \(\int_0^1 f(e_1)de_1 \leq \mu_1, 0 \leq \int_0^1 f(e_1)de_1 \leq 1\), and \(-d_1 \leq z_1 \leq d_1\). Since \(d_1 \leq a_1\), then \(g(z_1, d_1) \leq \mu_1 + a_1\).

Taking the derivative of \(p_{OC}^{DC}\) with respect to various parameters, we find that:

\[
\frac{\partial p_{OC}^{DC}}{\partial a} = 2(b_2(1 - \lambda) + 2s) \geq 0
\]

\[
\frac{\partial p_{OC}^{DC}}{\partial c_1} = -a(b_2 - s) \leq 0
\]

\[
\frac{\partial p_{OC}^{DC}}{\partial b_1} = \frac{b_1(b_1 a_1 + \mu_1 - g(z_1, d_1)) + s(a_2 + m u_2 - g(z_2, d_2))}{2(b_2 b_2 - s^2)} \leq 0
\]

\[
\frac{\partial p_{OC}^{DC}}{\partial b_2} = -s(a_1 + \mu_1 - g(z_1, d_1)) + b_2(a_2 + m u_2 - g(z_2, d_2)) \leq 0
\]

\[
\frac{\partial p_{OC}^{DC}}{\partial b} = \frac{2b_1(b_1 a_1 + \mu_1 - g(z_1, d_1)) + b_2(a_2 + m u_2 - g(z_2, d_2))}{2(b_2 b_2 - s^2)} \geq 0
\]

\[
\frac{\partial p_{OC}^{DC}}{\partial s} \geq 0
\]

\[
\frac{\partial p_{OC}^{DC}}{\partial s} = 0
\]

The results for \(p_{OC}^{DC}\) are similar to those for \(p_{RC}^{DC}\) and are omitted. □

**References**


