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A SPREADSHEET APPROACH FOR INCORPORATING ACTUAL MOTOR CARRIER FREIGHT RATES AND EXTERNAL ENVIRONMENTAL COSTS IN A NEWSVENDOR MODEL

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ABSTRACT

The purpose of this paper is to present a model for maximizing a retailer's total expected profit using actual motor carrier freight rates and estimates of environmental costs associated with the transportation of a seasonal product. It is assumed that a single seasonal product is sold at a fixed price and demand for that product is normally distributed. Prior to the selling season, the retailer must determine how many units of the seasonal product to purchase from the supplier—therefore, the newsvendor model is appropriate for analyzing this problem. It is assumed that the retailer arranges and pays for transportation, i.e., the product is shipped free on board (FOB) Origin, Freight Collect from the supplier. Items unsold at the end of the season can be sold at a reduced price (salvaged). Actual freight rates are incorporated in the model by considering less-than-truckload discounts, fuel surcharges for both less-than-truckload (LTL) and truckload (TL) shipments, and over-declaring of shipments. All-units purchase quantity discounts are assumed also. Due to the nonlinear nature of motor carrier freight rates, this problem does not have a closed-form solution. Therefore, we present an Excel-based model for solving this problem. As demonstrated in the model solution, when environmental costs are considered, the buyer's optimal purchase quantity decreases.

JEL: C61, D21, L11, L81

KEYWORDS: Newsvendor Model, Environmental Costs, Motor Career Freight Rates

INTRODUCTION

The purpose of this research is to present a newsvendor model that incorporates actual motor carrier freight rates and estimates of environmental costs. We demonstrate an Excel-based model for the single-period newsvendor problem of determining the profit-maximizing purchase quantity for a seasonal or perishable item. A newsvendor model balances the marginal cost of ordering (stocking) one unit too many with the marginal benefit of stocking (ordering) one unit too few to find the optimal quantity to stock to maximize the expected profit. The model presented in our study builds in actual less-than-truckload (LTL) and truckload (TL) freight rates and considers motor carrier industry practices of freight rate discounts, fuel surcharges, and over-declaring of shipments. Less-than-truckload carriers typically provide customers with software listing the base linehaul (point-to-point) rates to move various shipment weights between zip codes. Customers negotiate discounts from those base linehaul rates to determine their actual LTL freight rates for various weight-break ranges. In addition, current motor carrier practice for both LTL and TL carriers is to include a fuel surcharge to account for rising diesel fuel prices. Over-declaring of shipments, discussed in detail later in the paper, is designed into LTL carrier's software to determine if a customer's shipment should be artificially inflated to the next weight-break range to reduce the customer's total freight charge, e.g., if 499 pounds should be over-declared as 500 pounds.

In addition, we illustrate how to estimate external emission costs based on previous literature and how to incorporate those costs into the newsvendor model. External costs are costs created by a company, such as environmental damage, which are borne by society or the planet. Sustainability has been an important issue since the publication of the Brundtland Report, or *Our Common Future* (World Commission on Economic Development, 1987, p. 8), in which sustainable development was described as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." Later, other authors, e.g., Elkington (1994, 1998), expanded the definition of sustainability to include the triple bottom line of economic, environmental, and social performance. A purchasing decision maker has two options when attempting to build in external environmental costs into this type of purchasing model. The first option is to use company-specific estimates of environmental costs. The second option is to use an estimate from the previous literature and adjust that estimate for inflation and currency exchange rates. Given that we did not have access to company-specific estimates of environmental costs, we chose the latter approach. Our model, however, could accommodate either approach. Using an Excel spreadsheet, we compare the purchase quantity both with and without external costs. In addition, we enumerate all possible purchase order quantities because a closed-form solution for solving this model does not exist due to the nonlinear nature of the motor carrier freight rates. The next section discusses the literature review. After that, we present the model formulation, followed by the model description. The last two sections include results followed by discussion and conclusions.

LITERATURE REVIEW

As stated by Darwish (2008, p. 3902), "… the increased emphasis on transportation costs has enhanced the need to develop models with transportation consideration explicitly." We argue that these models also should reflect industry practices such as over-declaring of shipments, fuel surcharges, and the use of multiple modes of transportation. In addition, research in the supply chain field recently has begun to emphasize environmental and social effects of transportation (Ortolani, Persona, & Sgarbossa, 2011) and inventory management decisions (Battini, Persona, & Sgarbossa, 2014). Given the aforementioned concerns, the first section of the literature review focuses on inventory models extending the basic economic order quantity (EOQ) model to include transportation and/or environmental costs. The second section provides a review of newsvendor models that consider transportation and/or environmental costs.

EOQ-Type Inventory Models

The first type of purchasing model incorporating transportation costs was the inventory-theoretic model (Baumol & Vinod, 1970). The inventory-theoretic model added estimates of transportation costs into the economic order quantity (EOQ) model with deterministic demand. Follow-up studies demonstrated how to include actual motor carrier freight rates in the deterministic inventory-theoretic model (e.g., Carter & Ferrin, 1996; Gaither, 1982; Langley, 1980; Larson, 1988; Tyworth, 1991b; Wehrman, 1984). Those studies, similar to the current study, used enumeration techniques to solve for the minimum cost purchase quantity, i.e., the quantity that minimized the sum of the annual purchasing, ordering, carrying, and transportation costs. Follow-up studies employed algorithms for solving the inventory-theoretic model with actual motor carrier freight rates (e.g., Burwell, Dave, Fitzpatrick, & Roy, 1997; Hwan, Moon, & Shin, 1990; Lee, 1986; Madadi, Kurz, & Ashayeri, 2010; Ramasesh, 1993; Russell & Krajewski, 1991; Tersine & Barman, 1991; Tersine, Larson, & Barman, 1989). Further extensions included a study by Mendoza and Ventura (2008), who considered two modes of transportation (truckload and less-than-truckload) and two types of purchase quantity discounts (all-units and incremental). He, Hu, and Guo (2010) presented an algorithm for solving the deterministic inventory-theoretic model with actual freight rates; however, they ignored purchase quantity discounts for larger purchase quantities. Darwish (2008) developed procedures to solve an inventory-theoretic model with stochastic demand, all-units/incremental purchase quantity discounts, and all-weight/incremental freight discounts, but ignored current motor carrier practice of automatically over-declaring shipments.

The difficulty in solving the inventory-theoretic model arises due to the nature of the LTL linehaul freight rates, which resemble a nonlinear step function. In addition, LTL carrier software automatically considers whether to over-declare a customer's shipment weight. Russell and Krajewski (1991) were among the first to analyze this practice of over-declaring shipment weights. Over-declaring a shipment occurs when a shipment weight is inflated artificially to the next rate breakpoint (the next highest weight-break range) to decrease the total freight charge of the shipment, e.g., 990 pounds over-declared as 1,000 pounds. For each weight-break range (except the last one) in the LTL base freight rate schedule for a product, we could calculate an indifference point beyond which we would over-declare the shipment weight to the next LTL weight-break range. In addition, we need to determine the shipment weight for the last LTL weight-break range at which we would over-declare as a truckload and use the TL carrier to reduce the total freight charge. In fact, as demonstrated later in this paper, we may determine that shipment weights much less than the last LTL weight-break range might be transported using the TL carrier to reduce the customer's total freight charge. An alternate approach to using actual freight rates in the inventory-theoretic model is to estimate freight rates using a continuous freight rate function.

Examples of freight rate functions include an inverse function assuming that all shipments are charged the TL freight rate (Blumenfeld, Burns, Daganzo, Frick, & Hall, 1987; Sheffi, Eskandari, & Koutsopoulos, 1988; Swenseth & Godfrey, 2002; Yildirmaz, Karabati, & Sayin, 2009), a proportional (linear) function based on transport distance (Ballou, 1991), an exponential function (Buffa, 1987, 1988), an adjusted inverse function (Swenseth & Buffa, 1990, 1991; Swenseth & Godfrey, 1996, 2002), and a nonlinear function using load density, shipment weight, and shipment distance (Kay & Warsing, 2009). Some researchers, e.g. Ballou (1991), argued for using freight rate functions, rather than actual freight rates, to reduce time and effort when creating inventory-theoretic models. Mendoza and Ventura (2009) pointed out correctly that using actual freight rates in the inventory-theoretic model leads to a model for which no closed-form solution exists. However, Higginson (1993) and Tyworth (1991a) criticized existing freight rate functions for not estimating freight rates accurately.

Accounting for environmental costs is more difficult than accounting for transportation costs. One approach used in the research has been to estimate environmental costs. For example, Hovelaque and Bironneau (2015) developed a carbon-constrained EOQ model using a range of estimates for the carbon tax per unit. Their model, however, ignored transportation cost. Conversely, Bozorgi, Pazour, and Nazzal (2014) included transportation cost based on using full truckload shipments to find the minimum cost quantity, and then compared that quantity to the quantity found when trying to minimize overall emissions. Battini et al. (2014) developed a sustainable EOQ model to analyze economic and environmental trade-offs of lot sizing in material purchasing. In their model, they estimated transportation-related environmental (emissions) costs based on an earlier study by Ortolani et al. (2011), and estimated transportation costs using a simplified transport cost function consisting of a fixed and a variable portion. Although their model allowed for the possibility of a large shipment requiring more than one container, it is unclear whether they based vehicle capacity (saturation) on weight or cube.

<u>Newsvendor Models</u>

The newsvendor model, similar to the EOQ model, is one of the classical problems in inventory management. As is the case when using the EOQ model for purchasing continuously reviewed inventory items, a buyer must account for transportation and environmental costs when purchasing seasonal items for a single period (selling season). The studies reviewed below all assumed stochastic demand over the season. Abad (2006) created an optimal single period profit-maximizing model for determining the retailer's optimal order quantity under the following assumptions: no purchase quantity discounts and unit cost is given, trailer capacity is limited by weight (46,000 pounds), a combination of truckload and less-than-truckload shipments is possible, and actual motor carrier freight rates and over-declaring of shipments are considered. Limitations of their model included the assumption of truckload capacity determined by weight only (they ignored the possibility of a shipment cubing out a trailer) and omission of fuel surcharges and environmental costs. In a more recent study, Konur and Toptal (2012) analyzed the newsvendor problem for a single item lot-sizing and supplier selection profit-maximization problem with the following assumptions: unit cost from the supplier defined by an all-units quantity discount schedule, and the use of truckload carriers only. Their study was limited in that they ignored less-than-truckload shipments and freight rates, over-declaring of shipments, fuel surcharges, and environmental costs. Hua, Wang, and Cheng (2012) extended the newsvendor model to incorporate both purchase quantity discounts and freight rates (including over-declaring) to determine a retailer's optimal purchase quantity and selling price simultaneously. They used a generalized transport cost function with a fixed and a variable component, but ignored fuel surcharges. In addition, their model did not include environmental costs.

The integration of environmental costs into newsvendor models has occurred only recently. Bushuev, Guiffrida, Jaber, and Khan (2015) argued that research in this area has been scattered, and that the most used sustainability criterion has been units of carbon equivalent emissions (usually carbon dioxide). As an example, Arikan and Jammernegg (2014) created a newsvendor model under dual sourcing with a carbon footprint constraint. They proposed that an upper bound for carbon emissions could be derived either from a company's environmental target or from an industry standard. A few studies (e.g., Manikas & Godfrey, 2010; Zhang & Xu, 2013; Rosic & Jammernegg, 2013) estimated the per-unit cost of emissions based on the cost to purchase the right to emit carbon in a cap and trade market or an emissions tax per unit. Each of these previous research streams failed to integrate realistic motor carrier freight practices, purchase quantity discounts, and environmental costs into a single model for determining the profit-maximizing purchase order quantity for a seasonal item. Therefore, the model presented in the next section is designed to overcome these limitations in the context of an Excel-based spreadsheet.

Model and Notation

A newsvendor model calculates the optimal expected profit for a demand distribution where the mean, the standard deviation and the shape (normal, uniform, exponential, etc.) of the curve are known. The newsvendor typically is a single period model, which means that the items in stock cannot be sold for full price beyond the selling season (i.e., demand perishes). Items left over need to be either sold at a discount or disposed of at additional cost. Given that a seasonal product is considered in this paper, the use of the newsvendor model is appropriate. The profit maximizing quantity associated with the probability point on this demand curve depends on the cost parameters for a particular problem. At its most basic, the newsvendor balances marginal benefit with marginal cost to determine the point on the demand curve at which the cost of overstocking an additional unit equals the cost of understocking by one unit. The cost of overstocking by one unit is denoted by C_o. Any item left over will have incurred its cost (purchase cost, transportation cost, and external cost). The retailer might be able to sell the item at a reduced selling price after the selling season. This selling price is assumed to be less than the retailer's purchase cost, and is known as the salvage value. Further, it may be that instead of earning the salvage value, the retailer might have to pay an additional disposal fee instead. In addition, to ensure accurate accounting, we assume that any unsold units have been in our possession for the entire selling season, and thus incur a holding cost over that season. The cost of being short one unit is denoted by C_u. At a minimum, the retailer loses the profit that it would have made on that additional unit. The retailer also may experience goodwill issues that could affect its company image, but loss of goodwill costs is difficult to quantify and is omitted from the model that we present here. The complete list of variables and an explanation of those variables follow.

Variables

p = price per unit (retail selling price)
c = purchase cost per unit
s = salvage value per unit

C_h = holding cost for the entire selling season per unit unsold
C_s = inbound shipping cost per unit
C_e = external cost per unit
μ = mean demand
σ = standard deviation of demand
$f(x)$ = the normal density function
$f_s(\ )$ = the standard normal density function
F = the normal cumulative distribution function
$F_s(\ )$ = the standard normal cumulative distribution function
C_o = cost of overstocking by one unit
C_u = cost of understocking by one unit

Explanation of variables: p is the selling price at which the retailer sells the item to its customers, and c is the retailer's purchase cost per unit. In a simple scenario, the profit per item would equal $p - c$. This profit would equal the penalty for being one unit short of the realized demand, i.e., C_u would equal the cost of underage. However, for the model we present here, there are additional costs. We use C_s as the shipping (transportation) cost per unit to transport the item from the supplier's facility to the retailer's facility. To capture externalities, we quantify any environmental impacts as C_e. We estimated external costs using the approach of Ortolani et al. (2008). They analyzed the previous literature to derive estimates of road transport external costs imposed on society. They expressed all cost categories in terms of 2008 Euros, specifically, as €/ton-km, assuming an average load of 14.3 tons. They defined thirteen cost categories of external costs for road transport and calculated average costs for each category. Their thirteen categories included the following: emissions – air pollution (damage to human health from carbon monoxide, nitrogen oxides, and volatile organic compounds); emissions – greenhouse effect (climate change due to carbon dioxide emissions); congestion (economic damage of the loss of time of time suffered); noise (annoyance, decline in productivity, and adverse health effects); accidents; road damage; resource consumption; roadway land cost; land use impact; water pollution; waste disposal; traffic services; and barrier effect (cost related to delays and discomfort imposed on society). In their work, the average cost of total road transport external costs was 0.0949 €/ton-km. Next, applying the 2008 exchange rate (Yearly Average Exchange Rates – US Forex Foreign Exchange) to convert to US dollars (1 € = $1.1226), and converting kilometers to miles, resulted in 0.0949 €/ton-km * 1.1226 * 0.62 miles/km = $0.066052/ton-mile. Finally, adjusting for inflation from 2008 to 2016 (US Inflation Factor) provided $0.066052/ton-mile * (1 + 0.119) = $0.073912/ton-mile as the 2016 estimate of C_e. Given that the example in Table 1 uses a distance of 1,748 miles, we can determine the Total External Cost for a given shipment weight (in pounds) as follows:

$$\textit{Total } C_e = \$0.073912 * \text{Shipment Weight}/2{,}000 * 1{,}748 \tag{1}$$

The following example illustrates how to apply Equation (1):
Total external cost for transporting 400 pounds = $0.073912 * 400/2,000 * 1,748 = $25.84.
Total external cost for transporting 45,000 pounds = $0.073912 * 45,000/2,000 * 1,748 = $2,906.95.
After accounting for external costs, the cost of underage per unit is:

$$C_u = p - c - C_s - C_e \tag{2}$$

Conversely, if the retailer were to have a unit left over at the end of the selling season, the retailer would have incurred costs but not sold the unit for a profit, so there would be a cost of being over (C_o). Further, because the item remained unsold on the shelf for the entire selling season, the retailer would incur the one season holding cost (C_h). Finally, any salvage value (s) then would be subtracted from the overage cost. Salvage value (s) is a scrap value that the leftover item can be sold for (discounted price) Note: Instead of a salvage value, the retailer could incur a disposal fee to take the unit away; thus, salvage value could be a negative number. Therefore, the retailer's cost of overage per unit is:

$$C_o = c + C_h + C_s + C_e - s \quad (3)$$

We have outlined the cost of underage per unit and the cost of overage per unit. Next, we discuss the formulas that will allow us to find the quantity corresponding to the expected maximum profit. We start with our formulas for the cost of underage (2) and the cost of overage (3) for a given order quantity (q). If q units are ordered and realized demand (x) is $x \leq q$, each unit sold (x) increases profits by $p - c - C_s - C_e$, and each unsold unit ($q - x$) results in a loss of $c + C_h + C_s + C_e - s$. If demand is larger than q, q units are sold for a profit of $p - c - C_s - C_e$ each, and the remaining demand of $x - q$ goes unmet. As mentioned before, it may be that we want to include a loss of goodwill penalty in the cost of underage as well, but given that brand image and customer loyalty are difficult to quantify, we omitted a goodwill term here. We can express expected profit as:

$$\text{Expected Profit} = \int_{x=-\infty}^{q} [(p - c - C_s - C_e)x - (c + C_h + C_s + C_e - s)(q - x)] f(x)dx + \int_{x=q}^{\infty} (p - c - C_s - C_e) f(x)dx \quad (4)$$

The first term in (4) is the probability that demand is between negative infinity (0 units) and a quantity q. The x term means that the retailer would receive the profit (cost of underage) for each x units sold up to quantity q on hand. The next term in (4) represents the (q - x) scenario, where the retailer has more q on hand than actual demand x. The retailer incurs the overage cost for each of these (q - x) units. Notice that the retailer may recoup some of its costs via the subtraction of the salvage (s) term. Conversely, if the retailer has a disposal cost (s is negative), the retailer would incur additional costs beyond product cost, holding cost, shipping cost, and external cost. The final term in (4) represents the probability that realized demand is larger than q. The retailer would earn a profit (cost of underage) for selling q units demanded even if they had stocked more than q units (the remainder would be unsold and incur a cost of overage). If the retailer was confident in quantifying the loss of goodwill for not filling demand out of stock, a positive cost penalty term could be added into this third term. We know the following (Chopra & Meindl, 2013, p. 393):

$$\int_{x=-\infty}^{q} x f(x)dx = \mu F_s\left(\frac{q-\mu}{\sigma}\right) - \sigma f_s\left(\frac{q-\mu}{\sigma}\right) \quad (5)$$

By substitution, expected profits can be expressed using the following equations:

$$\text{Expected overstock units} = (q - \mu) F_s\left(\frac{q-\mu}{\sigma}\right) + \sigma f_s\left(\frac{q-\mu}{\sigma}\right) \quad (6)$$

$$\text{Expected understock units} = (\mu - q)\left[1 - F_s\left(\frac{q-\mu}{\sigma}\right)\right] + \sigma F_s\left(\frac{q-\mu}{\sigma}\right) \quad (7)$$

Knowing the costs of overstocked and understocked units allows us to write the expected profit as:

$$E[\pi] = (p + C_h - s)\mu F_s\left(\frac{q-\mu}{\sigma}\right) - (p + C_h - s)\sigma f_s\left(\frac{q-\mu}{\sigma}\right) - q(c + C_h + C_s + C_e - s)F(q, \mu, \sigma) + q(p - c - C_s - C_e)[1 - F(q, \mu, \sigma)] \quad (8)$$

The mean μ and standard deviation σ describe the expected demand curve. This expected profit function is concave (the second derivative is negative). To find the maximum of this concave function, we take the first derivative and set it to 0, thus finding the quantity q at the peak (zero slope). This is the point at which the marginal cost of overage equals the marginal cost of underage. Because shipments in each less-than-truckload (LTL) weight break range would be over-declared to the next LTL weight break range or to a TL charge, the function in (8) is not smooth, however. The actual freight range function would consist of alternating ranges for which a constant charge for shipment applies followed by a weight break range for which a constant charge per hundred pounds (CWT) applies. Given the non-smooth nature of the freight rates, a closed-form solution for this problem does not exist, hence the use of a spreadsheet. Each term is "marginal" because the C_o term is multiplied by the probability that the unit would not sell, and the C_u term is multiplied by the probability that the unit would sell. The quantity at which these two marginal costs are equal is, by definition, the optimal quantity, according the expected profit equation. For our model, the freight rates introduce jumps (local maxima) in the profit equation, but we still are interested in the global maximum expected profit that is found by our model.

Model Description

A detailed description of the Excel model is provided below. The spreadsheet is designed to apply realistic transportation practices (i.e., actual LTL and TL freight rates, including minimum LTL and TL charges; LTL and TL fuel surcharges; LTL discounts negotiated with the LTL carrier; and over-declaring of shipments). The model allows for the possibility that a purchase order quantity may result in a shipment quantity that exceeds the truckload capacity (based on weight or cube). Such a scenario would require a combination of one TL shipment plus one additional LTL shipment or TL shipment. For simplicity, we assumed that any shipments requiring more than two truckloads would be transported via rail instead; therefore, our model does not consider shipments larger than two truckloads (although the model easily could be modified for such large shipments). Our model allows for the inclusion of environmental costs—here we considered only an estimate of external cost based on the previous literature. However, in practice, a buyer using this model could use company-specific estimates of environmental costs. In addition, the model is designed to determine the profit-maximizing quantity, both when environmental costs are considered and when environmental costs are ignored.

Table 1 contains cells for both input data and output data. Explanations of the input and output data are provided below the table. The retailer's selling price per unit is entered in Cell B5. The retailer's season holding cost % is entered in Cell B6 and was calculated by taking the annual holding cost %/12 to convert the holding cost % to correspond to a 1-month season. The mean forecast demand and the standard deviation of demand for the selling season are entered in Cells B7:B8. Cells C6:D9 can be used to enter the all-units quantity discount schedule provided by the supplier. This range from C6:D9 (Range Name = "UNITCOST") allows for a maximum of four quantity ranges. As illustrated in this example, there are three quantity ranges corresponding to 1 – 299 units, 300 – 599 units, and 600+ units.

Rows 11 through 25 contain cells for entering transportation and environmental data (external cost). Unit weight and cubic feet must be entered in Cells B12:B13. The example nominal (base) LTL freight rate schedule is entered in Cells C13:D20. Note: The retailer, of course, would be able to look up current freight rates in software provided by its carrier. First, the Minimum LTL Charge is entered in Cell D13. The LTL rates per century weight (CWT) are entered in Cell D14 for 1 – 499.99 pounds, Cell D15 for 500 – 999.99 pounds, Cell D16 for 1,000 – 1,999.99 pounds, Cell D17 for 2,000 – 4,999.99 pounds, Cell D18 for 5,000 – 9,999.99 pounds, Cell D19 for 10,000 – 19,999.99 pounds, and Cell D20 for 20,000 pounds or more. The LTL discount, the LTL fuel surcharge, and over-declaring are considered in another part of the spreadsheet (Table 2) when determining the freight charge for a shipment. Cell B22 is where the TL Fuel Surcharge/Mile is entered, and the TL Rate/Mile is entered into Cell D22. The Maximum TL Weight capacity and the Maximum TL Cube capacity are entered into Cells B23:B24. Note: Capacity limits for a company's unique scenario may differ due to the type of product being transported, trailer length and weight, etc. Cell D23 is used to enter the distance (Miles) for the given route. The minimum truckload charge (Min TL Charge) is entered in Cell D24. The External Cost (expressed as $/ton-mile) is entered in Cell B25. The output data in Table 1 include the Optimal Quantity (profit-maximizing quantity) and the Expected Profit for two situations: (1) Cells B29:B30 show the optimal quantity and the expected profit when external costs are considered, and (2) Cells B33:B34 show the optimal quantity and the expected profit when external costs are ignored. The formulas for these cells are listed below and reference Table 4.

Table 1: Input Data & Output Data

	A	B	C	D	E
4	Inputs:			Unit Cost Schedule (*c*)	
5	Price per Unit (*p*)	$80.00	At Least	Unit Cost	
6	Season Holding Cost %	2%	1	$50.00	
7	Mean Demand (μ)	600	300	$48.00	
8	Standard Deviation of Demand (σ)	120	600	$46.00	
9					
10					
11				**Nominal LTL Freight Rate Schedule**	
12	Unit Weight (pounds)	40	Range	Rate	
13	Unit Cubic Feet	4.50	Minimum	$544.11	
14			1	$363.37	/CWT
15	LTL Discount (%)	55.00%	500	$278.43	/CWT
16	LTL Fuel Surcharge (%)	20.20%	1000	$236.69	/CWT
17			2000	$200.71	/CWT
18			5000	$175.09	/CWT
19			10000	$144.12	/CWT
20			20000	$135.48	/CWT
21					
22	**TL Fuel Surcharge/Mile ($)**	$0.64	**TL Rate/Mile ($)**	$1.35	
23	Maximum TL Weight	46,100	Miles	1748	
24	Maximum TL Cube	4,108	TL Min. Charge	$600.00	
25	External Cost ($/ton-mile)	$0.073912			
26					
27		**Output Data**			
28	**Profit-Maximizing Quantity (including External Costs)**				
29	Optimal Quantity	531			
30	Expected Profit	$2,215.15			
31					
32	**Profit-Maximizing Quantity (excluding External Costs)**				
33	Optimal Quantity	542			
34	Expected Profit	$3,601.41			

The top part of this table shows input data for the seasonal product including price per unit, mean and standard deviation of seasonal demand for the product, purchase cost per unit, and transportation data (LTL and TL costs per hundred pounds (CWT), shipping weight and cube). The bottom part of this table shows output data (optimal quantity and expected profit, with and without external emissions cost).

Cell B29: =INDEX(M10:M969,MATCH(B30,AB10:AB969,0))
Cell B30: =MAX(AB10:AB969)
Cell B33: =INDEX(M10:M969,MATCH(B34,AD10:AD969,0))
Cell B34: =MAX(AD10:AD969)

Table 2 displays the LTL and the TL freight rates after applying the negotiated LTL Discount and the LTL Fuel Surcharge % to nominal LTL rates, and the TL Rate/Mile, the TL Fuel Surcharge/Mile, Miles, and the Min. TL Charge to determine the relevant TL charge. First, the LTL Minimum charge (Range Name = "LTLMINCHARGE") is calculated in Cell I5 by taking the nominal charge in Cell D13 of Table 1, applying the LTL discount from Table 1 to that nominal charge, and then adding in the LTL fuel surcharge from Table 1 as shown in the following formula:
=D13*(1-B15)*(1+B16)

The actual freight rates and over-declared charges are calculated in Cells G6:J12 (Range Name = "ACTUALRATES") in Table 2. Cells H6:H12 are the actual freight rates per CWT for each of the LTL weight ranges after applying the LTL discount and the LTL fuel surcharge. The formulas for these cells are listed below:

Cell H6: =D14*(1-$B$15)*(1+$B$16)
Cell H7: =D15*(1-$B$15)*(1+$B$16)
Cell H8: =D16*(1-$B$15)*(1+$B$16)
Cell H9: =D17*(1-$B$15)*(1+$B$16)
Cell H10: =D18*(1-$B$15)*(1+$B$16)
Cell H11: =D19*(1-$B$15)*(1+$B$16)
Cell H12: =D20*(1-$B$15)*(1+$B$16)

Table 2: Actual Freight Rate Schedule

	G	H	I	J	K
4	Weight (lbs.)	Rate/CWT	Charge	Charge	
5	LTLMIN		$294.31		
6	1	$196.55		$753.01	
7	500	$150.60		$1,280.26	
8	1,000	$128.03		$2,171.28	
9	2,000	$108.56		$4,735.31	
10	5,000	$94.71		$7,795.45	
11	10,000	$77.95		$14,656.23	
12	20,000	$73.28		**$3,478.52**	**TL CHARGE**

*This table shows the determination of the actual less-than-truckload (LTL) and truckload (TL) charges along with the over-declared charge for each LTL weight break range. For example, for shipment weights between 1- 499.99 pounds, a minimum LTL charge ($294.31) would apply up to a given weight within that range (up to the weight at which the Weight (CWT) * Rate/CWT is greater than the minimum LTL Charge). The Rate/CWT ($195.65) would apply until over-declaring the shipment as 500 pounds at a rate of $150.50/CWT ($753.01) would reduce the total transportation charge for the shipment.*

Next, over-declared charges for each LTL weight range are determined. We ignored the extremely rare situation that Ferrin and Carter (1995) described as anomalous weight breaks in LTL pricing. An example of an anomalous weight break in LTL pricing would occur when a given LTL weight would be over-declared beyond the next immediate weight range, e.g., if 1,500 pounds were over-declared as 5,000 pounds, rather than as 2,000 pounds, because the total freight charge for 5,000 pounds was less than that for 2,000 pounds. We ignored anomalous weight breaks because LTL carriers ought to be able to prevent such situations given that their freight rates now are stored electronically within in a database. In the highly unlikely event that an anomalous weight break occurred, such a scenario would be easy to discern in Table 2, and the formulas could be adjusted accordingly. In addition, to simplify the calculation of LTL freight rates, we ignored special charges such as a single shipment charge for shipment weights between 1 – 499.99 pounds (although our model could be modified to handle this situation also).

Cell J6 corresponds to the freight charge for shipments of 1 – 499.99 pounds over-declared as 500 pounds. Cell J7 corresponds to the freight charge for shipments of 500 – 999.99 pounds over-declared as 1,000 pounds. Cell J8 corresponds to the freight charge for shipments of 1,000 – 1,999.99 pounds over-declared as 2,000 pounds. Cell J8 corresponds to the freight charge for shipments of 1,000 – 1,999.99 pounds over-declared as 2,000 pounds. Cell J9 corresponds to the freight charge for shipments of 2,000 – 4,999.99 pounds over-declared as 5,000 pounds. Cell J10 corresponds to the freight charge for shipments of 5,000 – 9,999.99 pounds over-declared as 10,000 pounds. Cell J11 corresponds to the freight charge for shipments of 10,000 – 19,999.99 pounds over-declared as 20,000 pounds. Cell J12 corresponds to the freight charge for shipments of 20,000 pounds or more over-declared as a TL shipment. Note: It is possible that shipment weights less than 20,000 pounds could be over-declared as a TL shipment if doing so would decrease the total freight charge. In the example used in this paper, the actual TL Charge shown in Cell J12 is $3,478.52 and the LTL Over-Declared Charge for 10,000 pounds (which occurs at 20,000 pounds) is $14,656.23 (Cell J11). In fact, the TL charge of $3,378.52 is less than the Over-Declared Charge for 5,000 pounds ($4,735.31) in Cell J9. Therefore, in this example, over-declaring the LTL to the TL rate is cheaper. The formulas for Cells J6:J12 are shown below. The formula in Cell J12 ensures that the calculated TL Charge would never be less than the TL Min. Charge (from Table 1), and then adds in the TL Fuel Surcharge/Mile from Table 1.

Cell J6: =G7/100*H7
Cell J7: =G8/100*H8
Cell J8: =G9/100*H9
Cell J9: =G10/100*H10
Cell J10: =G11/100*H11
Cell J11: =G12/100*H12
Cell J12: =MAX((D24+(D22+B22)),(D23*(D22+B22)))

Table 3 is used to determine the range of order quantities to consider when determining expected profit. Cell O4 is used to calculate the maximum number of units that could be loaded on a trailer based on weight (Maximum TL Weight/Unit Weight from Table 1). Next, Cell P4 is used to calculate the maximum cube that would fit on a trailer (Maximum TL Cube/Unit Cubic Feet from Table 1). Cell Q4 calculates the Maximum TL Capacity in units based on the lower of the two values in Cells O4 and P4. The TL Capacity (units) affects how total freight charge is calculated for shipments that exceed the capacity of single truckload. Next, Cell O5 calculates the Mean Demand + 3 sigma (from Table 1) to account for approximately 99.87% of the possible seasonal demand for the item. The vast majority of real data scenarios will have an optimal quantity that falls within 0 to mean + 3 standard deviations; however, Cell O5 could be altered easily to a multiplier greater than 3. Cell O5 will determine the number of rows required in the spreadsheet.

Table 3: Determination of Possible Order Quantities

	M	N	O	P	Q
3			**Weight**	**Cube**	**Capacity**
4	**TL Capacity (units) =**		1152	912	**912**
5	**Mean Demand + 3σ =**		960		

This table shows the truckload (TL) capacity in units determined based on taking the lower value of the TL Capacity Weight and TL Capacity Cube. In addition, the Mean Demand + 3σ is determined.

Table 4 is used to calculate cost values for all possible order quantities up to 960 units. Due to space limitations, only the rows for order quantities between 1 – 10 units are shown.

Table 4: Cost Calculations

	M	N	O	P	Q	R	S	T	U	V
8								Shipping	Total	External
9	Order	Unit	Holding Cost	Shipment	Excess	Excess	Freight	Cost per	External	Cost per
10	Quantity (q)	Cost (c)	per Unit (C_h)	Weight	Units	Weight	Charge	Unit (C_s)	Cost	Unit (C_e)
11	1	$50.00	$5.16	40.00	0	0.00	$294.31	$294.31	$0.43	$0.43
12	2	$50.00	$2.96	80.00	0	0.00	$294.31	$147.15	$0.85	$0.43
13	3	$50.00	$2.22	120.00	0	0.00	$294.31	$98.10	$1.28	$0.43
14	4	$50.00	$1.93	160.00	0	0.00	$314.47	$78.62	$1.71	$0.43
15	5	$50.00	$1.93	200.00	0	0.00	$393.09	$78.62	$2.13	$0.43
16	6	$50.00	$1.93	240.00	0	0.00	$471.71	$78.62	$2.56	$0.43
17	7	$50.00	$1.93	280.00	0	0.00	$550.33	$78.62	$2.99	$0.43
18	8	$50.00	$1.93	320.00	0	0.00	$628.95	$78.62	$3.41	$0.43
19	9	$50.00	$1.93	360.00	0	0.00	$707.57	$78.62	$3.84	$0.43
20	10	$50.00	$1.88	400.00	0	0.00	$753.01	$75.30	$4.27	$0.43

This table shows the calculations for order quantities between 1 – 10 units. First, the applicable unit cost and the holding cost per unit are determined. Next, the number of units (and their total weight) beyond the TL capacity are determined so that the relevant freight charge can be calculated. After that, the freight charge is converted to shipping cost per unit. Then the total external cost is determined and converted to external cost per unit.

Column M contains all of the possible order quantities. The order-up-to quantity each period [Order quantity (q)] goes from 1 unit to Mean + (3* standard deviation) units. We assumed that we would want to order at least one unit (i.e., if we were to order 0 units, profit would equal $0, thus being trivial). First, "1" is entered in Cell M11 to indicate that q = 1. Next, the formula in Cell M12 is entered as follows:

Cell M12: =IF(M11<>"",IF(M11+1<=$O$5,M11+1,""),"")

The formula in Cell M12 was copied down to Cells M13:M3010 to allow for a maximum order quantity of 3,000 units. If the order quantity were to exceed 3,000 units, we could copy the formula from Cell M12 to additional cells as needed. Given that the Mean Demand + 3σ = 960, all other formulas discussed below will need to be copied from Row 11 to Rows 12 through 970.

Column N is used to determine the applicable Unit Cost based on the all-units quantity discount schedule provided by the supplier in Cells C6:D9 of Table 1 (Range Name = "UNITCOST"). The formula in Cell N11 (shown below) needs to be copied down to Cells N12:N970.

Cell N11: =VLOOKUP(M11,UNITCOST,2)

Column O determines the Holding Cost per Unit for the selling season. Given that Total Cost per Unit = Unit Cost (c) + Shipping Cost per Unit (C_s), Holding Cost per Unit = Total Cost per Unit * Season Holding Cost %. The formula for Cell O11 (shown below) needs to be copied down to Cells O12:O970.

Cell O11: =(N11+T11)*$B$6

Column P determines the Shipment Weight. Shipment Weight = Units (q) * Unit Weight in pounds (from Table 1). The formula for Cell P11 (shown below) needs to be copied down to Cells P12:P970.

Cell P11: =$B$12*M11

Column Q determines the number of Excess Units (those q units beyond the maximum TL Capacity from Table 3). We need to know the number of excess units to be able to determine the total freight charge when shipment size exceeds the TL capacity. The formula for Cell Q11 (shown below) needs to be copied down to Cells Q12:Q970.

Cell Q11: =MAX(0,M11-$Q$4)

Column R determines the weight corresponding to the number of Excess Units. Excess Weight = Excess Units * Unit Weight (from Table 1). The formula for Cell R11 (shown below) needs to be copied down to Cells R12:R970.

Cell R11: =$B$12*Q11

Column S uses Cells G6:J12 (Range Name = "ACTUALRATES" from Table 2) to determine the Freight Charge for each order quantity (q). The formula for Cell S11 (shown below) needs to be copied down to Cells S12:S970.

Cell S11:
=IF(Q11=0,MIN(MAX(LTLMINCHARGE,VLOOKUP(P11,ACTUALRATES,2)*P11/100),VLOOKUP
(P11,ACTUALRATES,4),TLCHARGE),TLCHARGE+MIN(MAX(LTLMINCHARGE,VLOOKUP(R11
,ACTUALRATES,2)*R11/100),VLOOKUP(R11,ACTUALRATES,4),TLCHARGE))

Column T determines the Shipping Cost per Unit. Shipping Cost per Unit = Freight Charge/*q*. The formula for Cell T11 (shown below) needs to be copied down to Cells T12:T970.

Cell T11: =S11/M11

Column U determines the External Cost for a given order quantity (*q*) and is calculated as External Cost = External Costs ($/ton-mile) * Shipment Weight/2000 * Miles. External Cost and Miles are obtained from Table 1. The formula for Cell U11 (shown below) needs to be copied down to Cells U12:U970. External cost dollarizes the external impacts of environmental damage.

Cell U11: =$B$25*P11/2000*$D$23

Column V determines the External Cost per Unit (External Cost/*q*). The formula for Cell V11 (shown below) needs to be copied down to Cells V12:V970.

Cell V11: =U11/M11

Table 5 is used to calculate expected profit values for all possible order quantities up to 960 units. Due to space limitations, only the rows for order quantities between 1 – 10 units are shown.

Column W determines the probability (Pr Sell) of selling aggregate demand of *q* units or more given a normal distribution with the mean and the standard deviation in Table 1. The formula for Cell W11 (shown below) needs to be copied down to Cells W12:W970.

Cell W11: =IF(X11<>"",1-X11,"")
Column X determines the probability (Pr Not Sell) of not selling all *q* units given a normal distribution with the mean and the standard deviation in Table 1. The formula for Cell X11 (shown below) needs to be copied down to Cells X12:X970.

Cell X11: =IF(M11<>"",NORMDIST(M11,$B$7,$B$8,TRUE),"")

Table 5: Profit Calculations

	M	W	X	Y	Z	AA	AB	AC	AD
8							E Profit		E Profit
9	Order			Expected	Expected	Marginal	Including	Marginal	Excluding
10	Quantity (*q*)	Pr Sell	Pr Not Sell	Underage	Overage	Profit	External	Profit	Emissions
11	1	100.00%	0.00%	-$266.89	$0.00	-$266.89	-$266.89	-$264.31	-$244.31
12	2	100.00%	0.00%	-$119.74	$0.00	-$119.74	-$386.63	-$117.15	-$341.46
13	3	100.00%	0.00%	-$70.69	$0.00	-$70.69	-$457.32	-$68.10	-$389.57
14	4	100.00%	0.00%	-$51.20	$0.00	-$51.20	-$508.52	-$48.62	-$418.19
15	5	100.00%	0.00%	-$51.20	$0.00	-$51.20	-$559.72	-$48.62	-$446.80
16	6	100.00%	0.00%	-$51.20	$0.00	-$51.20	-$610.93	-$48.62	-$475.42
17	7	100.00%	0.00%	-$51.20	$0.00	-$51.20	-$662.13	-$48.62	-$504.04
18	8	100.00%	0.00%	-$51.20	$0.00	-$51.20	-$713.33	-$48.62	-$532.66
19	9	100.00%	0.00%	-$51.20	$0.00	-$51.20	-$764.54	-$48.62	-$561.28
20	10	100.00%	0.00%	-$47.89	$0.00	-$47.89	-$812.42	-$45.30	-$586.58

This table shows the probability of selling a particular unit (given the mean and standard deviation of demand), as well as the corresponding probability of not selling that unit. Expected Underage is the profit lost by not having this unit in stock (i.e., the marginal benefit from this unit). The Expected Overage is the marginal cost incurred by having this one unit left after the end of the selling season. Column AB shows the corresponding total profit where external (environmental costs are included in the model). Columns AC and AD shows the same information as columns AA and AB, but for the model that excluded emission costs.

Column Y determines the net expected underage cost from not being able to sell all *q* units demanded by customers. Expected Underage = Pr Not Sell * [Price per Unit – (Unit Cost + Shipping Cost per Unit + External Cost per Unit)]. The formula for Cell Y11 (shown below) needs to be copied down to Cells Y12:Y970.

Cell Y11: = W11*($B$5-N11-T11-V11)

Column Z determines the net expected overage cost from not selling all *q* units because realized demand was less than *q* units. Expected Overage = Pr Not Sell * (Unit Cost + Shipping Cost per Unit + External Cost per Unit + Holding Cost per Unit). The formula for Cell Z11 (shown below) needs to be copied down to Cells Z12:Z970.

Cell Z11: = X11*(N11+T11+V11+O11)

Column AA determines the marginal profit for selling *q* units. Marginal Profit is the net expected underage cost minus the net expected overage cost. The formula for Cell AA11 (shown below) needs to be copied down to Cells AA12:AA970.

Cell AA11:=Y11-Z11

Column AB determines the cumulative Expected Profit for a given *q* when including External Cost. E Profit = Sum of Marginal Profits. The formula for Cell AB11 (shown below) needs to be copied down to Cells AB12:AB970.

Cell AB11: =SUM(AA$11:AA11)

Column AC determines the marginal profit for selling *q* units without consideration of external costs. Marginal Profit is the expected underage cost minus the expected overage cost. The formula for Cell AC11 (shown below) needs to be copied down to Cells AC12:AC970. Note: In this cell, we combined the underage and overage costs similar to those components in columns Y and Z, respectively, but without the emission costs from column V).

Cell AC11:= W11*($B$5-N11-T11)-X11*(N11+T11+ O11)

Column AD determines the cumulative Expected Profit for a given *q* when excluding external cost. E Profit is calculated the same as in Column AB, but external cost (i.e., environmental damage) in column V is removed. The formula for Cell AD11 (shown below) needs to be copied down to Cells AD12:AD970.

Cell AD11: =SUM(AC$11:AC11)

RESULTS

As shown in Table 1, the profit-maximizing quantity when considering external environmental costs and transportation costs is 531 units for an expected profit of $2,215.15. When external costs are ignored, the profit-maximizing quantity is 542 units with an expected profit of $3,601.41 (62.6% higher than when including external costs). When comparing the expected profits for the optimal quantity of 531 units, the expected profit when considering external costs is $2,215.15 versus $3,587.24 when ignoring external costs (for a 61.9% increase in expected profit when ignoring external costs). As expected, when environmental costs are considered, the optimal order quantity and the expected profit both decreased. However, as we pointed out in an earlier work (Manikas & Godfrey, 2010), the retailer might be motivated to focus solely on the economic bottom line unless faced with the prospect of a government policy requiring purchase of pollution permits or dictating emission penalties. Companies more focused on corporate social responsibility, however, would employ more of a triple bottom line approach regardless of government policy. Customers may demand that their suppliers embrace corporate social responsibility, or factors other than profit might drive a company's decision to include environmental costs in decisions.

DISCUSSION AND CONCLUSIONS

The goal of this paper was to present an Excel spreadsheet for a newsvendor model that included actual motor carrier freight rates and estimates of external environmental costs. We presented a model to handle stochastic demand and all relevant costs (i.e., purchase quantity discounts, LTL and TL freight rates, underage and overage costs) along with the profit-maximizing quantities (when considering or ignoring external emissions costs). A purchasing manager could change our spreadsheet to account for company-specific date, including estimates of external environmental costs. One limitation of our spreadsheet is the requirement to enumerate possible purchase order quantities. Future research could include modifying the current model using a continuous freight rate function, for price-sensitive demand, extending the model to include UPS package rates for low shipment weights or rail freight rates for heavy shipment weights, or using the buyer's own estimate of environmental costs. In addition, the model could be modified to select both a supplier and an order quantity simultaneously. Each of these models could incorporate company-specific transportation costs and external costs. As manufacturing moves overseas, thereby increasing transportation distance, the focus on green transportation is even more important to companies wanting to embrace the triple bottom line.

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