Yuanjie He and Abolhassan Halati
Reverse Logistic Product Pricing Decision in a Supply Chain
with Substitutable Product and Random Yield

Reverse Logistic Product Pricing Decision in a Supply Chain with Substitutable Product and Random Yield

Yuanjie He[*]
Abolhassan Halati
California State Polytechnic University, Pomona, CA, U.S.A

University bookstores have a complex multi-product, multi-supplier supply chain with complex channel relationships such as product substitution, random yields, reverse logistics and returns, and risk sharing contracts. Supply chain efficiency is important to the bookstore due to low overall profit margin. The used book buyback activity is an example of reverse logistics with random yield with substantial impact on bookstore supply chain efficiency. In this paper, we develop a single period model to study the buyback pricing decision under assumption of product substitution and random yield. Model application is demonstrated with actual data collected at a university bookstore.

*Corresponding Author. E-mail address: he@csupomona.edu

I. INTRODUCTION

Despite apparent conceptual simplicity, a retail university bookstore supply chain exhibits features and channel relationships that are characteristic of more complex networks. Textbooks are ordered in different substitutable formats from different sources resulting in a multiproduct with multi-supplier supply chain. Channel relationships such as product substitution, returns, risk-sharing contracts, real-time and forecasted demand management, reverse logistics, and exogenous and endogenous pricing are present between the supply chain channel members.

New textbooks are ordered from the publishers prior to the beginning of a new academic term based on forecasted demand. Order for new textbooks may also be placed ex-post as total demand fulfillment is required by university policy. Used textbooks are ordered from the used book wholesalers and the actual number of used books received has a stochastic yield as it is a function of availability, timing of order, level of prior business with the

wholesalers, and other factors. It is in the interest of the bookstore to issue used book orders with sufficient lead time to maximize the allocation by the wholesaler. Unsold textbooks may be returned to the supplier depending on the supplier's return policy under risk-sharing contractual agreement which may provide full credit, partial credit commonly through application of restocking fees based on the total return value of the product, or limit the amount of returns.

Unused inventory of new and used textbooks that are not returned to the suppliers may optionally be stored for sale in a subsequent academic term or salvaged through sale to a used - book wholesaler. Introduction of new textbook editions and academic departmental adoption policies further complicates the channel relationships as both the stocking policies and the salvage value of the unsold textbooks are affected by these factors.

Students who purchase new or used textbooks at the beginning of an academic term become potential supplier of used book in a subsequent term. Used textbooks are purchased

Yuanjie He and Abolhassan Halati
Reverse Logistic Product Pricing Decision in a Supply Chain
with Substitutable Product and Random Yield

from the student at an endogenously established price during the buyback period. Pricing may be determined to encourage or discourage the students from selling their used textbooks and hence the buy-back process may be viewed as a reverse logistics process with pricing as the principal control of the reverse flow.

Aided by advances in technology and powerful search engines, the bookstore may purchase both new and used textbooks from local and international on-line sources. Textbooks purchased from different on-line sources vary in price and the purchase is commonly under no-return agreement. There is also a limited student interest in purchase of e-books. E-books do not require advance procurement, inventory processing or demand forecasting. Access codes are sold at the time of demand realization in real time and there are no availability or volume constraints. Despite the use convenience, the e-book purchases are not a substantial portion of overall sales probably due to cost and the provision of no return.

In this paper we develop a single period model to study the buyback pricing decision of the university bookstore. Application of the model is demonstrated utilizing real data provided by Cal Poly Pomona, Bronco Bookstore. The organization of the remainder of the paper is as follows: Section II provides the survey of related research. Section III introduces the simplified single period model and section IV discusses the data collected and demonstrates the model application.

II. LITERATURE SURVEY

This paper is related to a few well studied fields in the literature. First, Yano and Lee (1995) have extensively surveyed the problems related to random yield and provide a general review on the topic. Gerchak et al (1996) study the random yield model in a bi-level product supply chain. Similarly, we study the textbook supply chain, which also shows multiple level product characteristics. Our paper differs from

this stream of research by discussing the reverse logistic pricing in multi-level product supply chains. Also, reverse logistics has been extensively studied under different contexts. Pasternack (1985) shows the value of buyback policy in supply chain coordination. Salema, Barbosa-Povoa and Novais (2007) have proposed a general model considering multi-product reverse logistics network under demand and return uncertainty. Another model proposed by Wilcox et al (2011) studies the Markovian model of liquidity effects in reverse logistics process under return randomness. With numerical analysis approach, Inderfurth (2005) studies the impact of demand and return uncertainty on remanufacturing, which shows the potential obstacle that these uncertainties can cause to the reverse logistics system. Our paper contributes to the literature by studying the optimal price control strategy that may be used to mitigate this obstacle. As for the pricing decision in reverse logistics, Mukhopadhyay and Setoputro (2004) propose an economic model to study the joint price and return policy for e-business reverse logistics, where the optimal price and return policies are discussed. Different from this paper, we consider the optimal return pricing policy under return uncertainties for a product with different formats. Shulman, Coughlan and Savaskan (2009) study the optimal restocking fee and information provision for product return. Our paper studies the optimal pricing instead of information provision in reverse logistics under the context of textbook market.

III. METHODOLOGY

Bronco Bookstore at Cal Poly University, Pomona is a for-profit operation. In fiscal year 2009-2010, sale of text books accounted for 64% of the total revenue of $12.75 million. During the same period, the store sold a total of 140,738 textbooks comprised of 73,399 new, 66,154 used and 451 e-books sales. During the same period 734 textbooks were rented to the students under a recently established textbook rental program.

Yuanjie He and Abolhassan Halati
Reverse Logistic Product Pricing Decision in a Supply Chain
with Substitutable Product and Random Yield

Textbook sales and rentals resulted in a net income contribution of $273,576 for a profit margin of only 3%.

In this section, we present a single period model for analysis of the buyback pricing decision at Bronco Bookstore. We first introduce the underlying sequence of the events upon which the model is built. We then describe the assumptions, decision variables, and parameters of the model and present the model formulation. The event sequence for the model is as follows:

1. New book orders are placed with the publisher with sufficient lead time and in advance of the student registration based on department request. Needless to indicate that new book purchases are placed prior to demand realization.
2. The bookstore places used book order with the used book wholesalers. This order is also placed with sufficient lead time in advance of the student registration and has a random yield which depends on factors described earlier.
3. After observing the used book wholesaler supply realization, the buyback pricing decision is made.
4. At the beginning the new quarter, the demand is realized and the unsold new or used books are either stored for future use or salvaged through sales to used book buyers.

Halati and He (2007) studied the optimal stocking policy for new textbooks ordering process as a substitute product for used books. The work primarily focused on steps 1 and 2 of the above sequence of events. This paper focuses on another important managerial aspect of the bookstore supply chain which is the buyback pricing decision. The model does not include the impact of e-books sales, purchasing of new and used books from online sources and textbook rentals.

Buyback periods occur at the end of each academic term following the completion of the registration period for the subsequent term. At that time the demand for textbook may be estimated with low uncertainty based on number of registered students. Therefore, the model assumes a deterministic demand for the textbook. The unsatisfied demand may be fulfilled by emergency ordering of new textbooks at generally a higher handling cost and the model imposes a penalty cost for unsatisfied demand. We also assume that new textbooks are primarily a substitute for used textbooks. This assumption is plausible due to higher profit margin of the used textbooks for the bookstore and the lower cost to the students.

The following table describes the parameters used in our model.

TABLE 1: NOTATIONS

Notation	
τ	the realization of the yield from used book wholesalers
u	random yield from the used book buyback
$f(\cdot)$	density function for the random yield of used-book buyback
$F(\cdot)$	cumulative function of the random yield for used book buyback
μ	expected value of u
D	textbook demand for the new academic term
y_n	new books inventory position after receipt of the order
p_n	new book unit selling price
p_u	used book unit selling price
c_b	used book buyback price

Yuanjie He and Abolhassan Halati
Reverse Logistic Product Pricing Decision in a Supply Chain
with Substitutable Product and Random Yield

b	Penalty cost for emergency ordering of new books for unsatisfied demand
v_n	new book unit salvage value or holding cost
v_u	used book unit salvage value or holding cost
z	quantity of used book purchased through buyback program
Π	total expected profit

A linear model is utilized to capture the positive relationship between the buyback price and the buyback quantity,

$$z = a_u + e \cdot c_b + u.$$

The first term, a_u, is a positive constant representing the buyback quantity that is not influenced by the buyback price. This term captures the behavior of those students who sell their textbooks regardless of the buyback price offered by bookstore, for reasons such as lack of interest in course content, perception of lack of future use, or financial needs. The second term, $e \cdot c_b$, models behavior of students whose decision depends on the offered buyback price. The model assumes that more students will be enticed to sell their textbook to the bookstore as the buyback price increases. At lower prices, some students may choose to keep the textbook or become encouraged to sell their textbooks through alternative venues such as internet or direct campus advertisement. In this term, e, represents the students' sensitivity to buyback price changes. We use u to model the random component of the buyback quantity. Random variation in sales of the used book by students may be attributed to a number of reasons that may include sales postponement due to missed buy back period, utilizing the bookstore as a secondary market only after attempts at direct selling fail, or recently developed financial hardship. We assume that the random yield component, u, has a density function $f(.)$.

The model parameters a_u and e may be calibrated through appropriate regression analysis which requires availability of empirical data on the buyback quantity at different buyback prices. Needless to say that frequently such data

is unavailable due to short life cycle of textbook editions. In the next section, we examine the sensitivity of the results to the parameter values through numerical analysis.

Depending on the yield of used book buyback, there are three possible scenarios at the beginning of each new academic term.

Scenario 1*:* total supply of used books from student buyback, z, and used book wholesalers, τ, is sufficient to cover the demand, i.e. $z + \tau \geq D$.

Under this scenario, the bookstore's profit function may be expressed as,

$$\Pi_1 = p_u D + v_u (z + \tau - D) + v_n y_n - c_b z.$$

The first term is the total revenue from the sales of used books; the second and third terms represent the revenue from salvaging unsold used and new books respectively. The last term is the acquisition cost of used books through the buyback program. The condition $z + \tau \geq D$ may also be rewritten as $u \geq D - a_u - \tau - ec_b$.

Scenario 2*:* supply of used, $z + \tau$, and new books, y_n, is sufficient to cover the demand. Under this scenario, the bookstore will sell all of the available used books and part of the demand will be satisfied from sale of new books, that is;

$$D - y_n \leq z + \tau < D, \text{ or}$$

$$D - a_u - \tau - ec_b - y_n \leq u < D - a_u - \tau - ec_b.$$

The bookstore's profit function in this case is given by,

$$\Pi_2 = p_u (z + \tau) + p_n (D - z - \tau) + v_n (y_n + z + \tau - D) - c_b z.$$

The first and the second terms represent the bookstore's revenue from sale of the used and new textbooks respectively. The third term is the revenue from salvaging the excess new textbooks, and the last term is the purchasing cost

Yuanjie He and Abolhassan Halati
Reverse Logistic Product Pricing Decision in a Supply Chain
with Substitutable Product and Random Yield

of student used books through the buyback program.

Scenario 3: supply of used books, $z + \tau$, and new books, y_n, is not sufficient to meet the demand and emergency ordering of additional new textbooks is required. Therefore,

$z + \tau + y_n < D$, or $u < D - a_u - \tau - ec_b - y_n$.

Under this scenario, the bookstore's profit function would be,

$\Pi_3 = p_u(z + \tau) + p_n y_n - b(D - y_n - z - \tau) - c_b z$.

Again, the first and the second terms represent the bookstore revenue from sale of used and new books respectively. The third term is the cost of emergency ordering of additional new books to meet the student demand and the final term is the purchasing cost of the used books through buyback program.

Considering the above three scenarios, the bookstore's buy-back price decision problem may be summarized as,

$$\max_{c_b \geq 0} \ E_u[\Pi] = E_u[\Pi_1 + \Pi_2 + \Pi_3].$$

The bookstore's expected profit function may be written explicitly as,

$$E_u[\Pi] = \int_{D-a_u-\tau-ec_b}^{\infty} [p_u D + v_u(a_u + ec_b + \tau + u - D) + v_n y_n] f(u) du$$

$$+ \int_{D-a_u-\tau-ec_b-y_n}^{D-a_u-\tau-ec_b} [p_u(\tau + a_u + ec_b + u) + p_n(D - a_u - ec_b - \tau - u)$$

$$+ v_n(y_n + a_u + ec_b + \tau + u - D)] f(u) du$$

$$+ \int_0^{D-a_u-\tau-ec_b-y_n} [p_u(a_u + ec_b + \tau + u) + p_n y_n - b(D - a_u - ec_b - \tau - u - y_n)] f(u) du$$

$$- c_b(a_u + ec_b + \mu)$$

The following proposition describes the optimal solution to the above optimization problem.

Proposition: *Under the assumption $p_u - v_u \geq p_n - v_n$, the bookstore's expected profit function is concave on its buyback price decision c_b. The optimal buyback price is the solution to the following equation.*

$$(p_u - v_u + v_n - p_n)F(D - a_u - \tau - ec_b) + (b + p_n - v_n)F(D - a_u - \tau - ec_b - y_n)$$

$$= \frac{a_u + \mu + 2ec_b - ev_n}{e}$$

Proof of Proposition: Taking the first derivative on $E[\Pi]$ with respect to c_b, we have,

$$\frac{dE[\Pi]}{dc_b} = \int_{D-a_u-\tau-ec_b}^{\infty} ev_u f(u) du + \int_{D-a_u-\tau-ec_b-y_n}^{D-a_u-\tau-ec_b} e[p_u - p_n + v_n] f(u) du$$

$$+ \int_0^{D-a_u-\tau-ec_b-y_n} e[p_u + b] f(u) du - a - 2ec_b - \mu$$

Further,

$$\frac{d^2E[\Pi]}{dc_b^2} = e^2 f(D - a_u - \tau - ec_b)[v_u - p_u + p_n - v_n]$$

$$+ e^2 f(D - a_u - \tau - ec_b - y_n)[-b - p_n + v_n] - 2e$$

Yuanjie He and Abolhassan Halati
Reverse Logistic Product Pricing Decision in a Supply Chain
with Substitutable Product and Random Yield

The first term is non-positive as we have assumed $p_u - v_u \geq p_n - v_n$. The second term is also non-positive since $b \geq 0$ and $p_n > v_n$. Also, the sensitivity parameter $e > 0$. Therefore, $\dfrac{d^2 E[\Pi]}{dc_b^2} < 0$. The proof is now complete.

The assumption $p_u - v_u \geq p_n - v_n$ implies that the bookstore has higher incentive to sell used books than new books. As described earlier this is a plausible assumption since the profit margin for used books is commonly higher than new books. The Bronco bookstore at Cal Poly, Pomona has 56% profit margin on used books and 34% for new books. Similar behavior may also be present in car sales where used vehicle have higher profit margin than new cars.

If it is further assumed that the buyback random yield distribution has a uniform distribution on $[0, A]$, then the optimal buyback price, c_b^*, may be obtained from,

$$c_b^* = \frac{(D - a_u - \tau)(p_u - v_u + b) + Av_n - A\dfrac{a_u + \mu}{e} - (b + p_n - v_n)y_n}{(p_u - v_u + b)e + 2A}$$

It is interesting to note that c_b^* is not a monotone function of e.

IV. NUMERICAL EXAMPLE

Numerical studies were conducted to assess the relationship between the optimal buyback price and the student sensitivity to buyback price changes. Sales and financial data was collected for operations management course text book, "Operations Management" by Stevenson for the period between Fall 2009 through Fall 2010. In fall 2009 the new edition of the textbook was adopted and sales data from prior quarters was judged inconsistent with the purpose of the study. Needless to say that the available four quarters of sales and financial data is not sufficient to determine the random yield statistical distribution and to properly calibrate a number of model parameters.

The quarterly total sales, excluding summer quarter ranged from a low of 177 to a high of 210 with an average of 188 which is the value used for textbook demand. For the same period, the total number of used books acquired through student buyback was between 74 and 113 books. In absence of sufficient supporting data, random yield distribution is assumed to be uniform (0, 74). For new books the purchase price was $146.00 and for the used books it was $92.23. The corresponding retail sales prices were $195.95 and $146.95 respectively. These same values are used in this study.

The publishers provided a partial refund of 95% of the purchase price for returned new textbooks after deducting 5% restocking fee and the wholesalers provided only 20% refund. Therefore, the salvage values for the new and used textbooks are set to $186 and $29.39 respectively. For holding cost and freight charges estimates developed in Halati and He (2007) are also used in this study. Holding cost is approximated as the ratio of the bookstore controllable and uncontrollable costs to cost of goods sold and are set to 15% of purchase price for both new and used books and the new book emergency ordering freight cost is estimated as 2.5% of the purchase price. The initial inventory for new books is assumed to be zero.

In recent years there has been a gradual decrease in the quantity of text books that were purchased from the used book wholesalers. For realization of demand from used book from wholesalers, τ, values in the range of 20 to 40 and for a_u, values in the range of 5 to 20 were used to perform numerical evaluations to assess the sensitivity of the results to these model parameters. All numerical evaluations exhibited

Yuanjie He and Abolhassan Halati
Reverse Logistic Product Pricing Decision in a Supply Chain
with Substitutable Product and Random Yield

similar pattern of behavior as the one shown in Figure 1 which shows the result of the numerical evaluation for $\tau = 25$, $a_u = 10$.

As the sensitivity parameter, *e,* increases, the optimal buyback price, c_b^*, first increases at a fast rate and then gradually decreases. This behavior indicates that for low customer sensitivity toward buyback or reverse logistics prices, it is in the interest of the bookstore to offer stronger price incentive. However, it should also be realized that for students with high sensitivity to buyback prices, it is not the best strategy to offer higher and higher buyback price and actually, the buyback price should be slightly reduced. For the range of parameter values used in this study, a buyback price of $100 to $125 covers a wide range of sensitivity parameter values. This observation is consistent with the current practice of offering a buyback price which amounts to 50% of the new book selling price (i.e. $92.50). The results also consistently indicated that there is an upper limit on the buyback price which appears to be around $127.

FIGURE 1: IMPACT OF SENSTIVITY PARAMETER ON THE OPTIMAL BUYBACK PRICE ($\tau = 25$, $a_u = 10$)
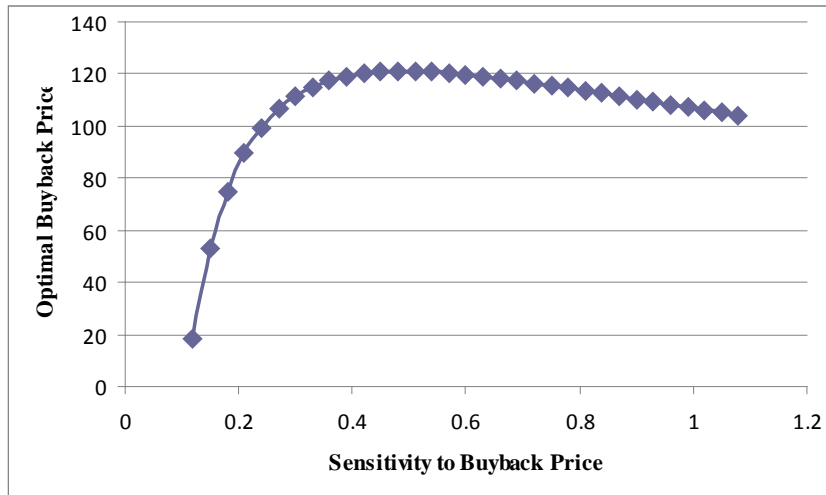
Given the observed changes within the dependent variable ROA documented in Tables 2a and 2b, our analysis employs a period dummy, PDUM. This variable is designed to indicate potential change in either the regression intercept or the slope parameter of DAYS between the respective pre- and post-event periods. In particular, the regression coefficient b_1 measures the change in the intercept term while b_6 performs a similar function for the slope coefficient on DAYS. To aid the reader, we include the following case illustrations on this method:

V. CONCLUSION

In this paper we examined the complex channel relationships present in a retail university bookstore. A single period model for buyback decision process under product substitution and stochastic yield was developed. The model was evaluated under realistic conditions using operational and financial data obtained from the Bronco university bookstore at Cal Poly, Pomona. The results indicated presence of a maximum buyback price and a threshold value for the sensitivity parameter below which it is in the interest of the management to offer stronger price incentive and when the threshold is crossed management

Yuanjie He and Abolhassan Halati
Reverse Logistic Product Pricing Decision in a Supply Chain
with Substitutable Product and Random Yield

should gradually decrease the buyback price. Future research is expected to study the joint impact of additional channel relationships.

VI. REFERENCES

Gerchak, Y., Tripathy, K., and K. Wang, "Co-production models with random functionality yields", IIE Transaction, 28, 1996, 391–403.

Halati, A., He, Y., and X. Xu, "Inventory Management with Product Substitution and Stochastic Yield", California Journal of Operations Management, 5(1), Feb. 2007, 12-18.

Inderfurth, K., "Impact of uncertainties on recovery behavior in a remanufacturing environment: A numerical analysis", International Journal of Physical Distribution & Logistics Management, 35(5), 2005, 318-336.

Mukhopadhyay, S.K. and R. Setoputro, "Reverse logistics in e-business: optimal price and return policy", International Journal of Physical Distribution & Logistics Management, 34, 2004, 70-88.

Pasternack, B.A., "Optimal Pricing and return policies for perishable commodities", Marketing Science, 4(2), 1985, 166-176.

Salema, M.I.G., Barbosa-Povoa, A.P., and A.Q. Novais, "An optimization model for the design of a capacitated multi-product reverse logistics network with uncertainty", European Journal of Operational Research, 179(3), 2007, 1063-1077.

Shulman, J.D., Coughlan, A.T., and R.C. Savaskan, "Optimal Restocking Fees and Information Provision in an Integrated Demand-Supply Model of Product Returns", Manufacturing & Service Operations Management, 11(4), 2009, 577-594.

Wilcox, W., Horvath, P.A., and S.E. Griffis, "A Markov Model of Liquidity Effects in Reverse Logistics Processes: The Effects of Random Volume and Passage", International Journal of Production Economics, 129(1), 2011, 86-101.

Yano, C.A., and H. Lee, "Lot Sizing with Random Yields: A Review", Operations Research, 43(2), 1995, 311-334.