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## Buyback contracts with price-dependent demands: Effects of demand uncertainty

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### ABSTRACT

We explore buyback contracts in a supplier–retailer supply chain where the retailer faces a price-dependent downward-sloping demand curve subject to uncertainty. Differentiated from the existing literature, this work focuses on analytically examining how the uncertainty level embedded in market demand affects the applicability of buyback contracts in supply chain management. To this end, we seek to characterize the buyback model in terms of only the demand uncertainty level (DUL). With this new research perspective, we have obtained some interesting new findings for buyback. For example, we find that (1) even though the supply chain's efficiency will change over the DUL with a wholesale price-only contract, it will be maintained constantly at that of the corresponding deterministic demand setting with buyback, regardless of the DUL; (2) in the practice of buyback, the buyback issuer should adjust only the buyback price in reaction to different DULs while leave the wholesale price unchanged as that in the corresponding deterministic demand setting; (3) only in the demand setting with an intermediate level of the uncertainty (which is identified quantitatively in Theorem 5), buyback provision is beneficial simultaneously for the supplier, the retailer, and the supply chain system, while this is not the case in the other demand settings. This work reveals that DUL can be a critical factor affecting the applicability of supply chain contracts.

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## 1. Introduction

It is well-known that because of the effect of double marginalization, the wholesale price-only contracts often lead to some impairment in the efficiency of the supply chain facing uncertain end market demand. In order to mitigate this loss of efficiency, numerous other contracting mechanisms have been developed in supply chain management. Typical among these is the buyback mechanism, by which the retailer still pays a wholesale price for each unit ordered, but is allowed to return at the end of the selling season all or part of the unsold items to the supplier with a predetermined full or partial refund per unit. Buyback contracts have been exploited extensively in various retail sectors such as publishing, fashion apparels, computers, and cosmetics (Kandel, 1996; Padmanabhan & Png, 1995, 1997; Emmons & Gilbert, 1998).

It is frequently observed in the retail industry that the retailer only has some knowledge (such as probabilistic knowledge) about the demand but not accurate and full information of the exact demand trend/curve. This situation arises when, e.g., the future (macro) market environment is uncertain (see Vaagen and Wallace (2008) for an illustration). Furthermore, the demand uncertainty level (DUL) often varies across different business settings, as reported by Nahmias and Smith (1994), it is common for the retail industry to observe a variability from 3 to 300 in the variance-to-mean ratio of demand. Motivated by these observations in industry, in this paper we take such demand uncertainty into account and explore its effects on the buyback contracts, with a supplier–retailer supply chain where for future demand, the retailer only knows the respective probabilistic price-dependent demand curve.

To existing research, a fundamental contribution of this work is to analytically examine how the uncertainty level inherent in market demand affects the applicability of buyback contracts in supply chain management. To this end, we seek to characterize

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the buyback model in terms of only the DUL. As shown by this work, taking such a research perspective does allow us to analytically develop some new results and obtain some interesting and profound findings for the buyback contracts. For instance, but not limited to, we have identified how the DUL relates to the buyback's efficiency and the analytical circumstances under which buyback increases the profit of the supplier, the retailer, or both and subsequently achieve Pareto-improvement in a decentralized supply chain setting. With these explorations, we obtain some interesting new findings for buyback. For example, we find that (1) even though the supply chain's efficiency will change over the DUL with a wholesale price-only contract, it will be maintained constantly at that of the corresponding deterministic demand setting with buyback, regardless of the DUL; (2) in the practice of buyback, the buyback issuer should adjust only the buyback price in reaction to different DULs, while leave the wholesale price unchanged as that in the corresponding deterministic demand setting; (3) only in the demand setting with an intermediate level of the uncertainty (which is identified quantitatively in [Theorem 5](#) of the paper), buyback provision is beneficial simultaneously for the supplier, the retailer, and the supply chain system, while this is not the case in the other demand settings; and vice versa.

In industry we can observe that in the same business setting, some forms of contracts are exploited more often than another, or the same form of contract is utilized more often in one specific business setting than in another business setting. Why is this the case? Even though we have never seen a systematical investigation on this issue, we note that some factors have been found to have significant effects on the applicability of supply chain contracts. For example, [Marvel and Peck \(1995\)](#) showed that the uncertainty type (they considered the valuation uncertainty and the consumer arrival number uncertainty) is one crucial factor. [Cachon \(2003, chap. 6\)](#) pointed out contract's administrative cost may also be one. With this study, we believe that DUL is another important dimension affecting the applicability of supply chain contracts. Of course, similar to other modeling research's limitation, our results and findings are derived based on the model setup and we cannot generalize them to all business settings. Despite the acknowledged limitations, we believe that our paper has revealed some important analytical closed-form properties of buyback contracts and made a good contribution to the related literature.

The remainder of the paper is organized as follows: [Section 2](#) reviews the relevant literature. [Section 3](#) formulates the model. [Section 4](#) characterizes the supply chain with wholesale price-only contract. [Section 5](#) characterizes the supply chain with buyback provision. [Section 6](#) discusses the value of buyback for the respective supply chain members and the system. [Section 7](#) examines the efficiency of buyback in coordinating the supply chain. [Section 8](#) explores the effects of buyback on the retail price. [Section 9](#) concludes the paper. All the proofs are put in Online Supplementary Appendix.

## 2. Literature review

There is a substantial literature on supply chain contracts. To enhance our exposition and highlight this paper's contributions, we will review only the literature that is the most closely related to our work and refer readers to excellent review papers by [Lariviere \(1999, chap. 8\)](#), [Tsay et al. \(1999, chap. 10\)](#), and [Cachon \(2003, chap. 6\)](#) for more details on this topic.

The first related research stream examines buyback in the classical price-taking newsvendor setting. [Pasternack \(1985\)](#) appears the first to explore the channel coordination issue with buyback contracts in this setting. He showed that (i) allowing full returns with full credit and allowing no returns are both channel

suboptimal and (ii) there exists a continuum of coordinating full-returns policies with partial credit that is independent of the demand distribution in the end market. Furthermore, the resulting coordinated profit can be allocated arbitrarily by a proper choice of the contract terms in the continuum. A commentary on this paper is available in [Pasternack \(2008\)](#). More research on buyback in this setting can be found in, e.g., [Donohue \(2000\)](#), [Tsay \(2001\)](#), with some additional complexities in their models.

The second related research stream explores buyback in a stochastic price-dependent demand setting, which our paper is classified to. In general, there is no buyback contract that can attain coordination in this setting except for more complex variations with it ([Bernstein and Federgruen, 2005](#); [Cachon, 2003, chap. 6](#); [Chen and Bell, 2011](#); [Chiu et al., 2011](#)). Hence, research of the buyback contract in this setting generally does not address the coordination issue, rather, it analyzes the decentralized setting in a Stackelberg framework. [Emmons and Gilbert \(1998\)](#) examined the effects of buyback on supply chain members' profits in a decentralized manufacturer–retailer supply chain with price-dependent multiplicative demand. [Granot and Yin \(2005\)](#) studied buyback in a similar framework. By assuming several types of deterministic demand functions, multiplied by a uniformly distributed random part, they analytically explored the Stackelberg equilibrium, the resulting supply chain members' profits, and the efficiency of using buyback. [Song, Ray, and Li \(2008\)](#) integrated the various demand-specific insights on the buyback contract from [Granot and Yin \(2005\)](#) and other sources, and extended them to develop fairly general structural properties of the optimal buyback contract for price-dependent multiplicative demand setting. Different from the above reviewed papers, we explore buyback in a price-dependent additive demand setting. It is worth noting that the main results developed by the above mentioned papers for multiplicative demand setting generally cannot be extended to additive demand setting. As pointed out by [Song et al. \(2008\)](#), none of the major results developed by them with multiplicative demand remains valid for additive demand. Furthermore, according to [Granot and Yin \(2005\)](#), it is more challenging to deal with additive demand model than multiplicative demand model. Nevertheless, in this paper, we are able to derive explicitly the Stackelberg equilibrium and the respective insights with additive demand, and hence make a contribution to the literature.

The most related research to our paper is [Padmanabhan and Png \(1997\)](#), which studied buyback in two market environments respectively, one is a competitive retail environment with deterministic demand curves and the other is an uncertain downward-sloping demand curve with no retail competition. For the first market environment, they showed buyback can increase the supplier's profit by intensifying the retail level competition. However, this result was disproved later by [Wang \(2004\)](#). Subsequently, [Padmanabhan and Png \(2004\)](#) returned to the problem and showed that this result holds only in the presence of demand uncertainty. For the second environment, they explored the conditions under which buyback can increase the supplier's profit. Our work is the most related to their studies of buyback for the second market environment, however, with some fundamental differences as follows:

First, they explored buyback by assuming full returns with full credit, which means only one decision variable, the wholesale price, is involved in their buyback scheme. Even though this considerably simplifies their model analysis, it imposes a restriction on the strategy space of the supplier and consequently results in a suboptimal outcome (see the discussions following [Theorems 4 and 5](#) for more details). Differentiated from them, we consider a full returns scheme with partial or full credit, which involves two decision variables. We argue that such a change is essential, because, as shown by our study, their buyback model leads to a

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