Int. J. Production Economics 146 (2013) 337–345

Contents lists available at ScienceDirect

Int. J. Production Economics

journal homepage: www.elsevier.com/locate/ijpe

Delayed production and raw materials inventory under uncertainty

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ARTICLE INFO

Article history:
Received 13 August 2012
Accepted 22 July 2013
Available online 9 August 2013

Keywords:
Raw materials inventories
Sunk costs
Safety stock
Uncertainty
Mean preserving spread
Newsvendor model

ABSTRACT

Firms producing seasonal goods often make order and production choices prior to highly uncertain sales, thus lending an investment quality to their decisions. Using specialized inputs imposes a delay in receiving them and linked with a long production period the firm makes its order, production and pricing choices under successively reduced uncertainty. The model shows that input and production costs have distinctive effects on the firm's order size with implications for the stock of raw materials inventory. Firms facing relatively low input costs are willing to risk leaving inputs unused as a bet for a good state of nature. Further, we investigate situations of greater uncertainty and find a more nuanced explanation of firm behavior than previous research. Firms with relatively inexpensive inputs facing equal odds of good and bad states of nature will increase their order size (a known result). However, a firm with a low relative cost of completing production may either raise or reduce its order size depending on the demand elasticity and the relative demand uncertainty. Intuitively, firms with expensive inputs facing highly uncertain demand and with many substitute output goods are inhibited by the high cost of insuring against stock-outs.

1. Introduction

It is well documented that inventories play an important role in the business cycle. "…the drop in inventory investment has accounted for 87 percent of the drop in GNP during the average postwar recession…" Blinder and Maccini (1991). This role has motivated much research in inventories. However, Blinder and Maccini (1991), Bivin (1989) and Humphreys et al. (2001) note that most of this research focuses on finished goods inventory while input (i.e. raw materials and work-in-process) inventories comprise a larger part of aggregate inventories and are also more volatile. Humphreys et al. (2001) extend the linear-quadratic model of output inventories by adding the joint determination of input inventories. Researchers now more frequently include input inventories in their analyses, e.g. Herrera et al. (2008).

Our model motivates firms' use of raw materials inventories as a secondary defense to finished goods inventory against lost sales, following e.g. Crowston et al. (1973), Bivin (1989), and Emery and Marques (2011). In this paper we focus exclusively on raw materials inventory; the full flexibility of output prices eliminate the possibility of finished goods inventories. Specifically, we examine those inputs the firm orders which are slated to be later used in production only in the good state of nature. Should the firm find itself in the bad state of nature, it will optimally cancel the production of some goods which then become unused raw materials. We interpret these set-aside inputs as an insurance payment that would have protected the firm from lower sales and profits had the good state of nature occurred. One of our main goals is to determine the influences on the amount of such raw materials.

In our model, a risk-neutral single product firm makes a decision in each of three periods. It first chooses an input quantity to order from its supplier. The state of nature is then revealed, informing the firm about whether the demand distribution is favorable or unfavorable. The second decision follows, a choice of the quantity of inputs to submit to the production process. Finally, after the demand curve is realized, the firm chooses a price. A simple pair of distributions permits to derive reduced form solutions using standard backward induction.

The firm we study has price setting ability; an example of such a firm might be a style goods producer (e.g. those making fashion goods and other apparel or bicycles), goods which are the epitome of a differentiated good. Sen (2008) cites US Department of Commerce that shows that the domestic apparel market is dominated by 12 major retail groups. Further, we assume that the firm makes a single input order per season, justified for example by a long production lead time at the upstream supplier of specialized inputs. Style goods producing firms must thus commit to purchase inputs prior to production. They also have a short selling season of high demand uncertainty (Silver et al., 1998; Sen, 2008; Choi, 2007; Hammond and Raman, 1996). Style goods often require a long production time. Bivin (1999) [using a

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http://dx.doi.org/10.1016/j.ijpe.2013.07.022

method derived by Carlson (1973)] estimates US industries' production lag for durable industries to "…cover a wide range of values" but that "…the lags are generally in excess of two months".[1] Sen (2008) cites a Deloitte and Touche estimate of a 26 week average concept-to-production cycle time for the apparel industry.

The firm in our model explicitly decomposes its order quantity into two parts; a fixed baseline part, *F*, which the firm will set to production whatever state of nature occurs. In addition it chooses a discretionary part, *D*, it aims to produce only in the good state of nature. These are the inputs to become unused raw materials inventories if the bad state of nature occurs. We note that quantity *F* is not riskless. If the demand realization is lower than expected, the firm will set a low price on its output good to reduce profits.

With a lower probability of a good state of nature, the firm views it more likely that part *D* of the input order will be wasted. Accordingly the firm tries to reduce *D* and indeed at some low probability to choose a negative *D*. As this is not reasonable behavior, we restrict *D* to be non-negative. We also define a threshold probability p_0 at which *D* is zero and find it increasing in input cost (*C*) relative to production cost (*W*).

Our model predicts that firms will have different threshold probabilities and thus distinct behavior concerning raw materials. Those firms with low input costs relative to completing products (low p_0) are likelier to sacrifice inputs as unsold raw materials inventory (even at zero scrap value) compared to firms facing higher relative input costs. This is intuitive. Rossana (1990) checked distinct input and production costs in three durable goods and the apparel industries in the only empirical analysis we are aware of. He found only in the (seasonal) apparel industry did raw materials prices have a significantly negative influence on raw materials stocks and that only in this industry did wage costs have a positive (albeit insignificant) effect on raw materials stocks. While this is consistent with our model, a more complete empirical study would clarify behavior of firms exposited in this paper.

We also investigate firm behavior after a rise in uncertainty; it affects firms differently based on their relative costs. At equal probabilities of a good and bad state of nature, a firm with relatively cheap inputs (a low threshold probability p_0) increases its order size while a firm with a low relative cost of completing production (a high threshold probability p_0) may reduce its order size. Intuitively, the latter firm may be inhibited by the cost of insuring against lost sales. As mentioned in Gerchak and Mossman (1992), the former result is standard in the literature of cost-minimizing single product order decisions while the latter result is intuitive and novel.

We have used backward induction to determine the firm's correct decisions over time. However, we have not imposed the firm's subsequent choices in each prior decision. And interestingly the firm in early choices acts to restrict its later self. Indeed when the firm faces a probability less than the threshold probability it will choose an order amount less than the amount it will optimally produce at time 1. It does this of course because at time 1 its input costs are sunk while at time 0, the order time, they are not. We note the firm often ties its own hands in its various choices.

The remainder of the paper is structured as follows: in Section 2 we briefly review related literature and then in Section 3 we introduce the basics of the model. In the subsequent section after specifying the uncertainty in the model, we analyze an optimizing firm facing constant elasticity and stochastic demand at its single main sales date. In Section 5 we examine the effects on order choice of an increase in uncertainty. In Section 6 we conclude.

[1] According to his Table 1, the chemical industry production lag is shortest at 0.89 months, while the corresponding length for the non-auto transportation sector is 7.99 months. For non-durable goods industries he finds the lag to be between 1.5 and 2.2 months.

2. Literature review

The model used in this study is related to the inventory, production vs. order, and single period order quantity newsvendor (or newsboy) literatures.

While the majority of inventory research has focused on finished goods, others have investigated raw materials inventories. Emery and Marques (2011) recently used a lens of transactions costs economics to determine whether a firm will hold raw materials inventories or its supplier will hold the identical intermediate goods as finished goods inventories. We assume that the supplier produces goods to order requiring time the downstream firm must consider in its plans. Bivin (1989) on the other hand determines in a flow model why cost-minimizing firms would choose to hold safety stocks as input inventories or output inventories. In our model flexible prices ensure all production is sold, so that the profit maximizing firm chooses an optimal order size, some of which may not be produced, a sacrifice taking the form of raw materials inventories. A firm in the Moon and Choi (1997) one period model satisfies demand using cheaper finished goods inventory (purchased or produced prior to the period) or making-to-order at higher cost. In our model, inputs must be transformed into finished goods to meet demand. The key issue is whether the firm can avoid the costs of production should demand be expected to arise from an unfavorable distribution.

Crowston et al. (1973) set up a production scheduling problem in which a firm tries to minimize inventories at each stage of a multistage process. The firm updates its demand forecast and tries to avoid excess inventories at each stage. Seen from an inventory perspective, this is a work-in-process inventory model in which raw materials are taken as a given. Kogan and Herbon (2008) similarly treat raw materials in determining the optimal production rate. In the Bryan et al. (1955) model, the firm again has a multistage production and inventory problem but does not receive updated information on the demand distribution. The firm in Bryan et al. (1955) holds raw materials inventory to the extent that consumers are willing to wait after finished goods inventories have been sold out. In our model, raw materials *F* are always used up and those *D* are foreseen at order time to remain unused at production time if the firm faces an unfavorable distribution.

Petruzzi and Dada (1999) review the newsvendor model with exogenous shortage and surplus costs in which price and quantity are chosen simultaneously in the face of random demand. We include production in this model. In our model a shortage or surplus affects the firm's profits endogenously by their impact on its price chosen subsequent to its order and production decisions. We use a very simple probability density function in order to obtain reduced form expressions for the firm's optimal choices.

Recent research has included production in the newsvendor model. For instance, Van Mieghem and Dada (1999) investigate pricing and production timing possibilities that different firms may face using a two period model. See also Tang et al. (2012). The firm in Van Mieghem and Dada always makes its capacity decision, corresponding to the order decision in our model, prior to the resolution of uncertainty. They investigate firms with differing abilities to delay price or production choice until after the uncertainty is resolved. According to their logic, the timing of the resolution of uncertainty implies our firm sequentially postpones production and then postpones price. In our model the excess of the order quantity over the production quantity (a choice subject to uncertainty) represents the quantity of raw materials that have insured the firm against lost sales. In their model of price