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The Liquidity Demand for Corporate Property Insurance

Arthur Hau

Abstract

This article suggests that liquidity may be an important reason for a corporation to purchase property insurance. A model of a risk-neutral producer facing an endogenously determined risk of property damage under an output contract that penalizes underproduction is formulated to exemplify such a real need of liquidity. Under the output contract, the producer may purchase full unfavorable property insurance even when postloss financing is available. Surprisingly, the conclusion may still hold when the cost of postloss financing equals that of long-term capital, provided that the rate of underproduction penalty is sufficiently high. Similar conclusions apply when postloss financing is replaced by planned internal reserve (self-insurance) that may be invested in the short run at an interest rate that is lower than the long-term cost of capital. When the capital market is perfect, however, the holding of planned internal reserve eliminates the purchase of actuarially unfavorable property insurance.

Introduction

According to Mayers and Smith (1982), shareholders can eliminate insurable risk through diversification so that corporations have no real need for purchasing actuarially unfavorable property insurance. Various authors have provided plausible explanations for optimal corporate insurance purchase with risk-neutral shareholders. Mayers and Smith (1982) and MacMinn (1987) suggest that a widely held corporation may purchase insurance to avoid the costs of bankruptcy. Mayers and

Arthur Hau is Associate Professor at the Department of Finance and Insurance, Lingnan University, Tuen Mun, N.T., Hong Kong, People's Republic of China. The author can be contacted via e-mail: ahau@ln.edu.hk. Financial support from the University Research Grants and Academic Programme Research Grants (Business, grant reference DB03A2) of Lingnan University is highly appreciated. The author wishes to thank the participants of the 7th Asia Pacific Risk and Insurance Association Annual Meeting for their constructive comments and two anonymous referees and one of the editors, Professor MacMinn, for their valuable comments that have led to substantial improvements of this article. Particularly, one of the referees has pointed out the importance of incorporating alternative sources of financing capital replacement into the model. The other referee has drawn the author's attention to some existing literature that is directly related to this article. All errors in this article belong to the author.

Smith (1982) and Main (1983a, 1983b) argue that there are tax incentives for purchasing corporate insurance. Mayers and Smith (1982, 1987), Schnabel and Roumi (1989), and Garven and MacMinn (1993) suggest that property insurance is often required under a bond covenant. Mayers and Smith (1982) argue that insurance companies have high real-service efficiency in handling liability claims. Hoyt and Khang (2000) suggest that insurers have economies of scale in designing and implementing loss prevention techniques. Mayers and Smith (1982) and Han (1996) argue that profit-sharing devices, such as stock options, provided to risk-averse CEOs to resolve potential principal–agent problems may induce the CEOs to purchase corporate insurance to protect their own interests. Finally, Grace and Rebello (1993) show that in the presence of private information on a company's cash flow and insurable losses, corporate insurance purchase can be optimal when high operating revenue is accompanied by a high insurable risk. Unfortunately, some of these explanations, though theoretically appealing, are not fully supported by simulations and empirical evidence.[1]

Recently, some authors have pointed out the similarities between insurance and other capital funding methods as liquidity provision devices. For instance, Doherty (2000) has advocated the "integrated risk management approach" under which insurance may be considered as an alternative source of short-term capital supplementing preloss and postloss debt financing arrangements for replacing damaged property. Bernstein (2000, p. 25) argues interestingly from a practitioner's point of view that insurance companies provide liquidity to decisions, assets, and outcomes that are inherently irreversible and beyond control that can have harmful consequences to their policyholders. Despite the importance of insurance for providing liquidity, no theoretical model is found in the literature to illustrate the nature of the liquidity demand for corporate insurance and how corporate insurance interacts with other alternatives to finance property damage.

The main purpose of this article is to introduce a new theoretical framework for explaining the purchase of actuarially fair or even unfavorable corporate property insurance by a risk-neutral company. This explanation is based on the fact that property insurance provides additional liquidity to a company that needs to replace damaged property to restore its productivity in order to fulfill maturing output contracts. Unfulfilled contracts often result in penalties that reduce a company's profitability, even without causing its bankruptcy.[2] Following Doherty's integrated approach, alternative methods of financing property replacement, besides corporate property

[1] Warner's (1977) study shows that bankruptcy costs may be relatively insignificant. Yamori (1999) finds that large corporations in Japan with low bankruptcy risk have significant insurance coverage. These suggest that bankruptcy cost may not be totally relevant for corporate insurance purchase. Yamori also shows that the effect of shareholder's equity-to-total-asset ratio on insurance premiums is statistically insignificant suggesting that corporate insurance purchase may not be related to bond covenant requirements. Chen and PonArul (1989) conclude using simulation that the tax benefits of purchasing property insurance are too small compared to typical loadings. Finally, large corporations are more likely to have their own risk management departments meaning that the real service argument for corporate insurance purchase may not apply.

[2] Moreover, an uninsured property loss may lead to a rise in the short-term cost of capital, downgrading of the company's credit rating, business interruption, and shortage of cash. It is

insurance, will be considered in this article. Two cases will be investigated, namely, the case in which postloss financing is available and the case in which internal reserve may be maintained and invested in the short run. The conditions under which corporate property insurance will be purchased in these cases will be derived.

This article is organized as follows. The "The Basic Model" section formulates a model of a risk-neutral producer under the risk of property damage. The "Corporate Property Insurance Demand in the Presence of Postloss Financing" section characterizes an output contract to be fulfilled by a risk-neutral producer. Two types of contracts are identified depending on the penalty rate of contract failure. This is followed by the derivation of the conditions under which property insurance is purchased in each type of contract in the presence of postloss financing. The "Corporate Property Insurance Demand in the Presence of Internal Reserve" section derives similar conditions when postloss financing is replaced by the producer's own planned internal reserve. The "Conclusion" section concludes.

THE BASIC MODEL

A risk-neutral producer produces a single output using a single capital input (such as equipment and raw material inventory). The producer produces under output contract C that specifies fixed output price p and contracted quantity $\hat{Q}$ where $\hat{Q}$ is chosen by the producer.[3] There are two time periods, namely, $t = 0$ and $t = 1$. Output may be produced in each of the two periods. The producer receives revenue based on the actual level of output produced in each period whenever the total output is lower than or equal to the contracted level. Any overproduction above the contracted level results in zero additional revenue; any underproduction is subject to per unit penalty δ.[4] The penalty may be stated explicitly in contract C or may be the result of deteriorated reputation or loss of future orders. Similar implicit penalties are considered in inventory models.[5] In general, even without any output contract, property damage may lead to business interruption and loss of loyal customers if damaged property is not replaced immediately.

stressed in risk management textbooks (see, e.g., Dorfman, 2002; Doherty, 2000) that liquidity management is an important topic in risk management.

[3] In fact, output markets are not always perfect in the sense that a producer is usually not a seller that sells its output directly in a competitive market. Instead, many producers produce under output contracts in which the inability to produce at some prespecified levels leads to penalties or even cancellation of contracts. According to Banker and Perry (1999), 21.7 percent of the value of crops and livestock, particularly fruits and vegetables, were produced under fixed-price contracts in the United States in 1997. Obviously, there are many other examples of output contracts. For instance, many manufacturers producing computer hardware, car and electronic parts, and textile products contract with original equipment manufacturer (OEM) customers. Well-known examples of OEM customers are IBM Corp., Hewlett-Packard Co., and large supermarkets selling "no-frill" generic products. Tertiary producers, such as construction contractors, trucking companies, and airlines often engage in service contracts.

[4] The actual output level may exceed the contracted level. It is assumed that there is neither cost of disposal nor salvage value for any excess output. This simplifying assumption will not affect the main conclusion on full property insurance purchase in this article.

[5] Kim and Chung (1989) suggest that if a company sells a product after a certain demand period, the value of the product can diminish significantly due to obsolescence, change in consumer tastes, or change in regulations.

At the beginning of $t = 0$, initial capital K_0 is financed by long-term capital arrangement at gross cost rate (i.e., $1 +$ net cost rate) r. For simplicity, capital is assumed to last for two periods and can only be used to produce the contracted output (i.e., it is project-specific or contract-specific). Moreover, even though capital is subject to zero depreciation, it is assumed that capital has zero salvage value by the end of $t = 1$ (because all capital will become obsolete by then). Since the producer's capital structure is not a concern in this article, one may think of r as either the long-term borrowing rate or the required rate of return of shareholders. The cost of initial capital investment by the end of $t = 1$ equals $r^2 K_0$. By the end of $t = 0$, production technology Q with $Q' > 0$ and $Q'' < 0$ (i.e., the marginal product of capital is positive and decreasing) gives rise to certain output $Q(K_0)$. Provided that $Q(K_0) < \hat{Q}$, the producer obtains $pQ(K_0)$ at the beginning of $t = 1$ with a value of $rpQ(K_0)$ by the end of $t = 1$.

At the beginning of $t = 1$, K_0 is subject to a one-time risk of property damage, $\tilde{x}$, such that without capital replacement, usable capital becomes $(1 - \tilde{x})K_0$. Assume that $\tilde{x}$ can take only two possible realizations, namely 0 (in the good state) and $\bar{x} \in (0, 1]$ (in the bad state) with probabilities $1 - \beta$ and β, respectively. Since bankruptcy cost is not a concern here, $\bar{x}$ is assumed to be sufficiently small such that bankruptcy will not occur.

Suppose property insurance becomes available at the beginning of $t = 0$. The producer can choose indemnification rate $\alpha \in [0, 1]$. Let $a \geq 1$ be the gross loading factor (i.e., $1 +$ loading factor). An insurance policy is said to be actuarially fair (c.f. unfavorable) when $a = 1$ (c.f. $a > 1$). To receive cash indemnity $\alpha \bar{x} K_0$ in the bad state at the beginning of $t = 1$, the producer has to pay premium $a\alpha\beta r^{-1}\bar{x}K_0$ at the beginning of $t = 0$ financed by long-term capital arrangement such that its cost by the end of $t = 1$ equals $a\alpha\beta r^{-1}\bar{x}K_0 \times r^2 = a\alpha\beta r\bar{x}K_0$.

In the bad state, the producer uses the cash indemnity to replace any damaged capital such that in the absence of other financing methods, usable capital at the beginning of $t = 1$ equals $[1 - (1 - \alpha)\bar{x}]K_0$. One can write the random capital available at the beginning of $t = 1$ as $[1 - (1 - \alpha)\tilde{x}]K_0$. The output produced by the end of $t = 1$ equals $Q\{[1 - (1 - \alpha)\tilde{x}]K_0\}$ and the (future value of) total revenue generated under contract C in the absence of other means of financing, therefore, equals $rpQ(K_0) + pQ\{[1 - (1 - \alpha)\tilde{x}]K_0\}$.

Before proceeding, note that it can be shown that in the presence of a perfect output market (in which a producer can sell any output at the prevailing competitive market price) and a perfect capital market (in which short-term capital is always available at an interest rate that is equal to the cost of long-term capital), a risk-neutral producer purchases property insurance only if it is actuarially fair or favorable exactly as suggested by Mayers and Smith (1982).[6] In the presence of an output contract, however, full property insurance may be purchased even if it is actuarially unfavorable. Two cases will be analyzed in the forthcoming sections, namely, the case with postloss financing and the case with planned internal reserve.

[6] The proof of this claim can be obtained from the author on request.

CORPORATE PROPERTY INSURANCE DEMAND IN THE PRESENCE OF POSTLOSS FINANCING

Characterizing the Producer's Output Contract

Suppose the producer can obtain postloss financing at gross cost rate (short-term borrowing rate) R that is greater than or equal to long-term cost of capital r (i.e., $R \geq r$). R is likely to be strictly greater than r when postloss financing is acquired from unplanned internal fund resulting in the displacing of other profitable projects or when short-term capital is hard to obtain due to capital market imperfection. In the presence of postloss financing, the capital available at the beginning of $t = 1$ can be written as

$$\tilde{K} = [1 - (1 - \alpha)\tilde{x}]K_0 + \Delta K,$$

where ΔK is the amount of capital replacement using postloss financing. Denote the realized value of $\tilde{K}$ in the bad state by K_1 such that

$$K_1 = [1 - (1 - \alpha)\bar{x}]K_0 + \Delta K.$$

Assume for simplicity that $K_0 \geq K_1$ for all $\alpha \in [0, 1]$ and all $\Delta K \geq 0$.[7] This assumption will be maintained throughout this article. The above discussion suggests that by the end of $t = 1$, the contract gives the producer

$$\begin{cases} p[r\,Q(K_0) + Q(\tilde{K})] - \delta[\hat{Q} - Q(K_0) - Q(\tilde{K})] & \text{if } Q(K_0) + Q(\tilde{K}) < \hat{Q}; \\ p\{r\,Q(K_0) + [\hat{Q} - Q(K_0)]\} & \text{if } Q(K_0) + Q(\tilde{K}) \geq \hat{Q}. \end{cases}$$

The following lemma relates $\hat{Q}, K_0, \Delta K$, and α under contract C:

Lemma 1: *The risk-neutral producer chooses $\hat{Q}, K_0, \Delta K$, and α such that $\hat{Q} \in [Q(K_0) + Q(K_1), 2Q(K_0)]$.*

Proof: See the Appendix.

Lemma 1 suggests that the producer chooses an output contract that is no larger than what is achievable in the good state and that is at least as large as what is achievable in the bad state, regardless of the optimal values of K_0, ΔK, and α. Clearly, having a contract that is not achievable even in the good state always results in unnecessary penalty and having a contract that is smaller than what is achievable in the bad state results in unnecessary loss in revenue.

[7] This assumption may affect some of the results in this article. However, the assumption is realistic and allows us to focus on capital replacement due solely to property losses. Note $K_1 > K_0$ implies that initial capital investment is less than full. This is possible only when β and $\bar{x}$ are jointly sufficiently large giving rise to a sufficiently large expected capital damage such that additional capital purchase may exceed capital replacement at the beginning of $t = 1$.

Given Lemma 1, the risk-neutral producer's problem reduces to

$$\max_{\{\hat{Q},K_0,\Delta K,\alpha\}} E\tilde{\pi} = \beta\{p[r\,Q(K_0) + Q(K_1)] - \delta[\hat{Q} - Q(K_0) - Q(K_1)]\} + (1-\beta)p\hat{Q}$$
$$- r^2 K_0 - a\alpha\beta r\bar{x}K_0 - \beta R\Delta K \qquad (1)$$

subject to

$$\hat{Q} \in [Q(K_0) + Q(K_1), 2Q(K_0)].$$

Denote the optimal values of $\hat{Q}$, K_0, K_1, ΔK, and α by $\hat{Q}^*$, K_0^*, K_1^*, ΔK^*, and α^*, respectively. For the problem to be interesting, assume that $\hat{Q}^* > 0$. The following lemma specifies the relationship between $\hat{Q}^*$, K_0^*, and K_1^*:

Lemma 2: *The risk-neutral producer's optimal choice of $\hat{Q}$ is such that*

$$\delta > \frac{(1-\beta)p}{\beta} \quad \textit{implies} \quad \hat{Q}^* = Q(K_0^*) + Q(K_1^*) \quad (\textit{large-penalty case});$$
$$\delta < \frac{(1-\beta)p}{\beta} \quad \textit{implies} \quad \hat{Q}^* = 2Q(K_0^*) \quad (\textit{small-penalty case}).$$

Proof: See the Appendix.

Lemma 2 is self-explanatory. When penalty rate δ is sufficiently high, the producer chooses the total output achievable in the bad state for $\hat{Q}$; otherwise, the producer chooses the total output achievable in the good state for $\hat{Q}$.

Note that when $(1-\beta)p = \beta\delta$, expected profit is constant for all $\hat{Q} \in [Q(K_0^*) + Q(K_1^*), 2Q(K_0^*)]$. That is, $\hat{Q}$ has multiple solutions. Since the condition holds only by coincidence, the rest of the article focuses on the large-penalty case and the small-penalty case.

Large-Penalty Case ($\hat{Q} = Q(K_0) + Q(K_1)$)

The producer's dynamic programming problem is solved backward. At the beginning of $t = 1$, the producer's problem in the bad state is

$$\max_{\Delta K} pQ(K_1) - R\Delta K$$

with first-order condition

$$pQ'(K_1) - R \leq 0 \qquad (2)$$

such that

$$pQ'(K_1) < R \Rightarrow \Delta K = 0 \text{ with } \frac{d\Delta K}{dK_0} = \frac{d\Delta K}{d\alpha} = 0; \qquad (3)$$

also,

$$\Delta K > 0 \Rightarrow pQ'(K_1) = R \tag{4}$$

with

$$\frac{d\Delta K}{dK_0} = -[1-(1-\alpha)\bar{x}] \quad \text{and} \quad \frac{d\Delta K}{d\alpha} = -\bar{x}K_0. \tag{5}$$

At the beginning of $t = 0$, the producer's problem is

$$\max_{\{K_0,\alpha\}} p[rQ(K_0) + Q(K_1)] - r^2K_0 - a\alpha\beta r\bar{x}K_0 - \beta R\Delta K$$

with first-order conditions

$$\begin{aligned}\frac{\partial E\tilde{\pi}}{\partial K_0} &= p\{rQ'(K_0) + [1-(1-\alpha)\bar{x}]Q'(K_1)\} - r^2 - a\alpha\beta r\bar{x} \\ &\quad + pQ'(K_1)\frac{d\Delta K}{dK_0} - \beta R\frac{d\Delta K}{dK_0} = 0;\end{aligned} \tag{6}$$

$$\frac{\partial E\tilde{\pi}}{\partial \alpha} = p\bar{x}K_0Q'(K_1) - a\beta r\bar{x}K_0 + pQ'(K_1)\frac{d\Delta K}{d\alpha} - \beta R\frac{d\Delta K}{d\alpha} \le 0 \tag{7}$$

subject to (3)–(5) such that

$$\frac{\partial E\tilde{\pi}}{\partial \alpha} < 0 \Rightarrow \alpha^* = 0; \quad \frac{\partial E\tilde{\pi}}{\partial \alpha} > 0 \Rightarrow \alpha^* = 1; \quad \text{and} \quad \alpha^* \in (0,1) \Rightarrow \frac{\partial E\tilde{\pi}}{\partial \alpha} = 0. \tag{8}$$

It can be shown that regardless of the optimal values of α and K_0, there are always plausible conditions under which $\Delta K = 0$ and under which $\Delta K > 0$. Particularly, it can be checked that $\Delta K^* = 0$ whenever[8]

$$[1-(1-\alpha)\bar{x}](Q')^{-1}\left\{\frac{r^2 + a\alpha\beta r\bar{x} - \beta R[1-(1-\alpha)\bar{x}]}{rp}\right\} < (Q')^{-1}(R/p). \tag{9}$$

[8] Suppose by contradiction that $\Delta K^* > 0$ such that (4) and (5) together imply that (6) can be written as

$$Q'(K_0) = \frac{r^2 + a\alpha\beta r\bar{x} - \beta R[1-(1-\alpha)\bar{x}]}{rp}.$$

Substituting this into (9) gives

$$pQ'(K_1) = pQ'\{[1-(1-\alpha)\bar{x}]K_0 + \Delta K\} < pQ'\{[1-(1-\alpha)\bar{x}]K_0\} < R$$

contradicting (3). Therefore, $\Delta K^* = 0$ if (9) holds.

For example, when $Q(K) = \ln K$, given (9), it can be checked that $\Delta K^* = 0$ regardless of the values of α and K_0 if[9]

$$R > \frac{r^2}{(1-\bar{x})(rp+\beta)}. \tag{10}$$

This is intuitive because R is the cost of postloss financing; a sufficiently high cost of postloss financing certainly eliminates its usage. On the other hand, one can let R tend to zero to check that there is always $\Delta K > 0$ satisfying (4).

The above first-order conditions give rise to the following proposition:

Proposition 1: *Suppose a risk-neutral producer under contract C may obtain postloss financing in the large-penalty case. (a) When $\Delta K^* = 0$, if $a < \frac{r}{\beta(r+1+\bar{x})}$, then $\alpha^* = 1$; if $a > R/\beta r$, then $\alpha^* = 0$. (b) When $\Delta K^* > 0$, if $a > R/r$, then $\alpha^* = 0$. (c) If $a > \frac{r}{\beta(1-\bar{x})}$, then $\alpha^* = 0$.*

Proof: See the Appendix.

The following corollary is a direct consequence of Proposition 1.

Corollary 1: *Suppose a risk-neutral producer under contract C may obtain perfect postloss financing (i.e., $R = r$). Under the large-penalty case, full property insurance may be optimal even when it is actuarially unfavorable.*

Proof: See the Appendix.

To understand Proposition 1, it suffices to realize that the unit marginal cost of property insurance equals $a\beta r$. Its unit marginal benefit equals the marginal benefit of capital replacement which is equal to the value of marginal product of second-period capital, $pQ'(K_1)$.

When zero postloss financing is optimal (i.e., $\Delta K = 0$), according to first-order condition (6), the value of marginal product of second-period capital equals its marginal cost (i.e., $pQ'(K_1) = \frac{r^2 + a\beta r\bar{x}}{r+1}$, at $\alpha = 1$ when $K_0 = K_1$). The condition $a < \frac{r}{\beta(r+1-\bar{x})}$ implies that the unit marginal cost of property insurance is smaller than its unit marginal benefit at $\alpha = 1$; therefore, full property insurance is optimal giving rise to the first part of Proposition 1a. For the condition to hold, it suffices to have relatively small loading and probability of damage, and relatively large damage and long-term cost of capital. The former tends to reduce the unit marginal cost of property insurance. The latter tends to raise its unit marginal benefit.

Besides, when $\Delta K = 0$, the marginal cost of postloss financing is greater than its marginal benefit (i.e., $R > pQ'(K_1)$). The condition $a > R/\beta r$ implies that the unit marginal cost of property insurance is larger than its unit marginal benefit at $\alpha = 0$; therefore, zero property insurance is optimal giving rise to the second part of Proposition 1a. The condition holds given relatively large loading, probability of damage and

[9] It suffices to check that $Q(K) = \ln K$ implies that (9) can be written as $R > \frac{r^2}{[1-(1-\alpha)\bar{x}](rp+\beta)}$ which is implied by (10) for all $\alpha \in [0, 1]$.

long-term cost of capital, and a relatively small cost of postloss financing. The first three items tend to raise the unit marginal cost of property insurance, whereas the last item tends to make postloss financing superior to property insurance for capital replacement.

On the other hand, according to first-order condition (6), the unit marginal benefit of property insurance is smaller than $\frac{r^2}{1-\bar{x}}$. The condition $a > \frac{r}{\beta(1-\bar{x})}$ implies that the unit marginal cost of property insurance is larger than its unit marginal benefit at $\alpha = 0$ such that zero property insurance is optimal as shown by the first case in the proof of Proposition 1c. The condition holds when a and β are relatively large and when r and $\bar{x}$ are relatively small. The former implies a relatively large unit marginal cost of property insurance, whereas the latter implies a relatively small unit marginal benefit.

When positive postloss financing is optimal (i.e., $\Delta K > 0$), the marginal cost of postloss financing equals its marginal benefit (i.e., $R = pQ'(K_1)$). A rise in property insurance coverage reduces the need for postloss financing in the bad state such that its expected marginal benefit is derived from expected cost saving $|\beta R d\Delta K/d\alpha| = \beta R\bar{x}K_0$ for using less postloss financing. When $a > R/r$, this is smaller than the marginal cost of property insurance, $a\beta r\bar{x}K_0$, such that no insurance will be purchased as stated in Proposition 1b. The condition holds when a and r are relatively large and when R is relatively small. The former reduces the unit marginal cost of property insurance, whereas the latter raises its cost saving.

Finally, with $\Delta K > 0$ and $R = pQ'(K_1)$, the expected unit marginal cost saving of property insurance equals βR which is again smaller than $\frac{r^2}{1-\bar{x}}$. The condition $a > \frac{r}{\beta(1-\bar{x})}$ again implies that the unit marginal cost of property insurance is larger than its unit marginal benefit at $\alpha = 0$ as shown by the second case in the proof of Proposition 1c.

Small-Penalty Case ($\hat{Q} = 2Q(K_0)$)

At the beginning of $t = 1$, the producer's problem is

$$\max_{\Delta K} pQ(K_1) - \delta[Q(K_0) - Q(K_1)] - R\Delta K \tag{11}$$

with first-order condition

$$(p + \delta)Q'(K_1) - R \leq 0 \tag{12}$$

such that

$$(p + \delta)Q'(K_1) < R \Rightarrow \Delta K^* = 0 \text{ and } \frac{d\Delta K}{dK_0} = \frac{d\Delta K}{d\alpha} = 0; \tag{13}$$

$$\Delta K^* > 0 \Rightarrow (p + \delta)Q'(K_1) = R \tag{14}$$

with (5) still holding.

At the beginning of $t = 0$, the producer's problem is

$$\max_{\{K_0,\alpha\}} E\tilde{\pi} = \beta\{p[rQ(K_0) + Q(K_1)] - \delta[Q(K_0) - Q(K_1)]\} + (1-\beta)p(r+1)Q(K_0)$$
$$- r^2 K_0 - a\alpha\beta\bar{x}rK_0 - \beta R\Delta K$$

with first-order conditions

$$\frac{\partial E\tilde{\pi}}{\partial K_0} = [pr + (1-\beta)p - \beta\delta]Q'(K_0) + \beta(p+\delta)[1-(1-\alpha)\bar{x}]Q'(K_1)$$
$$- r^2 - a\alpha\beta\bar{x}r + \beta(p+\delta)Q'(K_1)\frac{d\Delta K}{dK_0} - \beta R\frac{d\Delta K}{dK_0} = 0; \tag{15}$$

$$\frac{\partial E\tilde{\pi}}{\partial \alpha} = \beta(p+\delta)\bar{x}K_0Q'(K_1) - a\beta r\bar{x}K_0 + \beta(p+\delta)Q'(K_1)\frac{d\Delta K}{d\alpha} - \beta R\frac{d\Delta K}{d\alpha} \leq 0 \tag{16}$$

subject to (12)–(14) and (8). Similar to the "Large-Penalty Case" section, it can be checked that there are conditions under which $\Delta K^* = 0$ and under which $\Delta K^* > 0$.

The above first-order conditions give rise to the following proposition:

Proposition 2: *Suppose a risk-neutral producer under contract C may obtain postloss financing in the small-penalty case. (a) When* $\Delta K^* = 0$, *if* $a < \frac{r(p+\delta)}{p(r+1) - \beta(p+\delta)\bar{x}}$ *with* $p(r+1) - \beta(p+\delta)\bar{x} > 0$, *then* $\alpha^* = 1$. *(b) If* $a > R/r$ *or* $a > \frac{r}{\beta(1-\bar{x})}$, *then* $\alpha^* = 0$.

Proof: The proof is very similar to that of Proposition 1 and is thus omitted. Interested readers may obtain the proof from the author on request.

Proposition 2 is very similar to Proposition 1, except that the unit marginal benefit of property insurance now equals $\beta(p+\delta)Q'(K_1)$ which differs from that under the large-penalty case, namely, $pQ'(K_1)$. Under the large-penalty case, property insurance affects the producer's profit in both the good and the bad states. Whereas α affects K_1, the contract is always fulfilled with probability 1 so that the unit marginal benefit of property insurance does not involve β or δ. Under the small-penalty case, however, property insurance affects the producer's profit only in the bad state. Property insurance compensation not only results in additional value of marginal product of second-period capital, but also reduces the penalty of underproduction. Clearly, the condition $a < \frac{r(p+\delta)}{p(r+1) - \beta(p+\delta)\bar{x}}$ implies that the unit marginal benefit of property insurance is higher than its unit marginal cost so that full insurance is optimal. In addition to the factors giving rise to full insurance under Proposition 1, now a small p and a large δ also tend to encourage property insurance purchase. A relatively large δ tends to raise the unit marginal benefit of property insurance whereas a relatively small p tends to raise its net unit marginal benefit.

Proposition 2b states that the conditions under which zero insurance is optimal are independent of whether $\Delta K = 0$ or $\Delta K > 0$. When $\Delta K = 0$, the expected unit marginal benefit of property insurance equals $\beta(p+\delta)Q'(K_1) < \beta R$; when $\Delta K > 0$, the expected unit marginal benefit of property insurance equals its cost saving for using less postloss financing, βR. In either case, $a > R/r$ implies that the expected unit marginal benefit of insurance is smaller than its unit marginal cost $a\beta r$ such that zero property insurance purchase is optimal. The main difference between the small- and the large-penalty cases when $\Delta K = 0$ is that a rise in insurance coverage raises the contracted level of output and hence revenue in both states under the large-penalty case. On the other hand, a rise in insurance coverage raises output and hence revenue only in the bad state under the small-penalty case. Finally, the second part of Proposition 2b is exactly the same as Proposition 1c, so is its explanation. Similar to Proposition 1c, relatively large a and r and a relatively small R results in zero insurance purchase.

The following corollary is similar to Corollary 1 and is obtained simply by substituting $R = r$ into Proposition 2b.

Corollary 2: *Suppose a risk-neutral producer under contract C may obtain perfect postloss financing at the long-term cost of capital. Under the small-penalty case, full property insurance cannot be optimal if it is actuarially unfavorable.*

Proof: See the Appendix.

Remark: In the small-penalty case, loading a needs to be relatively smaller than in the large-penalty case, for full insurance to be optimal given $\Delta K = 0$. It can be checked from Propositions 1a and 2a that under the small-penalty case, where $\delta < \frac{(1-\beta)p}{\beta}$, one has $\frac{r(p+\delta)}{p(r+1)-\beta(p+\delta)\bar{x}} < \frac{r}{\beta(r+1-\bar{x})}$. Therefore, the marginal benefit of property insurance is higher under the large-penalty case than under the small-penalty case.

CORPORATE PROPERTY INSURANCE DEMAND IN THE PRESENCE OF INTERNAL RESERVE

Under output contract C, instead of obtaining postloss financing, the producer may hold planned internal reserve (as self-insurance) at the beginning of $t = 0$. To maintain internal reserve for replacing any damaged capital at the beginning of $t = 1$, the producer borrows at the beginning of $t = 0$ at interest rate r. Assume that the producer can invest its reserve in the short-term investment market at interest rate $r_c \leq r$. To have a dollar for capital replacement at the beginning of $t = 1$, the producer needs to borrow $1/r_c$ at the beginning $t = 0$ such that total cost of internal reserve by the end of $t = 1$ equals $(1/r_c)\Delta K \times r^2$, where ΔK now represents capital replacement using internal reserve. In the presence of property insurance and internal reserve, $K_1 = [1-(1-\alpha)\bar{x}]K_0 + \Delta K$ in the bad state as before. When there is no property loss, internal reserve ΔK available at the beginning of $t = 1$ is unused and has an *ex ante* expected value of $(1-\beta)\Delta K \times r$ by the end of $t = 1$ after having invested at interest rate r for one period.[10] Therefore, the net cost of internal reserve by the end of $t = 1$ equals $[(r^2/r_c) - (1-\beta)r]\Delta K$.

Note that when the capital market is perfect, in which case all assets can be liquidated perfectly, $r_c = r$ and the net cost of internal reserve by the end of $t = 1$ becomes $\beta r \Delta K$. Note also that the producer's expected profit functions under the large- and the small-penalty cases in the presence of internal reserve can be obtained by replacing

[10] Of course, the rate of return may be lower than r or simply equal to r_c. However, this particular assumption will not affect the main conclusion in this section.

the cost of postloss financing, $\beta r\Delta K$, with $[(r^2/r_c) - (1-\beta)r]\Delta K$ in the "Corporate Property Insurance Demand in the Presence of Postloss Financing" Section. Since the relations between $\hat{Q}^*$, K_0^*, and K_1^* are independent of the cost of ΔK, it is clear that Lemmas 1 and 2 still hold.

Large-Penalty Case ($\hat{Q} = Q(K_0) + Q(K_1)$)

At the beginning of $t = 0$, the producer's problem is

$$\max_{\{K_0, \Delta K, \alpha\}} E\tilde{\pi} = p[rQ(K_0) + Q(K_1)] - r^2 K_0 - a\alpha\beta r\bar{x}K_0 - [(r^2/r_c) - (1-\beta)r]\Delta K$$

with first-order conditions

$$\frac{\partial E\tilde{\pi}}{\partial K_0} = p\{rQ'(K_0) + [1-(1-\alpha)\bar{x}]Q'(K_1)\} - r^2 - a\alpha\beta r\bar{x} = 0; \tag{17}$$

$$\frac{\partial E\tilde{\pi}}{\partial \Delta K} = pQ'(K_1) - [(r^2/r_c) - (1-\beta)r] \leq 0; \tag{18}$$

$$\frac{\partial E\tilde{\pi}}{\partial \alpha} = p\bar{x}K_0 Q'(K_1) - a\beta r\bar{x}K_0 \leq 0 \tag{19}$$

subject to (8) and

$$\frac{\partial E\tilde{\pi}}{\partial \Delta K} < 0 \Rightarrow \Delta K^* = 0 \text{ and } \Delta K^* > 0 \Rightarrow \frac{\partial E\tilde{\pi}}{\partial \Delta K} = 0. \tag{20}$$

Again, one can find conditions under which $\Delta K^* = 0$ and under which $\Delta K^* > 0$. The first-order conditions give rise to the following proposition:

Proposition 3: *Suppose a risk-neutral producer under output contract C may hold internal reserve in the large-penalty case. (a) When $\Delta K^* = 0$, if $a < \frac{r}{\beta(r+1-\bar{x})}$, then $\alpha^* = 1$. (b) If $a > \frac{(r/r_c)-(1-\beta)}{\beta}$ or $a > \frac{r}{\beta(1-\bar{x})}$, then $\alpha^* = 0$.*

Proof: See the Appendix.

Maintaining internal reserve and obtaining postloss financing are very similar, except that one of the conditions for zero property insurance purchase under Proposition 3b (i.e., $a > \frac{(r/r_c)-(1-\beta)}{\beta}$) differs from those under Propositions 1a and 1b (i.e., $a > \beta R/r$ and $a > R/r$, respectively). The reason why the condition is invariant regardless of $\Delta K = 0$ or $\Delta K > 0$ in the case of self-insurance is that unlike postloss financing (that is conditional on the realization of the bad state), self-insurance is unconditional. Whenever $a > \frac{(r/r_c)-(1-\beta)}{\beta}$, there is a gap between the unit marginal cost of insurance, $a\beta r$, and the expected unit marginal benefit of insurance, $pQ'(K_1)$, (which equals the marginal benefit of self-insurance). The latter is always smaller than or equal to the marginal cost of self-insurance, $(r^2/r_c) - (1-\beta)r$, according to the condition for optimal self-insurance. Clearly, relatively large a and β tend to raise the unit marginal cost of property insurance. A small r and a large r_c tend to reduce the marginal cost of self-insurance making it more attractive than property insurance.

The following corollary is obtained by substituting $r_c = r$ into Proposition 3b.

Corollary 3: *Suppose a risk-neutral producer under output contract C may hold internal reserve. Under the large-penalty case, when $r_c = r$, $a > 1$ implies $\alpha^* = 0$.*

Proof: See the Appendix.

Corollary 3 is intuitive. Since both self-insurance and market insurance are unconditional, they are perfect substitutes in the sense that when the capital market is perfect, actuarially unfavorable market insurance is relatively more costly than and hence inferior to self-insurance.

Small-Penalty Case ($\hat{Q} = 2Q(K_0)$)

At the beginning of $t = 0$, the producer's problem is

$$\max_{\{K_0, \Delta K, \alpha\}} E\tilde{\pi} = \beta\{p[rQ(K_0) + Q(K_1)] - \delta[Q(K_0) - Q(K_1)]\} + (1-\beta)p(r+1)Q(K_0)$$
$$- r^2 K_0 - a\alpha\beta\bar{x}rK_0 - [(r^2/r_c) - (1-\beta)r]\Delta K \tag{21}$$

with first-order conditions

$$\frac{\partial E\tilde{\pi}}{\partial K_0} = [rp + (1-\beta)p - \beta\delta]Q'(K_0) + \beta(p+\delta)[1 - (1-\alpha)\bar{x}]Q'(K_1)$$
$$- r^2 - a\alpha\beta\bar{x}r = 0; \tag{22}$$

$$\frac{\partial E\tilde{\pi}}{\partial \Delta K} = \beta(p+\delta)Q'(K_1) - [(r^2/r_c) - (1-\beta)r] \leq 0; \tag{23}$$

$$\frac{\partial E\tilde{\pi}}{\partial \alpha} = \beta(p+\delta)\bar{x}K_0 Q'(K_1) - a\beta\bar{x}rK_0 \leq 0 \tag{24}$$

subject to (8) and (20). Again, one can specify conditions under which $\Delta K^* = 0$ and under which $\Delta K^* > 0$. The first-order conditions give rise to the following proposition:

Proposition 4: *Suppose a risk-neutral producer under output contract C may hold internal reserve that can be invested in the short run under the small-penalty case. (a) When $\Delta K^* = 0$, if $a < \frac{r(p+\delta)}{p(r+1) - \beta\bar{x}(p+\delta)}$ with $p(r+1) - \beta(p+\delta)\bar{x} > 0$, then $\alpha^* = 1$. (b) If $a > \frac{(r/r_c) - (1-\beta)}{\beta}$ or $a > \frac{r}{\beta(1-\bar{x})}$, then $\alpha^* = 0$.*

Proof: The proof is similar to that of Proposition 3 and is thus omitted. Interested readers may obtain the proof from the author on request.

The condition in Proposition 4a is identical to that in Proposition 2a. The second part of Proposition 4b is identical to that of Proposition 2b. The first part of Proposition 4b is comparable to that of Proposition 2b, except that the expected unit marginal benefit of property insurance now equals $\beta(p+\delta)Q'(K_1)$ and is smaller than or equal to the expected unit marginal cost of self-insurance $\beta[(r^2/r_c) - (1-\beta)r]$ according to the condition for optimal self-insurance. When $a > \frac{(r/r_c) - (1-\beta)}{\beta}$, the latter is smaller than the unit marginal cost of property insurance, $a\beta r$, such that zero property insurance is optimal. Note that this condition is identical to that of Proposition 3b; the factors affecting it have been explained previously.

The following corollary can be obtained by substituting $r_c = r$ into Proposition 4b.

Corollary 4: *Suppose a risk-neutral producer under output contract C may hold internal reserve. Under the small-penalty case, when $r_c = r$, $a > 1$ implies $\alpha^* = 0$.*

Proof: The proof is the same as that of Corollary 3.

Remark: Similar to the remark presented in the "Small-Penalty Case" section, here loading a needs to be relatively smaller than in the large-penalty case, for full insurance to be optimal given $\Delta K = 0$.

CONCLUSION

This article has formulated a two-state model under which a risk-neutral production firm facing the risk of property damage contracts with a customer such that underproduction is penalized. Two cases, namely, the large-penalty case and the small-penalty case are found to be possible depending on the penalty rate on underproduction. Property insurance is useful in either of the two cases because it provides immediate indemnity (liquidity) that can be used to replace damaged factors of production in order to avoid unnecessary penalty. Conditions under which property insurance will be purchased in the presence of postloss financing or self-insurance are derived.

In the case with postloss financing, it is found that actuarially unfavorable property insurance can be optimal. Under the small-penalty case, actuarially fair property insurance and postloss financing are perfect substitutes when the capital market is perfect. That is, when the interest rate on postloss financing equals the long-term cost of capital, no actuarially unfavorable insurance will be purchased. Under the large-penalty case, however, it is possible that actuarially unfavorable insurance can be optimal even when the capital market is perfect. This surprising result is due to the fact that a sufficiently large-penalty rate implies that the contracted level of output equals the output level in the bad state. A rise in insurance coverage raises the contracted level of output and revenue in both the good and the bad states such that the expected unit marginal benefit of property insurance is higher than the expected marginal benefit of postloss financing. The reason is that without any precommitment, a rise in postloss financing used for capital replacement only raises revenue in the bad state.

In the case with internal liquid reserve that can be invested in the short-term capital market, it is found that actuarially unfavorable property insurance can be optimal only if the short-term interest rate is at least as high as the long-term cost of capital. The difference between the case with postloss financing and the case with self-insurance is clearly the result of the lack of commitment in the former. Since market insurance and self-insurance both require precommitment, they are perfect substitutes of each other when market insurance is actuarially fair and the capital market is perfect. On the other hand, actuarially fair market insurance and postloss financing are perfect substitutes only in the small-penalty case when the capital market is perfect.

APPENDIX

Proof of Lemma 1: For any K_0, ΔK, and α, when $\hat{Q} > 2Q(K_0)$, the producer's expected profit equals

$$\beta\{p[rQ(K_0)+Q(K_1)]-\delta[\hat{Q}-Q(K_0)-Q(K_1)]\}+(1-\beta)(r+1)pQ(K_0)$$
$$-a\alpha\beta r\bar{x}K_0-r^2K_0-R\Delta K$$
$$\beta\{p[rQ(K_0)+Q(K_1)]-\delta[Q(K_0)-Q(K_1)]\}+(1-\beta)(r+1)pQ(K_0)$$
$$-a\alpha\beta r\bar{x}K_0-r^2K_0-R\Delta K. \tag{A1}$$

Since the right side of the inequality in (A1) is the producer's expected profit when $\hat{Q}=2Q(K_0)$, it is clear that setting $\hat{Q}=2Q(K_0)$ is preferred to setting $\hat{Q}>2Q(K_0)$.

Next, for any K_0, ΔK, and α, if $\hat{Q}<Q(K_0)+Q(K_1)$, then the producer's expected profit equals

$$p\{rQ(K_0)+[\hat{Q}-Q(K_0)]\}-a\alpha\beta r\bar{x}K_0-r^2K_0-R\Delta K$$
$$<p[rQ(K_0)+Q(K_1)]-a\alpha\beta r\bar{x}K_0-r^2K_0-R\Delta K \tag{A2}$$

Since the right side of the inequality in (A2) is the producer's expected profit when $\hat{Q}=Q(K_0)+Q(K_1)$, it is clear that setting $\hat{Q}=Q(K_0)+Q(K_1)$ is preferred to setting $\hat{Q}<Q(K_0)+Q(K_1)$. The above suggests that $\hat{Q}\in[Q(K_0)+Q(K_1),2Q(K_0)]$.

Proof of Lemma 2: It can be checked by differentiating (1) with respect to $\hat{Q}$ that the marginal benefit of increasing $\hat{Q}$ equals

$$\frac{\partial E\tilde{\pi}}{\partial\hat{Q}}=-\beta\delta+(1-\beta)p,$$

which suggests that $\partial E\tilde{\pi}/\partial\hat{Q}>(<)\,0,\forall\hat{Q}\in[Q(K_0)+Q(K_1),2Q(K_0)]$ if and only if $\delta<(>)\,\beta^{-1}\,(1-\beta)\,p$. Therefore, if $\delta<(>)\,\beta^{-1}\,(1-\beta)\,p$, then the producer will raise (lower) $\hat{Q}$ to its upper (lower) limit, i.e.,

$$\delta<(>)\;\beta^{-1}(1-\beta)p\Rightarrow\hat{Q}^*=2Q(K_0^*)\;\left(=Q(K_0^*)+Q(K_1^*)\right).$$

Proof of Proposition 1: To prove part (a), suppose $\Delta K=0$. Set $\alpha=1$ such that $K_0=K_1$. Equation (6) becomes

$$p(r+1)Q'(K_1)-r^2-a\beta r\bar{x}=0$$

implying that

$$pQ'(K_1)=\frac{r^2+a\beta r\bar{x}}{r+1}. \tag{A3}$$

$\Delta K=0$ implies that (7) can be written as

$$\frac{\partial E\tilde{\pi}}{\partial\alpha}=pQ'(K_1)\bar{x}K_0-a\beta r\bar{x}K_0. \tag{A4}$$

Combining (A3) and (A4), it can be checked that if $a < \frac{r}{\beta(r+1-\bar{x})}$, then $(\partial E\tilde{\pi}/\partial\alpha)_{\alpha=1} > 0$ and hence $\alpha^* = 1$. Now, substituting (3) into (A4) gives

$$\frac{\partial E\tilde{\pi}}{\partial\alpha} \leq R\bar{x}K_0 - a\beta r\bar{x}K_0. \tag{A5}$$

Equation (A5) implies that if $a > R/\beta r$, then $\partial E\tilde{\pi}/\partial\alpha < 0$ for all $\alpha \in [0, 1]$ and hence $\alpha^* = 0$. These prove part (a).

To prove part (b), assume $\Delta K > 0$. Substituting (4) and (5) into (7) gives

$$\frac{\partial E\tilde{\pi}}{\partial\alpha} = -a\beta r\bar{x}K_0 + \beta R\bar{x}K_0. \tag{A6}$$

Equation (A6) implies that if $a > R/r$, then $\partial E\tilde{\pi}/\partial\alpha < 0$ for all $\alpha \in [0, 1]$, and hence $\alpha^* = 0$. This proves part (b).

To prove part (c), set $\alpha = 0$. First, suppose $\Delta K = 0$. Substituting (4) into (6) gives

$$0 = prQ'(K_0) + (1-\bar{x})pQ'(K_1) - r^2 > (1-\bar{x})pQ'(K_1) - r^2. \tag{A7}$$

Substituting (A7) into (7) and using (3) gives

$$\left.\frac{\partial E\tilde{\pi}}{\partial\alpha}\right|_{\alpha=0} < \left[\frac{r^2}{1-\bar{x}} - a\beta r\right]\bar{x}K_0. \tag{A8}$$

It can be checked that if $a > r/[\beta(1-\bar{x})]$, then $(\partial E\tilde{\pi}/\partial\alpha)_{\alpha=0} < 0$ and hence $\alpha^* = 0$. Next, suppose $\Delta K > 0$. Equation (6) becomes

$$prQ'(K_0) + \beta R(1-\bar{x}) - r^2 = 0,$$

which implies

$$0 > \beta R(1-\bar{x}) - r^2.$$

Substituting this inequality into (A6) again gives (A8) which in turn implies that if $a > r/[\beta(1-\bar{x})]$, then $(\partial E\tilde{\pi}/\partial\alpha)_{\alpha=0} < 0$ and hence $\alpha^* = 0$. This proves part (c).

Proof of Corollary 1: Under the large-penalty case, when $R = r$, it can be checked that (9) may hold. Particularly, when $Q(K) = \ln K$, (10) may hold (such that $\Delta K = 0$) when $R = r$ as long as $\bar{x}$ is sufficiently small. According to Proposition 1a, if $\beta < \frac{r}{r+1-\bar{x}}$, it is possible that $a > 1$ and yet $\alpha^* = 1$.

Proof of Proposition 3: To prove part (a), suppose $\Delta K = 0$. Set $\alpha = 1$ such that $K_0 = K_1$. (17) becomes

$$\frac{\partial E\tilde{\pi}}{\partial K_0} = p(r+1)Q'(K_1) - r^2 - a\beta r\bar{x} = 0$$

such that

$$pQ'(K_1) = \frac{r^2 + a\beta r\bar{x}}{r+1}. \tag{A9}$$

Substituting (A9) into (19) gives

$$\frac{\partial E\tilde{\pi}}{\partial\alpha} = \left[\frac{r^2 + a\beta\bar{x}r}{r+1} - a\beta r\right]\bar{x}K_0.$$

It can be checked that if $a < \frac{r}{\beta(r+1-\bar{x})}$, then $(\partial E\tilde{\pi}/\partial\alpha)_{\alpha=1} > 0$ and hence $\alpha^* = 1$. This proves part (a).

To prove part (b), set $\alpha = 0$. Substituting (18) into (19) gives

$$\frac{\partial E\tilde{\pi}}{\partial\alpha} \leq [(r^2/r_c) - (1-\beta)r]\bar{x}K_0 - a\beta r\bar{x}K_0.$$

It can be checked that if $a > \frac{(r/r_c)-(1-\beta)}{\beta}$, then $\partial E\tilde{\pi}/\partial\alpha < 0$ for all $\alpha \in [0, 1]$ and hence $\alpha^* = 0$. Now, it can be checked from (17) that

$$\frac{\partial E\tilde{\pi}}{\partial K_0} = p[rQ'(K_0) + (1-\bar{x})Q'(K_1)] - r^2 = 0 \tag{A10}$$

implying that when $\alpha = 0$

$$pQ'(K_1) < \frac{r^2}{1-\bar{x}}.$$

Substituting this into (19) gives

$$\frac{\partial E\tilde{\pi}}{\partial\alpha} < \left[\frac{r^2}{1-\bar{x}} - a\beta r\right]\bar{x}K_0.$$

It can be checked that if $a > r/[\beta(1-\bar{x})]$, then $(\partial E\tilde{\pi}/\partial\alpha)_{\alpha=0} < 0$ and hence $\alpha^* = 0$. These prove part (b).

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