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Strategic Demand for Insurance

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Abstract

We focus on the corporate demand for insurance under duopoly. We consider the case in which firms purchase insurance in order to enhance their competitiveness. We show that a higher level of corporate insurance makes a firm more aggressive and its competitor less aggressive in the output market (strategic effect). The optimal coverage of insurance is determined by comparing the strategic effect of insurance and the cost of insurance. The optimal coverage is positive if the strategic effect is greater than the cost of insurance. An interesting implication is that a risk-neutral firm may purchase actuarially unfair insurance. The main strategic effect of insurance comes from the fact that firms purchase insurance before they produce outputs. Insurance makes firms more aggressive due to the limited risk costs of firms.

Introduction

Explaining the demand for insurance has been a major area of research in the insurance field. Risk aversion, risk shifting, real-service provision, reduction of agency cost, and tax advantage, among others, lead individuals and organizations to purchase insurance (see below for more details). In addition, some recent papers have dealt with the effect of insurance on a firm's competitive strategies in the product market (Ashby and Diacon, 1998; Seog, 2006).[1] In a similar line of thinking, this article is also focused on the strategic demand for insurance. We consider the case in which firms purchase insurance in order to enhance their competitiveness.

Let us briefly review the related literature before discussing the main points of this article. While risk aversion has been considered the main rationale for individuals' demand for insurance since Pratt (1964) and Arrow (1971), it is not enough to explain the corporate demand for insurance, as the owners of public firms can diversify risks. Mayers and Smith (1982) provide rationales for the corporate demand for insurance,

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[1] There may be diverse interpretations regarding the term "strategy." "Strategy" in our model implies the competitive strategy in the product market.

such as risk shifting, real-service provision, reduction of agency cost, and tax advantage. MacMinn (1987, 1997), Mayers and Smith (1987), Schnabel and Roumi (1989), Garven and MacMinn (1993), and MacMinn and Han (1990) suggest that insurance can reduce financial distress costs. Han (1996) shows that the corporate demand for insurance can be optimal depending on the managerial compensation scheme.

Han (1999) also shows that a firm may purchase insurance when the costs of insurance are less than the contribution of insurance to the real option value of future investment opportunity. Thakor (1982) and Grace and Rebello (1993) consider the case of asymmetric information. When a firm has private information about its cash flows, it has incentives to purchase insurance if the purchase of insurance signals the private information.

Ashby and Diacon (1998) explicitly focus on the strategic effects of insurance in the product market. In a simple 2×2 normal-form game structure of duopoly, they show that two firms may find it beneficial to purchase insurance as an equilibrium strategy or as a Pareto improving strategy. Seog (2006) considers an example in which purchasing insurance affects the strategic behavior of firms and individuals in the product market. Strategic consideration is the main reason for purchasing insurance in both examples.

This article resembles Ashby and Diacon (1998) in that we also consider duopoly in the Cournot–Nash game. However, we consider a more sophisticated model, in which the optimal insurance coverage and the optimal production levels are determined. This article is also related to Brander and Lewis (1986). Brander and Lewis consider the case in which higher financial leverage commits the firm to more aggressive behavior in the output market. Based on their model, we consider the case in which corporate insurance influences the firm's behavior in the output market.

We investigate the situation in which duopoly purchase insurance to cover possible losses that are affected by production activities. We focus mainly on the "no-commitment case" in which the insurance premium is determined before production decision. We show that a higher level of corporate insurance makes a firm more aggressive and its competitor less aggressive in the output market (strategic effect). The optimal coverage of insurance is determined by comparing the strategic effect of insurance and the cost of insurance.[2] The optimal coverage is positive if the strategic effect is greater than the cost of insurance. This result is highlighted by the finding that a risk-neutral firm may purchase actuarially unfair insurance.

For reference, we also study the "full-commitment case" in which the effect of production on the risk is fully reflected in the insurance premium. We show that a risk-neutral firm will never purchase actuarially unfair insurance, which is consistent with the conventional risk aversion rationale for insurance demand. The comparison between the no-commitment case and the full-commitment case reveals that the main strategic effect of insurance comes from the fact that firms purchase insurance before they produce outputs. This is reminiscent of the leverage effect of debt on the firm's behavior, as pointed out by Brander and Lewis (1986). As debt makes firms more aggressive

[2] Precise definitions of strategic effect and cost of insurance will be made in later sections.

due to the limited liability, insurance makes firms more aggressive due to the limited risk costs.

The remainder of the article is composed as follows. In the "Model Description" section, we set up a Cournot–Nash duopoly model in the no-commitment case. We first focus on the risk-neutral firms in the "No-Commitment Case: Risk-Neutral Firms" section. This section provides a strong case for the strategic demand for insurance. The "No-Commitment Case: Risk-Averse Firms" section investigates a more general case in which firms can be risk averse. The "Full-Commitment Case" section considers the full-commitment case in which each firm announces the output level with full commitment. In the last section, we summarize and conclude the article. Appendixes A and B provide proofs of propositions and an illustrative linear model, respectively.

MODEL DESCRIPTION

We consider a Cournot–Nash duopoly model with two periods. Firms determine insurance coverage in the first period and then determine output levels in the second period. The discount rate is assumed to be zero. We assume that the insurance market is competitive so that the expected profit of the insurance firm is zero.

Firms are denoted by i or $j = 1, 2$. Firm i's output level is denoted by y_i and the asset-in-place is denoted by x_i. Firm i's insurance coverage is α_i. We focus on $0 \leq \alpha_i \leq 1$. Insurance premium can be actuarially unfair and $\lambda \geq 0$ is used for the loading premium factor. $R^i(y_i, y_j)$ is the operating profit function of firm i from production activity when output levels are y_i and y_j and no loss is incurred. We assume that the operating profit of i is concave in i's output level with one global maximum, and decreasing in the competitor's output level.[3] Technically, we assume that $R^i_j(=\partial R^i(y_i, y_j)/\partial y_j) < 0$, $R^i_{ii}(=\partial^2 R^i(y_i, y_j)/\partial y_i^2) < 0$, $R^i_i(0, y_j) = \infty$, and $R^i_i(\infty, y_j) = -\infty$. A realized loss, given y_i and x_i, is denoted by $z_i f^i(y_i, x_i)$, a multiplication of z_i and $f^i(y_i, x_i)$, where z_i is a random factor and $f^i(y_i, x_i)$ is the nonrandom "loss base" given y_i and x_i. Loss base might be interpreted as a potential loss or an average loss depending on the circumstances.[4] We assume that the loss base of i is (weakly) convexly increasing in i's output level and increasing in asset-in-place, x_i: $\partial f^i(y_i, x_i)/\partial y_i = f^i_i > 0$, $f^i_{ii} \geq 0$, $f^i_{xi} \geq 0$.[5] Let μ be the common expectation of z_1 or z_2 and σ be the common risk (standard deviation) of z_1 or z_2: $\mu = \mathrm{E}(z_1) = \mathrm{E}(z_2)$, $\sigma = \sigma(z_1) = \sigma(z_2)$.

The net profit of firm i from production in the second period is calculated as the operating profit net of loss not covered by insurance: $R^i(y_i, y_j) - z_i(1 - \alpha_i)f^i(y_i, x_i)$. The risk (standard deviation) of the net profit is $(1 - \alpha_i)f^i(y_i, x_i)\sigma$. Risk can cause the firm to incur "risk-costs," due to, for example, risk aversion of owners, the convexity of

[3] The uniqueness of a global maximum can be obtained, for example, from the usual assumptions that revenues are strictly concave and costs are strictly convex.

[4] For a potential loss interpretation, we need $z_i \leq 1$. For an average loss interpretation, we need $\mathrm{E}(z_i) = 1$.

[5] The following example illustrates the convexity of loss base. Suppose that a firm needs to build another factory if the amount of output exceeds the capacity of existing factories. Thus, the potential loss (loss base) by, say, fire will include the value of the factories and foregone profits. This schedule can be approximated by a (weakly) convex function of output.

tax, bankruptcy costs, and financial distress costs. Unit risk cost of firm i is denoted by a^i. We will refer to a firm with $a^i = 0$ as a risk-neutral firm, and a firm with $a^i > 0$ as a risk-averse firm, respectively. Let $V^i(y_i, y_j) = V^i(y_i, y_j\colon \alpha_i, \alpha_j)$ be the expected utility of firm i in the second period, given α_i and α_j. Then,

$$V^i(y_i, y_j) = \mathrm{E}\big\{R^i(y_i, y_j) - z_i(1-\alpha_i)f^i(y_i, x_i)\big\} - a^i(1-\alpha_i)f^i(y_i, x_i)\sigma, \tag{1}$$

where $a^i(1-\alpha_i)f^i(y_i, x_i)\sigma$ is the total risk costs.[6]

By rearranging the equation, we have

$$V^i(y_i, y_j) = R^i(y_i, y_j) - (1-\alpha_i)[\mu + a^i\sigma]f^i(y_i, x_i). \tag{2}$$

Let $W^i(\alpha_i, \alpha_j)$ be the *ex ante* expected utility of firm i, given α_i and α_j in the first period. $W^i(\alpha_i, \alpha_j)$ is calculated as the second period expected utility net of insurance premium.[7]

$$\begin{aligned} W^i(\alpha_i, \alpha_j) &= V^i(y_i, y_j) - (1+\lambda)\alpha_i\mu f^i(y_i, x_i) \\ &= R^i(y_i, y_j) - \big[(1+\lambda\alpha_i)\mu + (1-\alpha_i)a^i\sigma\big]f^i(y_i, x_i). \end{aligned} \tag{3}$$

In the first period, each firm simultaneously determines insurance coverage considering its effect on the expected profit in the second period. Each firm i selects α_i to maximize $W^i(\alpha_i, \alpha_j)$, assuming α_j is given. In the second period, each firm simultaneously determines its output level, given the insurance coverage in the first period. Each firm i selects y_i to maximize $V^i(y_i, y_j)$, assuming y_j is given. The game in the second period is the usual one-period Cournot–Nash game. For the stability of equilibrium, we assume that

$$V^i_{ij} = R^i_{ij} < 0, \text{ and} \tag{4}$$

$$D \equiv V^i_{ii}V^i_{jj} - V^i_{ij}V^j_{ji} > 0 \Leftrightarrow R^i_{ii}R^j_{jj} - R^i_{ij}R^j_{ji} > 0.^8 \tag{5}$$

In equilibrium, each firm should not have any incentives to change its insurance coverage and output level, given its competitor's insurance coverage and output level. Now, let us investigate the relationship between the demand for insurance and output levels. To highlight the implications of the analysis, we will focus first on the case of risk-neutral firms with zero risk costs ($a^i = 0$). A more general case will be considered in later sections.

[6] Note that the expected utility in the typical mean–variance model has the form of $\mathrm{E}(\cdot) - a^i\sigma^2(\cdot)$. For expository simplicity, we replace $\sigma^2(\cdot)$ with $\sigma(\cdot)$, which does not change our main implications.

[7] Recall that the discount rate is assumed to be zero.

[8] Conditions (4) and (5) are standard in Cournot–Nash models. These conditions imply that the reaction curves are downward sloped and the slope of the reaction curve for j is steeper than that for i in the (y_j, y_i)-plane, guaranteeing the stability of the equilibrium.

NO-COMMITMENT CASE: RISK-NEUTRAL FIRMS

Output Selection

Let us start with the output selection problem in the second period. Given $a^i = 0$, firm i's expected profit in the second period can be stated as follows:

$$V^i(y_i, y_j) = \mathrm{E}\{R^i(y_i, y_j) - z_i(1-\alpha_i)f^i(y_i, x_i)\}. \tag{6}$$

The firm i solves the following problem, given α_i and α_j:

$$\mathrm{Max}_{y_i} V^i(y_i, y_j) = R^i(y_i, y_j) - (1-\alpha_i)\mu f^i(y_i, x_i). \tag{7}$$

The optimal solution satisfies the following condition:

$$[\mathrm{FOC}]\ \partial V^i/\partial y_i = 0 \Rightarrow R^i_i - (1-\alpha_i)\mu f^i_i = 0. \tag{8}$$

Note that the second-order condition is satisfied with $0 \le \alpha_i \le 1$, since $\partial^2 V^i/\partial y_i^2 = R^i_{ii} - (1-\alpha_i) f^i_{ii} < 0$. Similarly, the first-order condition for firm j is:

$$[\mathrm{FOC}]\ \partial V^j/\partial y_j = R^j_j - (1-\alpha_j)\mu f^j_j = 0. \tag{9}$$

The Cournot–Nash outcome (y_1^*, y_2^*) is the solution of the simultaneous equations of the two FOCs for firms i and j.[9] Now, we are interested in the effect of insurance coverage on the output level, which is discussed in the following proposition.

Proposition 1:

(1) *In equilibrium, an increase in insurance coverage increases the output level of a firm and decreases the output level of its competitor.*

(2) *Consider a symmetric case in which $\alpha_i = \alpha_j = \alpha$, $x_i = x_j = x$ with $y_i = y_j = y$. In equilibrium, an increase in insurance coverage increases the output level.*

Proof: See Appendix A.

Proposition 1 (1) shows that the higher insurance coverage of a firm is associated with the higher output level of the firm and the lower output level of its competitor. This effect comes from the fact that higher insurance coverage induces the firm to behave more aggressively. Note that the increase in output level has two offsetting effects on the utility: the increase in operation profit and the increase in loss sizes. However, with higher insurance coverage, the effect of increase in loss sizes is mitigated. Thus, the firm will increase its output level more aggressively. With the increased aggressiveness of the firm, the competitor reduces its output level since the marginal profit of firm j is reduced ($R^j_{ji} < 0$). Proposition 1 (2) implies that if the insurance coverage of both firms increases simultaneously in the symmetric case, then both firms will increase their output levels.

[9] The assumptions on R^i_i and R^i_{ii} imply that y_i^*, $y_j^* > 0$.

Insurance Coverage

Now, let us turn to the optimal choice of insurance coverage in the first period. Firms select insurance coverage considering its effect on the output level in the second period. The problem of firm i is stated as follows:

$$\text{Max}_{\alpha_i} W^i(\alpha_i,\ \alpha_j) = R^i(y_i, y_j) - (1 + \lambda\alpha_i)\mu f^i(y_i, x_i). \tag{10}$$

Noting that $R_i^i - (1 - \alpha_i)\mu f_i^i = 0$ from the optimality of y_i in the second period, an interior solution to the problem will satisfy:[10]

$$\text{[FOC]}\ \partial W^i(\alpha_i, \alpha_j)/\partial\alpha_i = -(1 + \lambda)\alpha_i\mu f_i^i(dy_i/d\alpha_i) + R_j^i dy_j/d\alpha_i - \lambda\mu f^i = 0. \tag{11}$$

Assuming that the second-order condition is satisfied, we can show the following proposition.

Proposition 2: *The optimal insurance coverage of firm i is positive if and only if $R_j^i\ dy_j/d\alpha_i > \lambda\mu f^i$ at $\alpha_i = 0$: strategic effect > premium loading.*

Proof: See Appendix A.

Proposition 2 shows that the firm will purchase insurance if $R_j^i\ dy_j/d\alpha_i > \lambda\mu f^i$ at $\alpha_i = 0$. Note that $R_j^i\ dy_j/d\alpha_i$ denotes the "strategic effect" of insurance coverage on the profit through the competitor's behavior. On the other hand, $\lambda\mu f^i$ is the "premium loading." Therefore, the condition for positive insurance coverage requires that the strategic effect be greater than the loading at $\alpha_i = 0$. With a positive loading, purchasing insurance increases disutility. However, if the profit increase due to the strategic effect is greater than the disutility from the positive loading, then the firm will purchase insurance.

An important implication of Proposition 2 is that a risk-neutral firm may purchase insurance if the premium loading is small enough to satisfy $R_j^i\, dy_j/d\alpha_i > \lambda\mu f^i$. Though simple, this example provides an interesting implication for insurance demand. Risk aversion does not completely explain the corporate demand for insurance, since firms can be considered less risk averse or risk neutral. Researchers find that efficient risk sharing, real-service provision, and resolving agency problems are important reasons for the corporate demand for insurance. Proposition 2 suggests another rationale for insurance demand: strategic reasons for insurance demand. As long as the strategic effect is larger than the premium loading, a risk-neutral firm can purchase an actuarially unfair insurance.

NO-COMMITMENT CASE: RISK-AVERSE FIRMS

Now, let us consider a more general case in which firms may incur costs due to risks. The logic will be the same as in the previous section, except that we need to consider additional term for risk costs.

[10] One problem is that the solution to the FOC (11) is not necessarily optimal, as will be shown in the linear model in Appendix B. In such a case, the optimal coverage is 0 or 1.

Output Selection

Recall that firm i's expected profit in the second period can be stated as follows:

$$V^i(y_i, y_j) = \mathrm{E}\{R^i(y_i, y_j) - z_i(1-\alpha_i) f^i(y_i, x_i)\} - a^i(1-\alpha_i) f^i(y_i, x_i)\sigma. \qquad (12)$$

Firm i solves the following problem, given α_i and α_j:

$$\mathrm{Max}_{y_i} V^i(y_i, y_j) = R^i(y_i, y_j) - (1-\alpha_i)[\mu + a^i\sigma] f^i(y_i, x_i). \qquad (13)$$

The optimal solution satisfies the following condition:[11]

$$[\mathrm{FOC}]\ \partial V^i/\partial y_i = 0 => R^i_i - (1-\alpha_i)[\mu + a^i\sigma] f^i_i = 0. \qquad (14)$$

Similarly, the first-order condition for firm j is:

$$[\mathrm{FOC}]\ \partial V^j/\partial y_j = R^j_j - (1-\alpha_j)[\mu + a^j\sigma] f^j_j = 0. \qquad (15)$$

The Cournot–Nash outcome (y_1^*, y_2^*) is the solution of the simultaneous equations of the two FOCs for firms i and j.[12] Now, we have Proposition 3 that is similar to but more general than Proposition 1. The implications of Proposition 3 are basically the same as those of Proposition 1.

Proposition 3:

(1) *In equilibrium, an increase in insurance coverage increases the output level of a firm and decreases the output level of its competitor.*

(2) *Consider a symmetric case in which $\alpha_i = \alpha_j = \alpha$, $a^i = a^j = a$, $x_i = x_j = x$ with $y_i = y_j = y$. In equilibrium, an increase in insurance coverage increases the output level.*

Proof: See Appendix A.

Insurance Coverage

The problem and the first-order condition of firm i in the first period are stated as follows:

$$\mathrm{Max}_{\alpha_i} W^i(\alpha_i, \alpha_j) = R^i(y_i, y_j) - \left[(1+\lambda\alpha_i)\mu + (1-\alpha_i)a^i\sigma\right] f^i(y_i, x_i). \qquad (16)$$

$$[\mathrm{FOC}]\ \partial W^i(\alpha_i, \alpha_j)/\partial\alpha_i = -(1+\lambda)\alpha_i\mu f^i_i(dy_i/da_i) + R^i_j dy_j/d\alpha_i - [\lambda\mu - a^i\sigma] f^i = 0. \qquad (17)$$

[11] The second-order condition is satisfied with $0 \le \alpha_i \le 1$, since $\partial^2 V^i/\partial y_i^2 = R^i_{ii} - (1-\alpha_i)[\mu + a^i\sigma] f^i_{ii} < 0$.

[12] Again, the assumptions on R^i_i and R^i_{ii} imply that y_i^*, $y_j^* > 0$.

Assuming that the second-order condition is satisfied, we can show the following result.

Proposition 4: *The optimal insurance coverage of firm i is positive if and only if* $R^i_j dy_j/d\alpha_i > [\lambda\mu - a^i\sigma]f^i$ at $\alpha_i = 0$*: strategic effect > risk-adjusted premium loading.*

Proof: See Appendix A.

Proposition 4 is a general case of Proposition 2. Proposition 4 shows that the firm will purchase insurance if $R^i_j\, dy_j/d\alpha_i > [\lambda\mu - a^i\sigma]f^i$ at $\alpha_i = 0$. As in Proposition 2, $R^i_j\, dy_j/d\alpha_i$ denotes the "strategic effect" of insurance coverage on the profit through the competitor's behavior. On the other hand, $[\lambda\mu - a^i\sigma]f^i$ may be interpreted as the "risk-adjusted loading," implying the loading ($\lambda\mu f^i$) above risk cost reduction ($a^i\sigma f^i$). Therefore, the condition for positive insurance coverage requires that the strategic effect be greater than the risk-adjusted loading. If the increase in profit due to the strategic effect is greater than the disutility from the positive risk-adjusted loading, then the firm will purchase insurance. Proposition 2 can be obtained as a specific case of Proposition 4 by setting $a^i = 0$.

Similarly for firm j, the optimal insurance coverage satisfies

$$\begin{aligned}[\text{FOC}]\ \partial W^j(\alpha_j, \alpha_i)/\partial\alpha_j = &-(1+\lambda)\alpha_j\mu f^j_j(dy_j/d\alpha_j) \\ &+ R^j_i dy_i/d\alpha_j - [\lambda\mu - a^j\sigma]f^j = 0. \end{aligned} \tag{18}$$

In equilibrium, the two FOCs (17) and (18) are satisfied simultaneously. However, it is not easy to characterize α and the effects of x_i and x_j on α (and on y_i) without having further information about the relevant variables.[13] Instead of pursuing this issue further, we present an illustrative linear model in Appendix B: $R(y_i, y_j) = (P - c)y_i$, and $f^i(y_i, x_i) = sy_i + tx_i$, where $P = P_0 - b(y_i + y_j)$ is the price function, c is the unit production cost, and s and t are positive constants. For the symmetry case, Appendix B shows that the output level (y) and the insurance coverage (α), for interior solutions, are determined by $y = [A - sK(1-\alpha)]/3b$ and $\alpha = -(9b/s^2K)Etx/(C - B) + [(sK - A)/sK]B/(C - B)$, where the parameter values, A, B, C, E, and K, are as defined in Appendix B. Note that the output level is positively related to the insurance coverage as shown in Proposition 3. The insurance coverage may well be

[13] In equilibrium, from (17) and (18), $T^iT^j[R^j_{ii} - M^jf^j_{jj}]M^if^i_{ii}\,\alpha_i^2 + \{T^iT^j[R^j_{ii} - M^jf^j_{jj}][R^i_{jj} - M^if^i_{ii}] + T^iM^jf^j_{jj}\{DN^jf^j - R^j_iM^jf^j_jR^i_{ij}\} + \{T^jM^if^i_{ii}\}\{R^i_jM^if^i_iR^j_{ji} - DN^if^i\}\}\alpha_i + T^j[R^i_{jj} - M^if^i_{ii}]\{R^i_jM^if^i_iR^j_{ji} - DN^if^i\} = 0$, where $M^k = \mu + a^k\sigma$, $N^k = \lambda\mu - a^k\sigma$, and $T^k = (1+\lambda)\mu(f^k_k)^2M^k$. The solution of this equation is the optimal insurance coverage for firm i. The optimal insurance coverage for firm j can be similarly obtained by interchanging i and j in the equation. In the symmetric equilibrium in which $T^i = T^j = T$, $M^i = M^j = M$, $N^i = N^j = N$, we have $TMf^i_{ii}\alpha_i^2 + T[R^i_{jj} - Mf^i_{ii}]\alpha_i + \{R^i_jMf^i_iR^j_{ji} - DNf^i\} = 0$. Thus,

$$\alpha = \frac{-T[R^i_{jj} - Mf^i_{ii}] \pm \sqrt{T^2[R^i_{jj} - Mf^i_{ii}]^2 - 4TMf^i_{ii}(R^i_jMf^i_i R^j_{ji} - DNf^i)}}{2TMf^i_{ii}}.$$

positive for some parameter values. We can also show that the insurance coverage is positive for a risk-neutral firm under a small premium loading (implying $E \approx 0$): $\alpha \approx (A - s\mu)/5s\mu > 0$. (See Appendix B for more details.)[14]

FULL-COMMITMENT CASE

The previous sections describe the situation in which firms first pay the insurance premium and then determine the output level. Thus, firms have some incentives for opportunistic behavior once they purchase insurance. As a result, insurance premium should be determined *ex ante*, considering such opportunistic behavior. In this sense, the previous model investigates a "no-commitment case." As a reference case, let us consider a "full-commitment case" in this section. In the full-commitment case, each firm first announces its output level with a full commitment. The insurance premium is determined based on the output level announced. The firm then purchases insurance and produces exactly the announced output level. There is no opportunistic behavior in this case, unlike in the no-commitment case. An example of the full-commitment case is the retrospective experience-rating plan, in which changes of risks are reflected in the insurance premium. A captive insurer is another example. Since the parent firm should take care of both production and captive insurers, the firm will have incentives for full commitment.

Output Selection

The full-commitment case can also be organized as a two-period model. As in the no-commitment case, firms determine insurance coverage in the first period and then determine output levels in the second period. The only difference is that firms now fully commit their output levels. Technically, we can treat this case as if the firms pay premiums right after production in the second period: The insurance premiums are determined, *ex post*. Therefore, firm i solves the following problem, given α_i, in the second period

$$\text{Max}_{y_i} U^i(y_i, y_j) = V^i(y_i, y_j) - (1+\lambda)\alpha_i \mu f^i(y_i, x_i) = R^i(y_i, y_j) - [\mu + \alpha_i \lambda \mu] f^i(y_i, x_i). \tag{19}$$

Note that the insurance premium $(1+\lambda)\alpha_i \mu f^i(y_i, x_i)$ is subtracted from $V^i(y_i, y_j)$. In the full-commitment case, the firm needs to consider the effect of production on the insurance premium, which was treated as fixed in the no-commitment case. The optimal output level satisfies[15]

$$[\text{FOC}]\ \partial U^i/\partial y_i = 0 \Rightarrow R^i_i - [\mu + \alpha_i \lambda \mu] f^i_i = 0. \tag{20}$$

Similarly, for firm j, we have

$$[\text{FOC}]\ \partial U^j/\partial y_j = R^j_j - [\mu + \alpha_j \lambda \mu] f^j_j = 0. \tag{21}$$

In equilibrium, (y_1^*, y_2^*) should satisfy both FOCs (20) and (21).

[14] Appendix B also includes some comparative statics results regarding the effects of x_i and x_j on the insurance coverage.

[15] The second-order condition is satisfied with $0 \le \alpha_i \le 1$: [SOC] $\partial^2 U^i/\partial y_i^2 = R^i_{ii} - [\mu + a^i\sigma + \alpha_i(\lambda\mu - a^i\sigma)] f^i_{ii} < 0$.

Proposition 5 [The Full-Commitment Case]:

(1) *In equilibrium, an increase in insurance coverage increases the output level of firm i and decreases the output level of its competitor, if and only if* $\lambda\mu - a^i\sigma < 0$.

(2) *Consider a symmetric case in which* $\alpha_i = \alpha_j = \alpha, a^i = a^j = a, x_i = x_j = x$ with $y_i = y_j = y$. *In equilibrium, an increase in insurance coverage increases the output level, if and only if* $\lambda\mu - a\sigma < 0$.

Proof: See Appendix A.

The effect of insurance coverage is different from that in the no-commitment case. Note that in the no-commitment case, the increase of coverage always increases the output level (Proposition 3). Since the insurance premium is given in the second period of the no-commitment case, the firm wants to increase its output level with the increase of insurance coverage. Note that the risk increase following the output level increase is mitigated by higher coverage.

In the full-commitment case, however, the firm should also consider a premium increase following the output level increase. Therefore, the firm will take into account both the premium increase and the risk-cost reduction. The "marginal risk-adjusted loading," $[\lambda\mu - a^i\sigma] f_i^i$, summarizes the (marginal) excessiveness of insurance premium ($\lambda\mu f_i^i$) as compared to risk cost reduction ($a^i\sigma f_i^i$). If the insurance premium increase is high relative to risk-cost reduction ($\lambda\mu - a^i\sigma > 0$), then the firm will optimally reduce its output level. If the insurance premium increase is low relative to risk-cost reduction ($\lambda\mu - a^i\sigma < 0$), then the firm will optimally increase its output level. Note that an increase in insurance coverage will decrease the output level of a risk-neutral firm, when the premium is actuarially unfair.

Insurance Coverage

Given that y_i and y_j are optimally determined as in the second period, the firm solves the following problem in the first period

$$\text{Max}_{\alpha_i} W^i(\alpha_i, \alpha_j) = U^i(y_i, y_j; \alpha) \tag{22}$$

$$[\text{FOC}]\; U_i^i dy_i/d\alpha_i + U_j^i dy_j/d\alpha_i + U_{\alpha_i}^i = 0. \tag{23}$$

$U_j^i dy_j/d\alpha_i + U_{\alpha_i}^i = 0$, noting that $U_i^i(y_i, y_j; \alpha) = 0$ from the optimality of y_i in the second period. FOC can be arranged to

$$R_j^i dy_j/d\alpha_i - [\lambda\mu - a^i\sigma] f^i = 0. \tag{24}$$

Proposition 6 [The Full-Commitment Case]: *Let us denote* α_i^* *for the optimal insurance coverage. Then,* $\alpha_i^* = 1$ *if* $\lambda\mu - a^i\sigma < 0$; $\alpha_i^* = 0$, *if* $\lambda\mu - a^i\sigma > 0$; *and* $\alpha_i^* = [0, 1]$, *if* $\lambda\mu - a^i\sigma = 0$.[16]

[16] Note that Proposition 6 exhibits the same result as the insurance demand by the risk averter who has the expected utility of the form $\text{E}(x) - a\sigma(x)$.

Proof: See Appendix A.

This proposition can be easily understood as follows. When the cost of insurance ($\lambda\mu - a^i\sigma$) is low (high), purchasing more (less) insurance is preferred. In addition, an increase in coverage increases (decreases) profit from production (Proposition 5). Thus, the full (zero) coverage is optimal. This result is contrasting with the no-commitment case in which the optimal coverage can be between 0 and 1 (see Proposition 4). Note that in the no-commitment case, FOC (17) is written as

$$R^i_j dy_j/d\alpha_i - [\lambda\mu - a^i\sigma] f^i = (1+\lambda)\mu f^i_i (dy_i/d\alpha_i)\alpha_i. \tag{17'}$$

The LHSs of both FOCs (24) and (17′) measure the effect of coverage increase through competitor ($R^i_j\, dy_j/d\alpha_i$) and the risk-adjusted premium loading ($[\lambda\mu - a^i\sigma]f^i$), given firm i's output level. The difference can be found in RHSs: $(1+\lambda)\mu f^i_i(dy_i/d\alpha_i)\alpha_i$ in the no-commitment case as compared to 0 in the full-commitment case. Note that $(1+\lambda)\mu f^i_i(dy_i/d\alpha_i)\alpha_i$ measures the effect of coverage increase on the premium through the change of firm i's output level. In the full-commitment case, the effect is already fully considered in selecting the firm's output level. In the no-commitment case, however, it is not considered in selecting the firm's output level, since the premium is fixed at that time. Thus, it should be considered now when selecting coverage. Different consideration of premium change leads to different results.

The distinction between the no-commitment case and the full-commitment case is highlighted for risk-neutral firms. In the no-commitment case, a risk-neutral firm may purchase actuarially unfair insurance (Proposition 2). However, in the full-commitment case, a risk-neutral firm will never purchase actuarially unfair insurance, since $\lambda\mu - a^i\sigma = \lambda\mu > 0$. Thus, the full-commitment case is consistent with traditional theories of insurance demand induced by risk aversion.

The comparison between the no-commitment case and the full-commitment case reveals that the main strategic effect of insurance comes from the fact that firms purchase insurance before they produce outputs. This is reminiscent of the leverage effect of debt on the firm's behavior, as pointed out by Brander and Lewis (1986). As debt makes firms more aggressive due to the limited liability of firms, insurance makes firms more aggressive due to the limited risk costs of firms. However, when the insurance premium is fully adjusted for the risk change as in the full-commitment case, firms should bear risk costs when transferring risk to insurance firms. Accordingly, the strategic purchase of insurance also disappears in the full-commitment case, as seen in Proposition 6.[17]

CONCLUSION

This article focuses on the corporate demand for insurance under duopoly. We consider the case in which firms purchase insurance in order to enhance their competitiveness. We focus on the "no-commitment case" in which firms cannot commit their output levels to insurance firms before paying premiums. The main results are as

[17] However, note that once firms purchase insurance, it can still affect the behavior of firms, as shown in Proposition 5.

follows: A higher level of corporate insurance makes a firm more aggressive and its competitor less aggressive in the output market (strategic effect). The optimal coverage of insurance is determined by comparing the strategic effect of insurance in the output market and the cost of insurance (measured by the risk-adjusted premium loading). The optimal coverage is positive if the strategic effect is greater than the cost of insurance. An interesting implication is that a risk-neutral firm may purchase actuarially unfair insurance.

On the other hand, in the full-commitment case in which firms can commit their output levels to insurance firms before paying premiums, the cost of insurance is critical. A risk-neutral firm will not purchase actuarially unfair insurance in the full-commitment case. The comparison between the no-commitment case and the full-commitment case reveals that the main strategic effect of insurance comes from the fact that firms purchase insurance before they produce outputs. Insurance makes firms more aggressive due to the limited risk costs of firms.

APPENDIX A: PROOFS

Proof of Proposition 1: The proof is obtained by setting $a^i = 0$ in the proof of Proposition 3.

Proof of Proposition 2: The proof is obtained by setting $a^i = 0$ in the proof of Proposition 4.

Proof of Proposition 3:

(1) Let us differentiate FOCs (14) and (15) with respect to α_i. Then we have:

$$\left\{R^i_{ii} - (1-\alpha_i)[\mu + a^i\sigma]\,f^i_{ii}\right\}dy_i + R^i_{ij}\,dy_j = -[\mu + a^i\sigma]\,f^i_i\,d\alpha_i$$

$$R^j_{ji}\,dy_i + \left\{R^j_{jj} - (1-\alpha_j)[\mu + a^j\sigma]\,f^j_{jj}\right\}dy_j = 0.$$

By Cramer's rule, we obtain

$$dy_i/d\alpha_i = -[\mu + a^i\sigma]\,f^i_i\left\{R^j_{jj} - (1-\alpha_j)[\mu + a^j\sigma]\,f^j_{jj}\right\}/D > 0, \quad \text{where} \quad D > 0.$$

$$dy_j/d\alpha_i = [\mu + a^i\sigma]\,f^i_i\,R^j_{ji}\}/D < 0.$$

(2) Using the symmetry condition, we can rewrite the FOCs (14) and (15) as follows:

$$R^i_i - (1-\alpha)[\mu + a\sigma]\,f^i_i = 0.$$

Differentiate FOC with respect to α:

$$\left\{R^i_{ii} + R^i_{ij} - (1-\alpha)[\mu + a\sigma]\,f^i_{ii}\right\}dy = -[\mu + a\sigma]\,f^i_i\,d\alpha$$

$dy/d\alpha = -[\mu + a\sigma]\,f^i_i/\{R^i_{ii} + R^i_{ij} - (1-\alpha)[\mu + a\sigma]\,f^i_{ii}\} > 0$, since the denominator < 0 and the numerator < 0.

Proof of Proposition 4: Recall the LHS of FOC (17): $-(1+\lambda)\mu f_i^i(dy_i/d\alpha_i)\alpha_i + R_j^i\, dy_j/d\alpha_i - [\lambda\mu - a^i\sigma] f^i$. With $\alpha_i = 0$, the LHS becomes $R_j^i dy_j/d\alpha_i - [\lambda\mu - a^i\sigma] f^i$. Thus, we have $\alpha_i > 0$ if and only if $R_j^i\; dy_j/d\alpha_i - [\lambda\mu - a^i\sigma] f^i > 0$, or $R_j^i\; dy_j/d\alpha_i > [\lambda\mu - a^i\sigma] f^i$, at $\alpha_i = 0$.

Proof of Proposition 5:

(1) In order to investigate the effect of insurance coverage on production, let us differentiate FOCs (20) and (21) with respect to α_i:

$$\left\{R_{ii}^i - [\mu + a^i\sigma + \alpha_i(\lambda\mu - a^i\sigma)] f_{ii}^i\right\} dy_i + R_{ij}^i\, dy_j = [\lambda\mu - a^i\sigma] f_i^i\, d\alpha_i$$

$$R_{ji}^j\, dy_i + \left\{R_{jj}^j - [\mu + a^j\sigma + \alpha_j(\lambda\mu - a^j\sigma)] f_{jj}^j\right\} dy_j = 0.$$

By Cramer's rule, we have:

$$dy_i/d\alpha_i = [\lambda\mu - a^i\sigma] f_i^i \left\{R_{jj}^j - [\mu + a^j\sigma + \alpha_j(\lambda\mu - a^j\sigma)] f_{jj}^j\right\}/D, \text{ where } D > 0.$$

$$dy_j/d\alpha_i = -[\lambda\mu - a^i\sigma] f_i^i\, R_{ji}^j\}\big/D.$$

If $\lambda\mu - a^i\sigma <(>)\, 0$, then $dy_i/d\alpha_i >(<)\, 0$, $dy_j/d\alpha_i <(>)\, 0$.

(2) In symmetric equilibrium, FOCs (20) and (21) can be rewritten as

$$[\text{FOC}]\; R_i^i - [\mu + a\sigma + \alpha(\lambda\mu - a\sigma)] f_i^i = 0.$$

Differentiate FOC with respect to α to have

$$\left\{R_{ii}^i + R_{ij}^i - [\mu + a\sigma + \alpha(\lambda\mu - a\sigma)] f_{ii}^i\right\} dy = [\lambda\mu - a\sigma] f_i^i\, d\alpha$$

$dy/d\alpha = [\lambda\mu - a\sigma] f_i^i/\{R_{ii}^i + R_{ij}^i - [\mu + a\sigma + \alpha(\lambda\mu - a\sigma)] f_{ii}^i\} >(<)\, 0$, since the denominator < 0 and the numerator $<(>)\, 0$ if $\lambda\mu - a\sigma <(>)\, 0$.

Proof of Proposition 6: Consider the FOC (24): $R_j^i\; dy_j/d\alpha_i - [\lambda\mu - a^i\sigma] f^i = 0$.

If $\lambda\mu - a^i\sigma < 0$, $dy_j/d\alpha_i < 0$. Thus

LHS = $(-)(-) - (-)(+) > 0$. Thus, $\alpha_i^* = 1$.

If $\lambda\mu - a\sigma > 0$, $dy_j/d\alpha_i > 0$. Thus

LHS = $(-)(+) - (+)(+) < 0$. Thus, $\alpha_i^* = 0$.

If $\lambda\mu - a\sigma = 0$, $dy_j/d\alpha_i = 0$. Thus

LHS = $(-)(0) - (0)(+) = 0$. Thus, $\alpha_i^* = [0, 1]$.

APPENDIX B: A LINEAR MODEL

We consider a simplified linear Cournot–Nash game for illustrative purposes. The following assumptions and definitions are made. This section shows that even a simple model has diverse cases to consider. For expository convenience, the insurance coverage is required only to be nonnegative ($0 \le \alpha_i$). If we do not allow overinsurance, the optimal coverage will be replaced with 0 or 1, depending on their corresponding values, when the optimal coverage is above 1.

Specifically, we assume: price $P = P_0 - b(y_i + y_j)$; c as unit cost; $R(y_i, y_j) = (P - c)y_i$; $f^i(y_i, x_i) = sy_i + tx_i$; $A = P_0 - c$; $K = \mu + a\sigma$; $a^i = a^j = a$.

$$R(y_i, y_j) = (P - c)y_i = (A - b(y_i + y_j))y_i$$

$$V^i(y_i, y_j; \alpha, x) = (A - b(y_i + y_j))y_i - (1 - \alpha_i)K(sy_i + tx_i).$$

For a meaningful analysis, we assume that a monopoly will have an incentive to produce with no insurance. Technically, we assume that the marginal profit of a monopoly at $y_i = 0$ with $\alpha_i = 0$ is positive. Suppose that $y_j = 0$ (monopoly). Now, the marginal profit becomes $V^i_{yi} = A - 2by_i - (1 - \alpha_i)sK$. Our assumption implies that, for $\alpha_i = 0$, $V^i_{yi}|_{yi=0} = A - sK > 0$.

Output Selection

We find the optimal output level given insurance coverage

$$\text{[FOC]}\ A - 2by_i - by_j - (1 - \alpha_i)sK = 0; \quad A - 2by_j - by_i - (1 - \alpha_j)sK = 0.$$

Thus, $y_i = [A - sK(1 - 2\alpha_i + \alpha_j)]/3b$; $y_j = [A - sK(1 - 2\alpha_j + \alpha_i)]/3b$.

Total output level is $y_i + y_j = [2A - sK(2 - \alpha_i - \alpha_j)]/3b$.

In the symmetric equilibrium, $y = [A - sK(1 - \alpha)]/3b$, for $\alpha_i = \alpha_j = \alpha$.

Total output level is $2y = 2[A - sK(1 - \alpha)]/3b$.

The maximized expected profit in the second period is

$$\begin{aligned} V^i(y_i, y_j; \alpha, x) &= (A - [2A - sK(2 - \alpha_i - \alpha_j)]/3)[A - sK(1 - 2\alpha_i + \alpha_j)]/3b \\ &\quad - (1 - \alpha_i)K\{s[A - sK(1 - 2\alpha_i + \alpha_j)]/3b + tx_i\} \\ &= [A - sK(1 - 2\alpha_i + \alpha_j)]^2/9b - (1 - \alpha_i)Ktx_i. \end{aligned}$$

In the symmetric case, $V^i(y; \alpha, x) = [A - sK(1 - \alpha)]^2/9b - (1 - \alpha)Ktx$.

Insurance Coverage

$$\begin{aligned} \text{Max}_{\alpha_i} W^i &= V^i(y_i, y_j; \alpha, x) - (1 + \lambda)\alpha_i \mu f^i(y_i, x_i) \\ &= [A - sK(1 - 2\alpha_i + \alpha_j)]^2/9b - (1 - \alpha_i)Ktx_i \\ &\quad - (1 + \lambda)\alpha_i \mu\{s[A - sK(1 - 2\alpha_i + \alpha_j)]/3b + tx_i\} \end{aligned}$$

[FOC]

$$4sK[A - sK(1 - 2\alpha_i + \alpha_j)]/9b$$
$$+ Ktx_i - (1+\lambda)\mu\big[\{s[A - sK(1 - 2\alpha_i + \alpha_j)]/3b + tx_i\} + 2s^2K\alpha_i/3b\big] = 0.$$

Arranging FOC, we have

$$\begin{aligned}\alpha_i &= (1/4)\{[4K - 3(1+\lambda)\mu]/[2K - 3(1+\lambda)\mu]\}\alpha_j \\ &\quad - (9b/4s^2K)\{[K - (1+\lambda)\mu]/[2K - 3(1+\lambda)\mu]\}tx_i \\ &\quad + [(sK - A)/4sK][4K - 3(1+\lambda)\mu]/[2K - 3(1+\lambda)\mu].\end{aligned}$$

For notational convenience, let $B = 4K - 3(1+\lambda)\mu$; $C = 4[2K - 3(1+\lambda)\mu]$; $E = K - (1+\lambda)\mu$.

Then, we can rewrite the FOC as:

$$C\alpha_i - B\alpha_j + (9b/s^2K)Etx_i - [(sK - A)/sK]B = 0.$$

For stability, we assume that $|B| < |C|$.

Note that the second-order condition for maximization (minimization) is as follows:

$$[\text{SOC}]\; C < (>)\, 0.$$

By solving the FOCs simultaneously, we have:

$$[1 - B^2/C^2]\alpha_i = -(9b/s^2K)(E/C)t[x_i + (B/C)x_j] + [(sK - A)/sK](B/C)(1 + B/C). \tag{B1}$$

In the symmetric case, we have (applied both for C > 0 or < 0),

$$[\text{FOC}]\, (C - B)\alpha = -(9b/s^2K)Etx + [(sK - A)/sK]B. \tag{B2}$$

$$\alpha = -(9b/s^2K)Etx/(C - B) + [(sK - A)/sK]B/(C - B).$$

Case 1: $C > 0$.

First, consider the case of $C > 0$. Note that $C > 0$ implies that $B, E > 0$.

If C > 0, then $\alpha_i = \alpha_i'$ satisfying (B1) minimizes the expected profit. Note that RHS < 0 and the coefficient of $\alpha_i > 0$ (due to the stability assumption) in (B1): $(+)\alpha_i = (-) + (-)$. Thus we have $\alpha_i' < 0$. Since the expected profit is minimized at α_i', the profit is increasing for $0 \le \alpha_i$. Thus $\alpha_i^* = \infty$. Note that the change of x_i or x_j will not affect the signs of each terms in (B1), thus the optimal α_i^* is not changed and is equal to ∞. In the symmetric case, (B2) becomes $(+)\alpha = (-)tx + (-)$. Thus, $\alpha' < 0$, which implies $\alpha^* = \infty$. The change of x does not affect the solution.

Case 2: $C < 0$.

If $C < 0$, then $\alpha_i = \alpha_i'$ satisfying (B1) maximizes the expected profit. There are two different subcases: $B > 0$, or $B \le 0$.

Subcase 2.1: $B > 0$.

Note that the stability condition implies that $|C| - B > 0$ or, $4K - 5(1 + \lambda)\mu < 0$.

(i) $E > 0$, i.e., $4K - 4(1 + \lambda)\mu > 0$.

(B1) becomes: $(+)\alpha_i = (+)x_i + (-)x_j + (+)$. Thus, if x_j is not so large, $\alpha_i' = \alpha_i^* > 0$. In this case, the increase of x_i and the decrease of x_j will increase α_i^*.

In the symmetry case, (B2): $(-)\alpha = (-)tx + (-)$. We have $\alpha' = \alpha^* > 0$. The increase of x will increase α.

(ii) $E < 0$, i.e., $4K - 4(1 + \lambda)\mu < 0$.

(B1) becomes: $(+)\alpha_i = (-)x_i + (+)x_j + (+)$. Thus, if x_i is not so large, $\alpha_i' = \alpha_i^* > 0$. In this case, the decrease of x_i and the increase of x_j will increase α_i^*. In the symmetry case, (B2): $(-)\alpha = (+)tx + (-)$. If x is not so large, $\alpha' = \alpha^* > 0$. In this case, the increase of x will decrease α.

(iii) $E = 0$.

(B1) becomes: $(+)\alpha_i = 0 + (+)$. Thus, we have $\alpha_i' = \alpha_i^* > 0$. Obviously, x_i and x_j have no effect. Note also that this case allows only symmetric outcome: $\alpha^* = \alpha_i^*$.

Subcase 2.2: $B \leq 0$.

Note that the stability condition implies that $|C| - |B| > 0$, or $4K - 9(1 + \lambda)\mu < 0$. Note that $B \leq$ implies E < 0.

(B1) becomes: $(+)\alpha_i = (-)x_i + (-)x_j + (-)$.

Thus, $\alpha_i' < 0$ and $\alpha_i^* = 0$. The changes of x_i and x_j do not affect $\alpha^* = 0$.

In the symmetry case, (B2): $(-)\alpha = (+)tx + (+)$. Thus, $\alpha' < 0$ and $\alpha^* = 0$. The change of x does not affect α^*.

Insurance Demand by a Risk-Neutral Firm

Suppose that the firm is risk neutral ($a = 0$) and the premium is actuarially fair ($\lambda = 0$). Then we have $K = \mu$, $B = \mu > 0$, $C = -4\mu < 0$, $E = 0$, and $B + C = -3\mu < 0$, which corresponds to Subcase 2.1 (3). FOC (B1) becomes

$$[\{C^2 - B^2\}/C^2]\alpha_i = [(sK - A)/sK](B/C)(1 + B/C).$$

Thus, $\alpha_i^* = \alpha^* = (A - s\mu)/5s\mu > 0$. With a small positive λ, we still have $\alpha^* > 0$ by continuity (see (B1)). Thus, a risk-neutral firm will purchase actuarially unfair insurance.

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