A Model of Insurance Premium in Response to Probability of Loss

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Abstract We apply a microeconomics model of the insurance firm designed to provide insight into firm price reaction to changes in loss probability. Based on the optimal insurance quantity and price from both consumer and firm points of view, comparative statics is shown in which buyer and seller interact to determine the insurance premium due to changes in the probability of loss. To test the theoretical model, we use a panel data set of 11 Korean liability insurance firms from 2008 to 2015. The regression results show that the insurance premium charged by the firm with more coverage benefit is more responsive to the probability of loss than that of the firm with less coverage benefit, in line with our theoretical result.

Keywords Liability Insurance · Insurance Premium · Price Response · Probability of Loss · Empirical Analysis

Introduction

Liability insurance is a part of the general insurance system of risk financing to prevent the insured from the risks of liabilities imposed by injuries and similar claims. It protects the

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insured if someone suffers from claims within the insurance policy coverage. This paper shows a model of price response in the liability insurance industry.

Given the background of the liability insurance industry, we propose three theoretical propositions as follows: 1) as there is an increase in the probability of negative exogenous shocks, consumers are likely to purchase products offered by more reliable insurers raising the demand for their product 2) as more consumers tend to contract with more reliable firms, the insurers are likely to increase product price 3) as there is an increase in the probability of adverse shocks, the insurers are likely to increase product price by the benefit per unit paid if there is an accident.

Based on a theoretical consideration of insurance market characteristics, this paper empirically investigates the price volatility in the liability insurance industry. Using a panel data set of 11 Korean liability insurance firms from 2008 to 2015, we find that the price imposed by the more reliable insurer is more responsive to changes in exogenous factors than those of the less reliable insurer. We empirically find that this logic applies to both the more reputable and less reputable insurers.

The paper consists of the following sections. In section 2, the theoretical model is described. Section 3 puts the implications to the test. Section 4 concludes.

Theoretical Model

Consider an insurance market where each potential insured faces two states of the world.

1) No accident with probability $1-p$, in which case wealth is w.
2) Accident with probability p, in which case wealth is $w-L$ (where $L>0$ stands for loss).

Thus, each person's wealth endowment is as follows:

$$W_i = \begin{cases} w & with\ probability \quad 1-p \\ w-L & with\ probability \quad p \end{cases}$$

If a person is insured, her endowment is changed as follows:

$$W_i = \begin{cases} w-xI & with\ probability \quad 1-p \\ w-L-xI+xB & with\ probability \quad p \end{cases}$$

Here, the parameters (I, B) describe the insurance contract per unit, equal to the insurance premium per unit (paid in either state of the world) and as the coverage benefit per unit if there is an accident. The variable denotes the number of insurance products the consumer purchases.

The liability insurance market is conceptualized as a sub-game between a representative insurance firm and a representative consumer. The insurance firm proposes an insurance premium to its consumers then the consumer chooses the optimal quantity of insurance product given the price of the insurance product.

Consumer Demand

The consumer chooses optimal number of insurance product x^* to maximize her utility as follows:

$$\max_x (1-p)\,U(w-xI) + pU(w-L-xI+xB) \tag{1}$$

The first-order condition for the consumer's optimal number of insurance products can be expressed as follows:

$$\left(\frac{1-p}{p}\right)\frac{U'(w-x^*I)}{U'(w-L-x^*I+x^*B)} = -\frac{I-B}{B} \tag{2}$$

Equation (2) implies that a risk-averse agent (every insured is assumed to be risk averse here) will optimally purchase units of insurance products if this is fair. In order to analyze the behavior of consumers at the equilibrium, the following proposition establishes based on the equation (2).

Proposition 1: For $U'(\cdot) > 0,\ U''(\cdot) < 0,\ \frac{\partial x^*}{\partial p} > 0.$

Proof: Using equation (2), we employ comparative statics as follows:

$$\frac{\partial x^*}{\partial p} = \frac{U'(w-L-x^*I+x^*B)(I-B) - U'(w-x^*I)}{(1-p)\,U''(w-x^*I)I + pU''(w-L-x^*I+x^*B)(1-B)^2} \tag{3}$$

According to the assumption of a risk averse agent that $U''(\cdot) < 0$, the denominator of equation (3) is negative. Since the numerator of equation (3) is also negative based on equation (2), we have $\frac{\partial x^*}{\partial p} > 0$. It implies that an increase in the probability of loss due to unexpected negative shock makes insurance more necessary thus, consumers buy more insurance products.

Price of Insurance Firm

The insurance firm chooses its premium I^* to maximize its profit as follows:

$$\max_I (I-pB)x \tag{4}$$

The first order condition for the firm's optimal price of insurance product can be expressed as follows:

$$pB - \frac{x}{x'} = I^* \tag{5}$$

Equation (5) implies that the insurance firm will optimally make the price equal to marginal cost and a mark-up. To analyze the behavior of insurance firms at the equilibrium, the following proposition establishes based on the equation (5).

Proposition 2: For $x'(\cdot) < 0$, $x''(\cdot) < 0$, $\frac{\partial I^*}{\partial x} > 0$.

Proof: Using equation (5), we employ comparative statics as follows:

$$\frac{\partial I^*}{\partial x} = \frac{-1}{x' + (I - pB)x''} \tag{6}$$

According to the assumption that $x'(\cdot)$, $x''(\cdot) < 0$, and non-negative profit $(I - pB > 0)$, the denominator of equation (6) is negative thus $\frac{\partial I^*}{\partial x} > 0$. This implies that an increase in the demand of insurance product by consumers makes insurance more valuable so that insurance firm raises its premium.

Proposition 3: For $\frac{x'}{x''} > 1$, $0 < \frac{\partial I^*}{\partial p} = \frac{B}{1 + \frac{(x')^2}{x' - x''}}$.

Proof: Using equation (5), we employ comparative statics as follow.

$$B - \frac{x' - x''}{(x')^2} \frac{\partial I^*}{\partial p} = \frac{\partial I^*}{\partial p} \tag{7}$$

The insurance firm raises its premium proportional to the coverage benefit per unit. It shows that the price charged by the firm with more coverage benefit is more responsive to an increase in the probability of loss than that of the firm with less coverage benefit. This implies that an increase in the probability of loss due to unexpected negative shocks makes insurance more valuable.

Empirical Evidence

Based on a theoretical model of insurance market characteristics, we empirically analyze the price response in the liability insurance industry. We collected a monthly panel data set of the top 11 Korean liability insurance firms from 2008 to 2015.[1] The General Insurance Association of Korea provides liability-insurance market data and annual reports. On its website, monthly activity reports for the number of new contracts, total amount of new contracts, and original

[1] The top 11 Korean liability insurance firms are ACE, AIG, Dongbu, Hanwha, H.Kook, Hyundai, KB, Lotte, Meritz, Samsung, and The K.

premium can be found. We also collected macro-level data such as GDP and interest rate obtained from the Bank of Korea and made an index variable considering all negative exogenous shocks in Korea, such as MERS and Sewolho obtained from SNSs and newspapers.[2] [3]

Figure 1 shows the average insurance premium of 11 Korean liability insurance firms. The average prices of most insurance firms are volatile and increase over time, although it varies in magnitude.

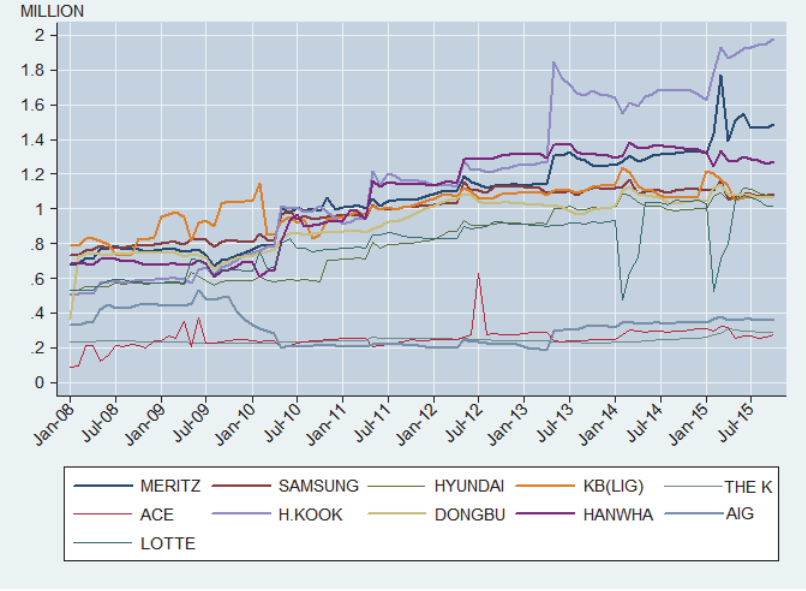

Fig. 1 Average Insurance Premium of 11 Korean Liability Insurance Firms

We derived a simple empirical regression to analyze insurance premium response to several exogenous variables.

$$I_{it+1} = \alpha_0 + \alpha_1 I_{-it} + \alpha_2 GDP_t + \alpha_3 Rate_t + \alpha_4 LOSS_t + \alpha_i + \varepsilon_{it} \qquad (8)$$

The error term ε_t is assumed to be distributed i.i.d. $(0, \sigma_\varepsilon^2)$. The variable I_{it+1} is the average insurance premium of firm i at period $t-1$ same as in the theoretical model. The exogenous variable I_{-it} is average insurance premium of other insurance firms at period t. GDP_t, $Rate_t$

[2] We made a monthly index variable to represent the probability of loss due to all exogenous shocks happened during 2008-2015 in Korea such as MERS and Sewolho in our own method. The raw data are obtained from various resources from blogs, News, SNSs. We then counted total number of words "our targeted event" cited by various resources and computed average level of probability of events happened based on emotional quotient. More information is available upon request.

[3] The sinking of the Sewol ferry occurred on the morning of April 16, 2014, on a route from Incheon to Jeju in Korea. The ferry capsized while carrying 476 people, and 304 passengers and crew members died in the disaster, resulting in widespread social and political reactions within Korea.

and $LOSS_t$ are GDP per capita, interest rate and probability of loss due to negative exogenous shocks happened at period t, respectively. The variable α_i is the firm i's specific dummy variable (firm fixed-effects). We also used time trend to capture the impact of technology change over time on insurance contract (Model 1) and 11-month dummies to reflect seasonal patterns in liability insurance consumption (Model 2). We finally included interaction terms of 11 firm dummies and probability of exogenous shocks to investigate heterogeneous impact of exogenous shocks on each firm (Model 3). Table 1 reports summary statistics of average premium, GDP per capita and interest rate, while all regression results are reported in Table 2.

In Table 1, the average insurance premium of each firm varies in magnitude, suggesting that insurance firms in Korea are differentiated in terms of insurance product.[4] H.Kook has 1.98 million won as the maximum premium, and Dongbu has 0.04 million won as the minimum premium to offer unit insurance product. The average GDP per capita and interest rate in Korea is 2.18 million won and 2.77 percent, respectively.

Table 1 Summary Statistics of Average Insurance Premium

Variables	Mean	Std. Dev.	Min	Max
Insurance Premium				
Meritz	1.07	0.25	0.67	1.77
Samsung	0.98	0.14	0.73	1.17
Hyundai	0.81	0.20	0.53	1.12
KB	1.01	0.12	0.73	1.24
The K	0.25	0.02	0.22	0.31
ACE	0.25	0.06	0.09	0.63
H.Kook	1.17	0.46	0.51	1.98
Dongbu	0.91	0.17	0.04	1.14
Hanwha	1.05	0.30	0.07	1.38
AIG	0.31	0.09	0.20	0.53
Lotte	0.80	0.16	0.47	1.08
GDP per Capita	2.18	0.21	1.75	2.54
Interest Rate (%)	2.77	0.95	1.50	5.25

Premiums, GDP per Capita are in Korean million won.

Table 2 shows that the premium of other firms is negative and strongly significant in all three cases considered and varies little in magnitudes across specifications. One million won increase in the premium of other firms means around 0.3 million won decrease in the targeted firm's premium, indicating that insurance firms in Korea are more competitive than collusive. The interest is also negative, but significance varies in magnitude across specifications, suggesting a one percent increase in interest rate lessons 0.06 million won in the firm's premium. Moreover, GDP per capita is positive and strongly significant regardless of model specification. This implies that a one thousand won increase in GDP per capita increases the firm's premium by about 0.08 million Korean won. However, the variable for the probability of loss in all specifications has correct signs but is not statistically significant in Model (3). It would be an interesting finding,

[4] This is supported by the annual report from Korea Finance Consumer Federation that the top 5 liability insurance firms are as follows: Samsung, KB, Hyundai, Meritz, and Dongbu. More detailed information is www.kfco.org.

Table 2 Empirical Result (Dependent variable: Average Insurance Premium)

Variables	Model (1)	Model (2)	Model (3)
Premium of Other Firms	-0.2716*** (0.0166)	-0.3306*** (0.0178)	-0.3261*** (0.0178)
GDP per Capita	0.0824*** (0.0121)	0.0831*** (0.0133)	0.0857*** (0.0130)
Interest Rate	-0.0637*** (0.0229)	-0.0679** (0.0287)	-0.0698* (0.0346)
Probability of Loss	0.0317** (0.0146)	0.0365** (0.0169)	-0.0314 (0.05231)
Coverage Benefit	0.0003*** (0.0001)	0.0003*** (0.0001)	0.0003*** (0.0001)
Time Trend	0.0087*** (0.0007)	0.0078** (0.0034)	0.0089*** (0.0033)
Seasonal Dummies			
February		-0.0090*** (0.0027)	-0.0093*** (0.0027)
March		-0.0065*** (0.0028)	-0.0069** (0.0028)
May		0.0127*** (0.0021)	0.0122*** (0.0021)
Interaction Term (Probability of Loss*Firm Dummies)			
Meritz			0.1122** (0.0435)
Samsung			0.0422 (0.0436)
Hyundai			0.1575*** (0.0435)
KB			0.1239*** (0.0435)
The K			0.0531 (0.0437)
ACE			0.1196** (0.0435)
H.Kook			0.1187** (0.0435)
Dongbu			0.1295** (0.0435)
Hanwha			0.0790* (0.0435)
AIG			0.1074** (0.0435)
Constant	3.85	4.19	7.73
R^2	0.9451	0.9783	0.9928
Number of observations	1034	1034	1034
Month dummies	No	Yes	Yes
Firm Fixed Effect	Yes	Yes	Yes

Standard errors are in parentheses.
*, **, and *** denote significance at 10%, 5%, and 1% respectively.
Premiums, GDP per Capita and Coverage Benefit are in Korean million won.
The significant month dummies (december as based month) are only included. The full result is available upon request.

especially when considering interaction terms between firm dummies and the probability of loss. It suggests that each insurance firm has a different impact on the probability of loss on its premium for insurance coverage benefits, which is in line with our theoretical result.

We include time trend and seasonal dummy variables in our model to show whether time and seasonal factors affect a firm's premium. As shown in model (1), (2), and (3), the time trend is positive and strongly significant. Regarding the seasonal dummies, February and March negatively affect the firm's premium, indicating that insurance firms are likely to decrease product prices more during these periods. On the other hand, May positively and significantly affects the firm's premium, implying that insurance firms are likely to raise insurance prices more in May.

Conclusion

We develop a microeconomics model of the insurance firm designed to provide insight into firm price reaction to changes in loss probability. The theoretical model is put to the test. We find the optimal insurance unit and price from both consumer and firm points of view and conduct comparative statics in which buyer and seller interact to determine the insurance premium due to changes in the probability of loss. The regression results use a panel data set of 11 Korean liability insurance firms from 2008 to 2015. The results show that the insurance premium charged by the firm with more coverage benefit is more responsive to the probability of loss than that of the firm with less coverage benefit, in line with our theoretical result.

References

Appel, D., Jack D. Worrall and Richard J. Butler, 1985, "Survivorship and the Size Distribution of the Property Liability Insurance," *The Journal of Risk and Insurance, vol. 52,* 424-440.

Beenstock, M., Dickinson, G. and Khajuria, S., 1988, "The Relationship between Property-Liability Insurance Premiums and Income: An International Analysis," *The Journal of Risk and Insurance, vol. 55,* 259-272.

Berger, Lawrence A., 1988, "A Model of the Underwriting Cycle in the Property/Liability Insurance Industry," *The Journal of Risk and Insurance, vol. 55,* 298-306.

Dafny, L., Duggan, M. and Ramanarayanan, S., 2012, "Paying a Premium on Your Premiun? Consolidation in the US Health Insurance Industry," *The American Economic Review, vol. 102,* 1161-1185.

Doherty, N., 1981, "The Measurement of Output and Economies of Scale in Property-Liability Insurance," *The Journal of Risk and Insurance, vol. 48(3),* 390-402.

Finkelstein, A. and Kathleen McGarry, 2006, "Multiple Dimensions of Private Information: Evidence from the Long-Term Care Insurance Market," *American Economic Review, 96(4),* 938-958.

Grace, M. F. and Hotchkiss, J. L., 1995, "External Impacts on the Property-Liability Insurance cycle," *The Journal of Risk and Insurance, vol. 62(4),* 738-254.

Joskow, P., 1973, "Cartels, Competition and Regulation in the Property-Liability Insurance Industry," *The Bell Journal of Economics, vol. 4,* 375-427.

Sommer, D. W., "The Impact of Firm Risk on Property-Liability Insurance Prices, *The Journal of Risk and Insurance, vol. 63(3),* 501-514.

Starc, A., 2014, "Insurer Pricing and Consumer Welfare: Evidence from Medigap," *The RAND Journal of Economics, vol. 45(1),* 198-220.