# Which Insurers Write Cyber Insurance? Evidence from the U.S. Property and Casualty Insurance Industry

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**Abstract:** This article is the first to analyze the relationship between corporate characteristics and the writing of cyber insurance in the U.S. property and casualty insurance industry. Given that cyber risk is an emerging dynamic and difficult-to-quantify risk category, we interpret the writing of cyber insurance as a risky activity, and link our results to the broad literature on insurers' risk taking. The results show that insurers with more capital, lower asset risk, greater diversification among business lines and geographic areas, and group members are more likely to write cyber insurance. The results for different ownership types are ambiguous: although many mutual insurers are more likely to offer cyber coverage as part of existing policies, stock insurers are more likely to sell standalone cyber insurance. We also analyze the interrelationship between writing cyber risk and capital and reinsurance usage with a simultaneous equation model. Besides the positive relationship between capital and the undertaking of cyber risk, the results show that insurers writing cyber insurance policies use more reinsurance to transfer their risk. [Key words: cyber risk; cyber insurance; risk taking; logistic regression; simultaneous equation model]

## INTRODUCTION

Cyber risk is a significant and economically costly risk faced by companies and individuals.[3] Although completely avoiding cyber risk is impossible, the use of cyber insurance as a principal means of transferring

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risk has been very limited and is far below expectations.[4] For example, in 2002 it was predicted that the global cyber insurance market would reach $2.5 billion in 2005 (Baer, 2003; Böhme and Schwartz, 2010), but this volume was not achieved until 2015. Meanwhile, cyber risk is attracting the attention of companies across most industries (see Allianz, 2017; PriceWaterhouseCoopers, 2017).

Research on cyber risk in the business and finance area is limited, but the body of literature in the IT domain is large (see Eling and Schnell, 2016, for an overview). The academic literature has concentrated on the difficulties of modeling cyber risk in an interconnected environment using simulation frameworks (Böhme, 2005; Böhme and Kataria, 2006; Herath and Herath, 2007; Mukhopadhyay, Saha, Mahanti, Chakrabarti, and Podder, 2005; Mukhopadhyay, Chatterjee, Saha, Mahanti, and Sadhukhan, 2013). Only recently have some preliminary empirical analyses on cyber risk been conducted. Romanosky (2016) uses the Advisen database to analyze the costs and causes of cyber incidents. Biener, Eling, and Wirfs (2015) examine cyber loss data derived from the SAS operational risk database, and discuss the insurability of cyber risks. While these papers empirically analyze cyber incidents, to our knowledge no empirical research on the cyber insurance market has yet been conducted.[5]

The U.S. cyber insurance market is more advanced than its counterparts in Europe and Asia. This paper examines the U.S. market and analyzes the characteristics of insurers that write cyber insurance. We provide the first empirical analysis of this kind, using data in statutory filings for Cybersecurity and Identity Theft Coverage established by the National Association of Insurance Commissioners (NAIC) in 2015, which have been publicly available since April 2016. More than 500 individual

[3]For example, the annual losses caused globally by cybercrime have been estimated at $445 billion (McAfee, 2014). According to the World Economic Forum (2014), there is a 10% probability of a critical information infrastructure breakdown in the next 10 years that would cost about $250 billion.

[4]The U.S. insurance industry's net premiums written amounted to $1,155 billion in 2015 (Insurance Information Institute, 2017), while direct written premiums in the U.S. cyber insurance market amounted to $1.2 billion (see Insurance Information Institute, 2016). Additional premiums are ceded via Lloyds. Advisen (2015) estimates the premium volume for the U.S. market in 2015 at $2.4 billion. The market outside the U.S. is very small—around $0.5 billion (see Marsh, 2016).

[5]Current research on the cyber insurance market consists mostly of industry reports based on surveys (e.g., Betterley, 2015, 2016; ENISA, 2016; NetDiligence, 2016). The few academic papers on the cyber insurance market are also based on surveys or interviews; see Franke (2017) on the Swedish cyber insurance market or Strupczewski (2017) on the Polish cyber insurance market. Romanosky et al. (2017) provides a content analysis of 100 cyber insurance policies filed with U.S. state insurance commissioners.

insurance companies provided cyber insurance for businesses and individuals, considering both standalone and packaged coverage. We are interested in understanding whether there are significant differences between insurers that do and do not write cyber insurance.

Considering the ever-changing nature of cyber risk, we interpret the offering of cyber insurance as a risk-taking behavior and embed our results in the broad literature on insurers' risk-taking behavior. Baranoff and Sager (2003) suggest that riskier products involve relational contracts that are complex, incomplete, and uncertain. The proportion of liabilities in certain lines of insurance is also commonly used as a proxy for underwriting risk. For example, Cheng and Weiss (2013) and Mankaï and Belgacem (2015) use the proportion of premiums written in risky lines as a measure of underwriting risk.[6] Baranoff, Papadopoulos, and Sager (2007) use the proportion of firm premiums in health and annuity lines as a proxy for product risk in life insurance.

We thus interpret the writing of cyber insurance as a risk-taking behavior and examine the relationship between the writing of cyber insurance and insurers' financial, managerial, and underwriting characteristics derived from the literature on the risk-taking behavior of insurers. The characteristics examined are capital levels, asset risk, organizational structure, business and geographic diversification. Size, age, group affiliation, financial strength rating, reinsurance usage, and commercial lines focus are the control variables. A logistic regression model is used to examine the relationship between these characteristics and the writing of cyber insurance. We also use a simultaneous equation model to analyze the relation between the writing of cyber insurance and capital and reinsurance usage.

The result shows that underwriters of cyber insurance are bigger, have more capital, have lower asset risk, and are more diversified across business lines and geographic areas. We find that stock insurers are more likely to provide standalone cyber policies, which are both more complex and riskier. Besides the positive relationship between capital and the undertaking of cyber risk, we also find that insurers providing cyber insurance use more reinsurance to transfer the risk taken.

[6]The risky lines are those that have the highest risk factors in calculating risk-based capital: commercial auto liability, allied lines, earthquake, surety, theft, inland marine, fire, international, boiler and machinery, reinsurance, and medical malpractice occurrence. Mankaï and Belgacem (2015) use the proportion of direct premium on property insurance in Eastern coastal states and on earthquake insurance as a measurement of underwriting risk. Our treatment of cyber insurance writing is analogous.

Our research contributes to the literature in several ways. First, the research on the cyber insurance market is limited[7]; we offer an original empirical analysis of the U.S. cyber insurance market, which is the world's largest. Second, our research provides new and complementary evidence on insurers' risk taking. Although there is as yet no capital requirement on cyber-related products, insurers need to hold enough capital and use risk management methods such as reinsurance to maintain solvency.

The second section describes the characteristics that we will examine in our model and the hypotheses to be tested. The third section presents the data and the regression models. The fourth section discusses the results and provides robustness tests. Finally, we conclude.

## RELATED LITERATURE AND HYPOTHESIS DEVELOPMENT

In the U.S. property and casualty (P&C) insurance industry, cyber insurance protects companies and individuals from cyber risks (Insurance Information Institute, 2016).[8] Empirical studies on cyber insurance are based on industrial survey data of limited sample size (e.g., Betterley, 2015, 2016; Franke, 2017), and suggest that coverage of cyber insurance is low, especially considering the heavy losses incurred by cyber incidents (Bradford, 2015). Using a quantitative analysis of cyber loss data from an operational risk database, Biener et al. (2015) suggest that interdependence, lack of predictability, and information asymmetry are the main challenges in insuring cyber risk.

Considering the ever-evolving nature of cyber risk and immaturity of the cyber insurance market, we interpret the writing of cyber insurance as a risk-taking behavior.[9] First, we consider the relationship between writing cyber insurance and company characteristics related to risk-taking behavior based on the literature.

[7]Only a few industry studies with limited sample size have been published (Betterley, 2015, 2016; Franke, 2017).

[8]As shown in the NAIC supplement, insurers provide two types of coverage (see Appendix A): cybersecurity and identity theft. Cyber policies cover commercial risks. Identity theft is a personal line of coverage that offers protection should the policyholder's identity be stolen.

[9]There are several fundamental insurability problems for cyber risk; we thus believe that writing cyber insurance can be interpreted as riskier than writing other types of insurance. Among these problems are the lack of data, the lack of modelling approaches, the risk of extreme events, unclear dependence structures, and asymmetric information; see Biener et al. (2015) for a more detailed analysis of the characteristics of cyber risk and the resulting insurability problems.

**Table 1.** Characteristics of Insurer Considered and Related Literature

| Characteristics of insurer | | Related literature |
|---|---|---|
| Financial characteristics | Capital | Cummins and Sommer (1996); Baranoff and Sager (2002, 2003); Shim (2010); Cheng and Weiss (2012, 2013); Mankaï and Belgacem (2015) |
| | Asset risk | Baranoff and Sager (2002, 2003); McShane, Zhang, and Cox (2012); Cheng and Weiss (2013); Che and Liebenberg (2017) |
| Managerial/ organizational characteristics | Ownership structure | Mayers and Smith (1981, 1988, 1994); Lamm-Tennant and Starks (1993); Lee, Mayers, and Smith (1997); Baranoff and Sager (2003); MacMinn and Ren (2011). Berry-Stölzle et al. (2012); Ho et al. (2013); Adamson et al. (2014); Mankaï and Belgacem (2015) |
| Underwriting characteristics | Business concentration | Elango et al. (2008); Liebenberg and Sommer (2008); Berry-Stölzle et al. (2012); Cheng and Weiss (2013); Ho et al. (2013) |
| | Geographic concentration | Cheng and Weiss (2013); Ho et al. (2013) |
| Control variables | Company size | Cheng and Weiss (2013); Eling and Marek (2012, 2014) |
| | Company age | Eling and Marek (2012) |
| | Group affiliation | Cummins and Sommer (1996); Baranoff et al. (2007); Cheng and Weiss (2013); Mankaï and Belgacem (2015) |
| | Other | Financial strength rating, reinsurance usage, Commercial lines focus |

## The Characteristics of Cyber Insurance Writers

The financial and managerial characteristics of cyber insurance writers influence their decision to write cyber insurance, in addition to the underwriting characteristics. Financial characteristics include capital-level and asset risk; managerial characteristics are the organizational structure; and underwriting characteristics are the business and geographic concentration. Other characteristics, such as group affiliation, company size, and age, are taken as control variables. The characteristics analyzed in this paper and in the literature are summarized in Table 1.

### *Capital*

Insurers hold capital to support the liability of policies they issue. According to the capital buffer theory, insurers hold excess capital above the regulatory minimum capital required against unanticipated loss and to avoid regulatory costs (Shim, 2010). The relationship between capital levels (typically defined as capital-to-assets ratio) and risk has been studied extensively, and most of the literature shows a positive relationship supported by empirical results. Cummins and Sommer (1996) provide evidence of a positive relationship between capital and underwriting risk in non-life insurance firms. More recently, Cheng and Weiss (2013) find evidence that capital increases are associated with increases in investment and underwriting risk, especially in the post-RBC period. Mankaï and Belgacem (2015) also find that risk taking is positively related to capital levels, proving the effectiveness of regulatory mechanisms and the relevance of the capital buffer hypothesis.

Cyber risk is fast evolving and difficult to model. Accordingly, writing cyber insurance is a risky behavior for insurers. Despite some controversial evidence (e.g., Baranoff and Sager (2002) finding a negative relation between product risk[10] and capital ratio among life and health firms), most papers support a positive relationship.[11] Thus, we propose our first hypothesis, that insurers with higher capital levels are more likely to write cyber insurance.

> H1: *Insurers with higher capital levels are more likely to write cyber insurance.*

### *Asset Risk*

Asset risk and underwriting risk are the two main sources of risk for insurers. Under the finite risk paradigm, excessive risk taking on the asset or product side may require higher capital levels (less risky capital structure) to offset risk (Baranoff, Sager, and Shi, 2013). Thus, if the capital level

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[10]Product risk is measured by the ratio of premiums in health insurance to total premiums.

[11]We note that although there is no explicit capital requirement on cyber-related products, all insurers that underwrite cyber policies must hold capital for that business according to the RBC standards defined by the NAIC. While there is no specific risk factor for cyber insurance policies, the one for "other liabilities" might be used in RBC calculations. It would be appealing to separate the capital requirements for cyber risk from the capital requirements for other risks in our empirical study, but this is difficult without internal data and might need additional assumptions (e.g., how to allocate diversification effects). If we assume that the companies treat cyber insurance as "other liabilities" under the RBC model, then we might calculate a capital requirement for cyber based on the premium and reserve information we have.

remains unchanged, higher risk on the product side may be associated with lower asset risk (Baranoff and Sager, 2003).[12] However, empirical results (Baranoff and Sager, 2003) do not verify this assumption.[13]

Asset risk might also be related positively to underwriting risk when a company is consistent on both the underwriting and investing side. Baranoff and Sager (2002) show a positive relationship between product risk and regulatory asset risk[14] in their simultaneous model, which includes regulatory asset risk, product risk, and capital. In contrast, Che and Liebenberg (2012) and McShane, Zhang, and Cox (2012) show a negative relation between underwriting risk and investment risk referring to the coordinated risk management hypothesis (see Schrand and Unal, 1998).[15] Therefore, two contradictory hypotheses are possible.

H2a: *Insurers with higher asset risk are more likely to write cyber insurance.*

H2b: *Insurers with higher asset risk are less likely to write cyber insurance.*

### *Ownership Structure*

The two predominant ownership structures of insurers are stocks and mutuals. The organizational structure and the resulting risk-taking behavior have been widely examined (see MacMinn and Ren, 2011, for an overview). Stock insurers owned by shareholders with limited liability might be more likely to take on excess risk at the expense of policyholders. The managerial discretion hypothesis (Mayers and Smith, 1981, 1988) provides evidence that mutual insurers are more successful in lines of insurance characterized by standardized policies that need less discretion, while stock insurers are more successful in selling riskier and more individualized lines of insurance. Lamm-Tennant and Starks (1993) suggest that mutual insurers are involved in less risky activities. Lee, Mayers, and

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[12]Table 1 in Baranoff and Sager (2003) predicts a negative relationship between premium ratio on health insurance and asset risk, taking health insurance as a risker product than annuity insurance. The empirical result in Table 8 is negative, yet not significant.

[13]Also, empirical results in Cheng and Weiss (2013) show a negative but not significant relationship between underwriting and asset risk.

[14]There are two kinds of asset risk measurement commonly used in the extant literature: Regulatory Asset Risk (RAR) and Opportunity Asset Risk (OAR); see Baranoff and Sager (2002, 2003, and 2007), Eling and Marek (2014). RAR is an approximation of the ‘‘regulatory’’ definition of asset risk given in the RBC formula (see also Cheng and Weiss, 2013) and OAR measures the insurer's asset risk based on its investment portfolio and the external financial market.

[15]The coordinated risk management hypothesis is also termed risk allocation hypothesis. Underwriting is considered as core business, where on average more risk is taken, while asset risk is considered as non-core business, where typically less risk is taken.

Smith (1997) offer empirical evidence that mutual insurers have lower underwriting risk than stock insurers. Cummins, Phillips, and Smith (2000) suggest that there are no conflicts between shareholders and policyholders in mutual insurance companies, and that mutual insurers are less likely to take excessive risks. Stock and mutual insurers also differ in their access to external capital. Mutual insurers find it harder to raise capital than stock insurers do because the only way that they can raise capital is by issuing surplus notes; this implies that mutual insurers will take less risk.

At the same time there is some evidence to the contrary. For example, Ho, Lai, and Lee (2013) find mutual insurers taking less risk, while mutual insurers whose boards are larger tend to have higher underwriting risk than stock insurers. However, based on the literature, we propose that stock insurers are more likely to write cyber insurance, leading to the third hypothesis.[16]

H3: *Stock insurers are more likely to write cyber insurance.*

### *Business Line and Geographic Concentration*

Business line and geographic concentration are important influences on corporate performance (see Elango, Ma, and Pope, 2008; Liebenberg and Sommer, 2008). Diversification either geographically or by line of business might reduce an insurer's overall risk; for example, Ho et al. (2013) find a positive relationship between business concentration and underwriting risk[17] and a positive relationship between geographic concentration and total risk.[18] Risk might be diversified as a result of writing on more lines and geographic areas. We may thus consider a negative sign of business line and geographic concentration on the writing of cyber insurance as a risk-increasing activity.

However, Cheng and Weiss (2013) find that both business and geographic concentration have a significant negative effect on underwriting risk; that is, less diversification is associated with less underwriting risk. Berry-Stölzle, Liebenberg, Ruhland, and Sommer (2012) do not find that insurers operating in more volatile business lines diversify more than insurers operating in less volatile lines either. These results support Mankaï and Belgacem's (2015) statement that high concentration may also reflect insurers specialized in certain lines or areas. More concentrated insurers

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[16]It would be interesting to explore the managerial and ownership characteristics by looking at executive compensation (Ma and Wang, 2014), board leadership structure (Miller and Yang, 2015) or family control (Pooser, Wang, and Barrese, 2017). Unfortunately, our dataset does not include detailed information on these items.

[17]Underwriting risk is measured by the standard deviation of the loss ratio.

[18]Total risk is measured by standard deviation of ROA.

may have better risk-pricing skills and better expertise. Cyber insurance still lacks valid data and actuarial models; considering that insurers with higher concentration may be more specialized, we may also expect a positive relationship between business line and geographic concentration and cyber insurance writing.[19] Thus, the sign of business line and geographic concentration cannot be determined *a priori*.

> H4a: *Insurers with less concentration (more diversified) in line of business and geographic areas are more likely to write cyber insurance.*

> H4b: *Insurers with less concentration (more diversified) in line of business and geographic areas are less likely to write cyber insurance.*

### *Control Variables*

We include several control variables commonly used in the empirical literature; these variables might affect the decision to write cyber policies. Company size is a control variable in almost every empirical study of insurer behavior (e.g., Cheng and Weiss, 2013). Large companies are often expected to have adequate capital, strong market power, and an advantage in diversifying risks. We therefore expect size to be positively related to the writing of cyber insurance. Company age is another commonly used control variable in empirical papers (e.g., Eling and Marek, 2012); however, to our knowledge, the relationship between age and writing cyber insurance cannot be determined. Group affiliation is also often taken into consideration as a control variable (e.g., Baranoff et al., 2007), showing a positive relationship between group affiliation and risk taking. Hence, we also include group affiliation as a control variable and expect a positive sign.

An insurer's financial strength and ability to meet its ongoing insurance policy and contract obligations might also influence their decision on risky activities; we thus use the financial strength rating of insurers as another control variable, with a better-rated insurer more likely to offer cyber insurance. We also control for the use of reinsurance and distinguish pure commercial insurers from those offering both personal and commer-

[19]Also note that for extreme risks diversification might not work as it is usually expected; see the discussion on the non-diversification trap in Ibragimov et al. (2009). If insurers anticipate a potential non-diversification trap, it might reduce their willingness to engage in cyber insurance. The geographical diversification for cyber risk also might not work so well, because cyber risks do not know any geographical boundaries. Even the effect of product diversification is not fully clear, because some lines of businesses might contain silent covers when cyber risks are not explicitly excluded.

cial lines; given that cyber is predominantly a commercial business, we expect pure commercial insurers to be more likely to offer cyber insurance.

## The Impact of Undertaking Cyber Risk on Capital and Reinsurance Usage

The literature has shown a simultaneous relationship between risk and capital for reasons such as regulation and market discipline (see, e.g., Cheng and Weiss, 2013). Insurers thus decide their risk taking and capital level at the same time based on the constraints they face. The consequence is that an insurer's decision in writing cyber insurance policies will also affect its capital. Besides holding more capital, insurers can use reinsurance to transfer risk (Shiu, 2011). Mankaï and Belgacem (2015) find a positive relationship between risk and reinsurance usage. Following this literature, we propose that insurers' underwriting of cyber risk will be positively related with capital and reinsurance usage. For the relationship between capital and reinsurance, we expect a negative relationship, since reinsurance can be taken as a substitute for capital (Powell and Sommer, 2007).

In the second section we analyzed the characteristics that may influence cyber risk. Under the assumption that risk taking, capital level, and reinsurance usage are decided simultaneously, risk taking will influence capital and reinsurance usage. We thus take them as endogenous variables in our simultaneous analysis.

To make a better estimation, we consider a few other determinants that may have an impact on capital and reinsurance in the simultaneous equations. For the capital level, the insurer's performance and profitability will influence the sufficiency of internal funds that can be transformed into capital (Mankaï and Belgacem, 2015). According to pecking order theory, insurers prefer internal to external sources of funding. Thus, we expect a positive relationship between capital and performance and use return on assets as a measurement of performance. For reinsurance usage, we propose that leverage ratio is positively related to reinsurance usage (implying a negative relation between capital and reinsurance usage). Highly leveraged insurers are more exposed than others to the risk of insolvency, and are expected to use more reinsurance, suggesting positive interactions (Shiu, 2011). Reinsurance can also be seen as an internal capital market, and for more leveraged insurers it is hard to raise capital from the external capital market (Mankaï and Belgacem, 2015). We thus expect a positive relationship between leverage ratio and reinsurance.

# DATA AND METHODOLOGY

## Market and Product Overview

Although the first cyber insurance products were issued in the late 1990s (AON, 2017), the cyber insurance market is still in its infancy. The U.S. market started to develop after 2000, especially because reporting requirements for data breaches were introduced in many U.S. states after 2002 (Eling and Schnell, 2016).[20] Insurers tried to exclude cyber risk from traditional policies like commercial general liability (CGL) and commercial property or crime policies (see Zelle and Whitehead, 2014). Today there is a co-existence of standalone cyber insurance products (new policies only for cyber) and packaged policies (specified endorsement on current policies that also include other coverages). The direct written premiums in the U.S. cyber insurance market in 2015 amounted to $1.2 billion (Insurance Information Institute, 2016) and this number is expected to grow by 30% in the next years. The top carriers in terms of premium volume are AIG ($215 million direct premiums), Chubb Limited ($121 million direct premiums), and XL Group Ltd. ($113 million direct premiums).

Cyber risk and cyber insurance are receiving more attention than ever, even from the regulatory side. The NAIC developed the Cybersecurity and Identity Theft Insurance Coverage Supplement for insurer financial statements to gather information on the financial performance of insurers that are writing cyber-liability coverage nationwide. The first supplement was filed with the 2015 Annual Statement in April 2016. Table A1 of Appendix A features a sample page of the Cybersecurity and Identity Theft Coverage supplement. Two types of coverage are included: cybersecurity and identity theft. Cybersecurity policies cover commercial cyber risks, and identity theft is a personal lines coverage that protects a policyholder whose identity has been stolen (Insurance Information Institute, 2016). Table 2 shows that the identity theft policy has a lower premium per policy ($43) and larger policy numbers (around 17.5 million).

Cybersecurity coverages tend to be in the property and liability domain, especially business interruption, errors and omissions, media liability, crisis management, and cyber extortion (Ernst and Young, 2017). While aggregate industry information for 2015 indicates low loss ratios (less than 50% including loss adjustment expenses), the riskiness of the

[20]AON (2017) summarizes the historical development and growth drivers for the cyber insurance market. We note that cyber coverage is the fastest-growing surplus line business in history. See NAIC (2016).

**Table 2.** Premiums and Policy Numbers of Cyber Insurance Policies

| Type of insurance | Standalone policy | | | Packaged policy | |
|---|---|---|---|---|---|
| Coverage | Premium written ($000) | Policy number | Average premium per policy | Premium written ($000) | Policy number |
| Cybersecurity | 483,198 | 58,342 | 8,282 | 515,100 | 519,048 |
| ID theft | 21,184 | 496,883 | 43 | 219,950 | 17,002,122 |

Note that some companies cannot split the cyber part of the premium from the overall premium amount. These cases are included in the policy number, but not in the premiums written. The average premium per policy is thus not informative for the packaged policy and is thus not presented in Table 2.

cyber insurance market should not be underestimated—for example, when the few public loss cases are considered.[21] The data indicate that the company level loss ratio of standalone cybersecurity policy ranges from 0 to more than 580%.

## Sample

Our sample is a cross-sectional dataset of U.S. P&C insurance companies in 2015 from the NAIC statutory database. To gain more information and understanding of the cyber insurance market, the NAIC has designed the Cybersecurity and Identity Theft Coverage Supplement. It contains detailed information on cyber-related coverage, such as premiums, claims, and policy number. We can thus distinguish companies that write cyber insurance from those that do not. Financial and other underwriting information can be found in the annual statement.

Insurers underwrite cyber risk either through a standalone cyber insurance policy or through a packaged policy. Many cyber policies underwrite cyber risk through a packaged policy, which is an extension of a current policy (e.g., error and omission policies) to cover some aspects of cyber risk. The more customized standalone policy covers only cyber-related risk. We regard standalone policies that cover cyber risks more explicitly and are less standardized as riskier than packaged policies, and analyze the relationship between corporate characteristics and the writing of standalone and packaged cyber policies.

[21]For example, we might compare the claims from the Target breach with the market's cyber premiums for the year. According to the 2016 annual report and SEC filings of Target, the total costs of the data breach was $292 million. A cyber-insurance policy covered $90 million reducing Target's net loss to $202 million. See Lynch (2017).

**Table 3.** Number of Insurers Writing Different Types of Cyber Insurance

| | Type of insurance | | |
|---|---|---|---|
| Coverage | Standalone policy | Packaged policy | Total |
| Cybersecurity | 102 | 264 | 306 |
| ID theft | 12 | 314 | 322 |
| Total | 113 | 465 | 512 |

The initial sample consists of 2,653 individual insurance companies with cyber insurance data for 2015. We exclude companies with negative and zero direct written premium or total admitted asset; we also exclude organizational structures other than stocks or mutuals[22] and insurers established in or after 2014, since lagged independent variables are used in our regression model. Insolvent insurers (RBC ratio less than 1) are excluded, as are insurers that write only personal lines. Our final sample consists of 1,785 insurers.

## Identification of Cyber Insurance Writers

Two kinds of coverage (cybersecurity, identity theft) and policies (standalone, packaged) are provided in the Cybersecurity and Identity Theft Coverage supplement, resulting in four categories (see Tables 1–4 in the Appendix A). To use all the information provided in the supplement, we apply the following method to identify cyber insurance writers. If at least one cell in Table 1 (Standalone Cybersecurity Insurance Policies) is more than 0, we identify it as a standalone cyber insurance writer. If at least one cell in Table 3 (Cybersecurity Insurance that is a part of package policy) of Appendix Table A1 reports a number larger than 0, we identify the insurer as a cyber insurance writer. Using this method, we identify 306 insurers underwriting cybersecurity risk, from which 102 insurers provide standalone cybersecurity policies, 264 insurers write packaged policies, and 60 insurers write both standalone and packaged coverage.[23]

[22]There are 319 insurers in the data that are neither mutual nor stock companies. These are risk retention groups, U.S. branches of alien insurers, syndicate reciprocal exchanges, limited liability corporations, and other types of partnerships. An additional analysis including a category "other" shows that these 319 insurers are not more likely to write cyber insurance than stock and mutual insurers.

[23]The same identification method is used to identity theft insurance writer.

The NAIC (2016) points out that insurers reporting a zero value for packaged policies might also be cyber insurance providers because they were unable to break out the premium charged for cyber coverage from the packaged policy. We thus also consider an alternative identification method that takes an insurer who reports zero premium on packaged cyber policies as a packaged cyber provider. Empirical results under this alternative definition of cyber insurance writers are available from the authors upon request, resulting in largely consistent findings and reflecting differences between standalone and packaged policy providers. We checked whether some types of companies (e.g., mutual insurers) are overrepresented in the group that reports 0 premium of packaged policies and found no structural differences; this suggest no structural differences in reporting.

## Regression Model

### *Logistic Model on the Characteristics of Cyber Insurance Writers*

We use a logistic regression model to investigate the relationship between company characteristics and whether or not the insurers write cyber insurance. The dependent variable is thus binary, while the independent variables contain both continuous and binary variables. We estimate our regression using a lag structure by regressing the dependent variable in year *t* on characteristics in year *t – 1* to correct for potential endogeneity. The model is specified as follows:

$$\begin{aligned} Y1_{i,t} = {} & \beta_0 + \beta_1 Capt_{i,t-1} + \beta_2 Assetr_{i,t-1} + \beta_3 Stock_{i,t-1} + \beta_4 GeoC_{i,t-1} \\ & + \beta_5 BusC_{i,t-1} + \beta_6 Lnsize_{i,t-1} + \beta_7 Lnage_{i,t-1} + \beta_8 Group_{i,t-1} + \\ & \beta_9 Reins_{i,t-1} + \beta_{10} FSR_{i,t-1} + \beta_{11} Coml_{i,t-1} + e_{i,t} \end{aligned} \tag{1}$$

$$\begin{aligned} Y2_{i,t} = {} & \beta_0 + \beta_1 Capt_{i,t-1} + \beta_2 Assetr_{i,t-1} + \beta_3 Stock_{i,t-1} + \beta_4 GeoC_{i,t-1} \\ & + \beta_5 BusC_{i,t-1} + \beta_6 Lnsize_{i,t-1} + \beta_7 Lnage_{i,t-1} + \beta_8 Group_{i,t-1} + \\ & \beta_9 Reins_{i,t-1} + \beta_{10} FSR_{i,t-1} + \beta_{11} Coml_{i,t-1} + e_{i,t} \end{aligned} \tag{2}$$

where in equation (1), $Y1_{i,t} = \ln\frac{P_{i,t}}{1-P_{i,t}}$, $P_{i,t}$ is the probability of insurance company *i* writing cyber insurance in year *t* (1 if company *i* writes a standalone or packaged cyber insurance policy); in equation (2), $Y2_{i,t} = \ln\frac{P_{i,t}}{1-P_{i,t}}$, $P_{i,t}$ is the probability of insurance company *i* writing standalone cyber insurance in year *t* (1 if company *i* writes standalone cyber insurance, and 0 otherwise).

The remaining variables are the same in both equations (1) and (2). $Capt_{i,t-1}$ is the capital level measured by the ratio of capital and surplus to assets[24] in year *t – 1*. This measure is consistent with the literature (e.g., Cheng and Weiss, 2013; Mankaï and Belgacem, 2015). $Assetr_{i,t-1}$ is the measurement of asset risk (or investment risk) and is calculated as the ratio of investment in common stock, mortgage, and real estate to total assets (same as Cummins and Nini (2002) and also consistent with the regulatory asset risk measurement in Cheng and Weiss (2013) and Eling and Marek (2014)). $Stock_{i,t-1}$ is a dummy variable of ownership structure. It is depicted as 1 if the insurer is a stock company and as 0 if the insurer is a mutual. $GeoC_{i,t-1}$ equals the Herfindahl index (HHI) of direct premiums written across the 58 states or areas[25] of the U.S. $BusC_{i,t-1}$ equals the Herfindahl index (HHI) of direct premiums written in 36 lines of business categorized by the NAIC; thus, a higher $GeoC_{i,t-1}$ or $BusC_{i,t-1}$ means greater concentration and less diversification. $Lnsize_{i,t-1}$ equals the natural logarithm of net total assets. $Lnage_{i,t-1}$ equals the natural logarithm of year 2014 minus the year the insurer was established. $Group_{i,t-1}$ is a dummy variable with a value of 1 if the insurer is a member of an insurance group, and 0 otherwise. $e_{i,t}$ is the error term. Table 4 summarizes the definition of the variables and the expected link to the probability of writing cyber insurance.

### *Simultaneous Equation Model on Interrelationships between Undertaking Cyber Risk, Capital, and Reinsurance*

To analyze the impact of undertaking cyber risk on insurers' capital and reinsurance usage in the same period, a simultaneous equation model is needed due to potential endogeneity. We follow the commonly used partial adjustment model in analyzing the relationship between risk and capital in the insurance industry (e.g., Cummins and Sommer, 1996; Baranoff and Sager, 2002; Cheng and Weiss, 2013). Our model is comparable to

[24]Capital and surplus as a percentage of net admitted assets less net admitted separate account assets; capital and surplus equal the difference between statutory admitted assets and statutory admitted liabilities.

[25]56 NAIC member-jurisdictions, including commonwealth of the U.S. plus Canada and other aliens.

**Table 4.** Variable Definitions and Expected Signs in the Logistic Model

| Variables | | Description | Expected signs |
|---|---|---|---|
| Capital | Capt | Ratio of capital and surplus to assets | + |
| Asset risk | Assetr | Ratio of investment in common stock, mortgage, and real estate total unaffiliated investments | +/– |
| Stock/Mutual | Stock | 1 if the insurer is a stock firm, 0 if it is a mutual | + |
| Business concentration | BusC | Herfindahl index (HHI) of direct premiums written across 36 business lines | +/– |
| Geographic concentration | GeoC | Herfindahl index (HHI) of direct premiums written across the 58 states or areas | +/– |
| Company size | Lnsize | Natural logarithm of net total assets | + |
| Company age | Lnage | Natural logarithm of number of years since the year the insurer was established | +/– |
| Group affiliation | Group | 1 if the insurer belongs to a group, 0 otherwise | + |
| Reinsurance ratio | Reins | Ratio of premium ceded to direct premium written | + |
| Financial strength rating | FSR | 1 if the insurer's financial strength rating by AM Best is above A[a], 0 otherwise | + |
| Pure commercial insurer | Coml | 1 if the insurer provides only commercial insurance, 0 otherwise | + |

[a] A.M. Best's ratings include excellent (A, A–) and superior (A+, A++), and good (B+, B++), fair ( B, B–), marginal (C+, C++), weak (C, C–), and poor (D). We followed Eling and Schmit (2012) to define insurance above A as a high rating.

Mankaï and Belgacem's (2015) in which reinsurance usage is considered. The model contains three equations:

$$\begin{cases} Y_{capt_{i,t}} = \beta_0 + (1-\varphi_{capt})Y_{capt_{i,t-1}} + \beta_1 Y_{risk_{i,t}} + \beta_2 Y_{reins_{i,t}} + \beta X_{cap} + \varepsilon_{i,t} \\ Y_{risk_{i,t}} = \gamma_0 + (1-\varphi_{risk})Y_{risk_{i,t-1}} + \gamma_1 Y_{capital_{i,t}} + \gamma_2 Y_{reins_{i,t}} + \gamma X_{risk} + \mu_{i,t} \\ Y_{rein_{i,t}} = \vartheta_0 + (1-\varphi_{reins})Y_{reins_{i,t-1}} + \vartheta_1 Y_{capt_{i,t}} + \vartheta_2 Y_{risk_{i,t}} + \vartheta X_{rein} + \omega_{i,t} \end{cases}$$

where $Y_{capt_{i,t}}$ equals $Capt_{i,t}$ as defined in Table 4 , $Y_{risk_{i,t}}$ equals $P_{i,t}$ or $P'_{i,t}$ as defined in equations (1) and (2); since we only have one-year data,

**Table 5.** Expected Signs between Cyber Risk Taking, Capital, and Reinsurance

| Variables | | Description | Expected Signs | | |
|---|---|---|---|---|---|
| | | | Risk equation | Capital equation | Reinsurance equation |
| $Y_{risk_{i,t}}$ | $P_{i,t}$ or $P'_{i,t}$ | 1 insurer writes (standalone) cyber insurance, 0 otherwise. | NA | + | + |
| $Y_{capital_{i,t}}$ | Capt | Ratio of capital and surplus to assets | + | NA | – |
| $Y_{reins_{i,t}}$ | Reinsurance | Ratio of premium ceded to direct premium written | + | – | NA |

$Y_{risk_{i,t-1}}$ is assumed to be 0 for all insurers. $Y_{reins_{i,t}}$ is the reinsurance usage of insurer $i$ in year $t$, which equals the ratio of premium ceded to direct premium written. $X_{capt}$, $X_{risk}$, and $X_{reins}$ are exogenous variable vectors.

$$X_{capt} = (Perf_{i,t-1}, Stock_{i,t-1}, GeoC_{i,t-1}, BusC_{i,t-1}, lnsize_{i,t-1}, lnage_{i,t-1}, Group_{i,t-1}, Reins_{i,t-1}, FSR_{i,t-1}, Coml_{i,t-1}, Premp_{i,t})$$

$$X_{risk} = (Assetr_{i,t-1}, Stock_{i,t-1}, GeoC_{i,t-1}, BusC_{i,t-1}, lnsize_{i,t-1}, lnage_{i,t-1}, Group_{i,t-1}, Reins_{i,t-1}, FSR_{i,t-1}, Coml_{i,t-1})$$

$$X_{reins} = (Levg_{i,t-1}, Stock_{i,t-1}, GeoC_{i,t-1}, BusC_{i,t-1}, lnsize_{i,t-1}, lnage_{i,t-1}, Group_{i,t-1}, Reins_{i,t-1}, FSR_{i,t-1}, Coml_{i,t-1}).$$

*Perf* is the return on assets, *Assetr* is the ratio of investment in common stock, mortgage, and real estate to net total assets, and *Levg* is the ratio of net premium to surplus. The expected signs are shown in Table 5. We will use the three-stage least squares method to estimate the coefficients. Three-stage least squares assumes that the dependent variable is continuous. Our proxy for cyber insurance writing is binary and not continuous. However, Aldrich and Nelson (1984) demonstrate that this is not necessarily a serious problem.

# RESULTS

## Descriptive Statistics and Correlation Analysis

Table 6 provides descriptive statistics for our sample insurers and Table 7 a univariate comparison between the 512 insurers that write cyber

**Table 6**. Descriptive Statistics: Sample for the Logistic Model

| Variables | Full sample (1,785 insurers) | | | | |
|---|---|---|---|---|---|
| | Mean | Median | Std. Dev. | Min | Max |
| Capt | 0.521 | 0.472 | 0.226 | 0.112 | 0.999 |
| Assetr | 0.117 | 0.047 | 0.158 | 0.000 | 0.702 |
| Stock | 0.784 | 1.000 | 0.411 | 0.000 | 1.000 |
| GeoC | 0.535 | 0.480 | 0.391 | 0.040 | 1.000 |
| BusC | 0.545 | 0.457 | 0.300 | 0.126 | 1.000 |
| Lnsize | 11.458 | 11.464 | 1.604 | 8.986 | 13.997 |
| Lnage | 3.500 | 3.526 | 0.989 | 0.000 | 5.142 |
| Group | 0.738 | 1.000 | 0.440 | 0.000 | 1.000 |
| Reins | 0.506 | 0.469 | 0.360 | 0.000 | 1.000 |
| FSR | 0.782 | 1.000 | 0.413 | 0.000 | 1.000 |
| Coml | 0.331 | 0.000 | 0.471 | 0.000 | 1.000 |

*Note:* See Table 4 for the variable definitions.

insurance (standalone or packaged coverage) and those that do not. As shown in the last column of Table 7, most characteristics differ significantly between the two groups of insurers based on a t-test with unequal variances.[26] Insurers writing cyber insurance policies are more likely to belong to a group, are less concentrated across lines of business and geographically, are both larger and older, use more reinsurance, and have a better rating.

If we compare the standalone policy-writing insurers with all other insurers, the results in Table 7 show that the standalone policy-writing insurers have more capital and are more likely to be a stock company. The latter results confirm the managerial discretion hypothesis that stock insurers are more prone to riskier and individualized lines of insurance since standalone policies are more complicated and difficult to design and price.[27]

[26]More descriptive comparisons are presented in Table B1 and B2 in the Appendix B.

**Table 7.** Univariate Comparison

| Variables | Cyber insurance writer and non-writer | | | Standalone cyber writer and non-writer | | |
|---|---|---|---|---|---|---|
| | Mean writers (512 insurers) | Mean non-writers (1,273 insurers) | Mean difference | Mean writers (113 insurers) | Mean non-writers (1,672 insurers) | Mean difference |
| Capt | 0.525 | 0.520 | 0.005 | 0.568 | 0.518 | 0.050** |
| Assetr | 0.102 | 0.123 | –0.020** | 0.117 | 0.117 | 0.001 |
| Stock | 0.803 | 0.777 | 0.026 | 0.973 | 0.772 | 0.202*** |
| GeoC | 0.388 | 0.594 | –0.206*** | 0.177 | 0.559 | –0.382*** |
| BusC | 0.364 | 0.618 | –0.253*** | 0.354 | 0.558 | –0.204*** |
| Lnsize | 12.125 | 11.189 | 0.936*** | 12.556 | 11.383 | 1.172*** |
| Lnage | 3.723 | 3.411 | 0.313*** | 3.591 | 3.494 | 0.097 |
| Group | 0.900 | 0.673 | 0.227*** | 0.965 | 0.723 | 0.242*** |
| Reins | 0.611 | 0.464 | 0.147*** | 0.686 | 0.494 | 0.191*** |
| FSR | 0.918 | 0.641 | 0.277*** | 0.991 | 0.702 | 0.289*** |
| Coml | 0.148 | 0.405 | –0.256*** | 0.327 | 0.331 | –0.004 |

Note: *, **, and *** denote statistical significance at the 10, 5, and 1 percent levels. See Table 4 for the variable definitions.

# Empirical Results

## *Results of the Logistic Model*

We now test for differences in a multivariate regression context. Table 8 reports the estimation results of model (1), whose coefficients show the

[27]The Pearson correlations between the variables included in our regression model are available from the authors upon request. We also assess the degree of multicollinearity among independent variables using the variance inflation factor (VIF). The VIF quantifies the severity of multicollinearity in an ordinary least squares regression analysis. It provides an index that measures how much the variance (the square of the estimate's standard deviation) of an estimated regression coefficient is increased because of collinearity. A rule of thumb is that if VIF is more than 10, then multicollinearity is high. All VIF values are less than 2 so that multicollinearity is not a serious problem. The VIF results are also available from the authors upon request.

**Table 8.** Estimation Results for Equation (1) / Standalone or Package Writers

| Variables | (Full sample) | (Stock insurer) | (Mutual insurer) | (Group member) | (Non-group member) |
|---|---|---|---|---|---|
| Capt | 1.727*** | 2.050*** | 0.770 | 1.826*** | 0.595 |
| | (0.321) | (0.372) | (0.725) | (0.349) | (1.184) |
| Assetr | –2.271*** | –2.441*** | –1.933** | –2.198*** | –2.727** |
| | (0.495) | (0.590) | (0.856) | (0.545) | (1.122) |
| Stock | –0.656*** | – | – | –0.409* | –1.778*** |
| | (0.197) | | | (0.227) | (0.462) |
| GeoC | –0.381** | –0.247 | –0.810** | –0.284 | –0.926* |
| | (0.192) | (0.222) | (0.400) | (0.208) | (0.523) |
| BusC | –2.865*** | –2.962*** | –2.770*** | –2.804*** | –3.598*** |
| | (0.343) | (0.377) | (0.985) | (0.367) | (1.038) |
| Lnsize | 0.456*** | 0.575*** | 0.128 | 0.439*** | 0.528*** |
| | (0.0586) | (0.0705) | (0.110) | (0.0657) | (0.166) |
| Lnage | –0.0943 | –0.103 | –0.241 | –0.0141 | –0.434* |
| | (0.0897) | (0.0996) | (0.223) | (0.0967) | (0.227) |
| Group | 0.276 | 0.498 | 0.215 | – | – |
| | (0.213) | (0.308) | (0.361) | | |
| Reins | 0.745*** | 0.784*** | 0.530 | 0.638*** | 1.443* |
| | (0.217) | (0.253) | (0.518) | (0.229) | (0.738) |
| FSR | 0.451** | 0.412* | 0.728** | 0.600** | 0.245 |
| | (0.199) | (0.244) | (0.339) | (0.255) | (0.459) |
| Coml | –0.203 | –0.232 | –0.0691 | –0.110 | –0.496 |
| | (0.201) | (0.223) | (0.529) | (0.218) | (0.562) |
| Constant | –5.441*** | –7.833*** | –0.415 | –5.671*** | –3.108 |
| | (0.894) | (0.984) | (2.077) | (1.039) | (2.288) |
| Observations | 1,785 | 1,400 | 385 | 1,318 | 467 |
| Prob > chi2 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Pseudo R-squared | 0.224 | 0.246 | 0.171 | 0.173 | 0.267 |

*Note:* Mean and standard deviation (in parentheses). The dependent variable in equation (1) is $Y1_{i,t} = ln\frac{P_{i,t}}{1-P_{i,t}}$, where $P_{i,t}$ is the probability of insurance company *i* writing cyber insurance (standalone or packaged coverage) in year *t* (1 if company *i* writes cyber insurance, 0 otherwise); *, **, and *** denote statistical significance at the 10, 5, and 1 percent levels. See Table 4 for the other variable definitions.

difference between insurers that write standalone policy or packaged policy and the rest. Table 9 reports the estimation result of model (2), whose coefficients show the difference between insurers that write standalone policy and the rest.[28] In Table 9 we report the results for the subsample of the 512 cyber insurance writers only to compare standalone writers with packaged policy writers (column (2)).

In Table 8, most of the results in the full sample and the subsamples are consistent with our expectations and with the research. Firstly, capital levels are positively related to cyber insurance writing. This is consistent with hypothesis H1 and supports the capital buffer theory as well as evidence on capital-risk relationship (e.g., Cummins and Sommer, 1996; Shim, 2010; Cheng and Weiss, 2013; Mankaï and Belgacem, 2015). Secondly, asset risk is negatively related to cyber insurance writing, supporting hypothesis H2a and consistent with the finite risk paradigm (Baranoff and Sager, 2003; Baranoff et al., 2013). For organization type we find a negative sign, indicating that mutual insurers are more likely to sell cyber insurance policies, which contradicts Hypothesis H3; this result will be interpreted in more detail below together with the results for Table 9. Business and geographic concentration are negatively related to cyber insurance writing, supporting hypothesis H4a that insurers that are more diversified in lines of businesses or geographic areas are more likely to be involved in risky new products. For the control variables, the results also show that insurers writing cyber insurance are larger and younger, although the latter result is significant in only one of the five specifications. Insurers with a good rating and using more reinsurance are more likely to writer cyber coverage.

Comparing the results of Tables 8 and 9, we see an ambiguous relationship of ownership structure and cyber insurance writing. In Table 8, mutual insurers are more likely to be involved in cyber-related policies, but in Table 9 if we compare standalone cyber insurance writers with the rest, it is more likely to be a stock company. Since standalone cyber policy is more customized and complicated, this result is consistent with the assumption that stock companies are more likely to take excess risk with limited liability and in line with the managerial discretion hypothesis (Mayers and Smith, 1981, 1988). The fact that many mutuals are involved in packaged cyber coverage might be explained by mutual insurers being more willing to extend current policy to cover some kind of cyber risk. This compared to stock insurers that might be more in favor of separately selling and pricing such policies. The packaged policy might be considered less

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[28]The results for mutuals and non-group members in Table 9 must be interpreted with caution, because among the 113 standalone cyber insurance writers, there are only three mutuals and four non-group members. For this reason also a few variables are dropped in the regression. That is, all three mutuals are group members and have an above-B rating; all four non-group members are stocks and pure commercial lines writers; thus the latter two variables are dropped in the respective regressions.

**Table 9.** Estimation Results of the Coefficient of Equation (2) / Standalone Writers

| Variables | (1) (Full sample) | (2) (Cyber sample) | (3) (Stock insurer) | (4) (Mutual insurer) | (5) (Group member) | (6) (Non-group member) |
|---|---|---|---|---|---|---|
| Capt | 2.693*** | 1.963*** | 2.854*** | –3.911 | 2.542*** | 10.48 |
| | (0.569) | (0.652) | (0.572) | (5.210) | (0.561) | (8.725) |
| Assetr | –0.840 | 1.619* | –0.745 | –4.100* | –0.703 | –18.24 |
| | (0.766) | (0.961) | (0.771) | (2.221) | (0.793) | (13.28) |
| Stock | 1.497** | 1.832** | – | – | 1.351** | – |
| | (0.675) | (0.731) | | | (0.683) | |
| GeoC | –1.855*** | –2.242*** | –1.875*** | –3.442 | –2.038*** | –4.841 |
| | (0.472) | (0.566) | (0.490) | (3.754) | (0.505) | (6.748) |
| BusC | –2.946*** | –1.307* | –3.102*** | 0.0185 | –3.051*** | –5.280 |
| | (0.541) | (0.769) | (0.561) | (1.925) | (0.551) | (5.033) |
| Lnsize | 0.631*** | 0.372** | 0.632*** | 0.539 | 0.540*** | 3.222** |
| | (0.115) | (0.147) | (0.119) | (0.335) | (0.109) | (1.291) |
| Lnage | –0.278* | –0.425** | –0.261* | –0.691 | –0.287* | 0.0615 |
| | (0.148) | (0.181) | (0.154) | (0.769) | (0.154) | (1.286) |
| Group | 0.440 | 0.254 | 0.297 | – | – | – |
| | (0.561) | (0.691) | (0.570) | | | |
| Reins | 0.630 | 0.465 | 0.552 | 3.852 | 0.391 | 9.814*** |
| | (0.393) | (0.533) | (0.398) | (3.321) | (0.391) | (3.644) |
| FSR | 1.994** | 1.337* | 1.942** | – | – | –2.051 |
| | (0.967) | (0.780) | (0.955) | | | (1.367) |
| Coml | 1.313*** | 2.167*** | 1.319*** | 1.838* | 1.261*** | – |
| | (0.327) | (0.419) | (0.337) | (1.095) | (0.336) | |
| Constant | –13.17*** | –8.293*** | –11.55*** | –6.145 | –9.107*** | –46.46*** |
| | (1.751) | (2.326) | (1.642) | (5.319) | (1.796) | (18.00) |
| Observations | 1,785 | 512 | 1,400 | 153 | 1,121 | 159 |
| Prob > chi2 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Pseudo R-squared | 0.290 | 0.263 | 0.264 | 0.239 | 0.206 | 0.615 |

*Note:* Mean and standard deviation (in parentheses). The dependent variable in equation (1) is $Y2_{i,t} = ln\frac{P'_{i,t}}{1-P'_{i,t}}$, where $P'_{i,t}$ is the probability of insurance company $i$ writing cyber insurance (standalone or packaged coverage) in year $t$ (1 if company $i$ writes cyber insurance, 0 otherwise); *, **, and *** denote statistical significance at the 10, 5, and 1 percent levels. See Table 4 for the other variable definitions.

risky than a standalone policy since it is just a matter of adding a few clauses to an existing policy.

Moreover, when comparing Tables 8 and 9, we see that many results are very robust and consistent (capital, geographical concentration, business concentration, size), while the results for asset risk are only clear in Table 8. The same observations are made in various robustness tests presented in the fourth section. We thus conclude that the results for capital, geographical concentration, business concentration, and size are very robust, while the results for asset risk can only be documented consistently for the full sample (not for the standalone writers only). The comparison of standalone writers and packaged policy writers in Table 9 (column (2)), however, again yields robust results compared with the full sample presented in column (1).

### *Results of the Simultaneous Equation Model*

For the impact of underwriting cyber risk on insurers' capital and reinsurance use, the result of the simultaneous equation model (Table 10) shows that the interaction between cyber risk taking and reinsurance is significantly positive. This confirms our assumption that cyber insurance is a risky line and insurers will use reinsurance to transfer the cyber risk they have assumed. This result is consistent with Mankaï and Belgacem (2015). As expected, we see that capital and risk are positively related, reinsurance and capital are negatively related, performance and capital are positively related, and leverage and reinsurance usage are positively related, although parts of the results are statistically significant either for the full sample or for the sample of standalone writers.

## Robustness Test

To test the robustness of our findings, we conduct the following tests. Firstly, we consider alternative measures for capital and asset risk. We use the leverage ratio (ratio of net premium written to surplus; see Cheng and Weiss, 2012) as a substitute measurement for capital level; a higher leverage ratio means less capital. We also use the volatility of the quarterly net yield rates on invested assets in 2014 to measure the asset risk. This approach is similar to the methodology Eling and Marek (2014) used to calculate the opportunity asset risk measurement. The results are available from the authors upon request, yielding consistent results with our previous results in Tables 8 and 9. We also conduct another robustness test using an alternative definition of cyber insurance writer as specified in the previous section. These materials (available from the authors upon request) show consistent results that bigger insurers with a higher capital level and

**Table 10.** Estimation Results for the Simultaneous Equation Model

| Variables | Coefficient | | | Coefficient | | |
|---|---|---|---|---|---|---|
| | Y_capital | Y_risk1 | Y_reins | Y_capital | Y_risk2 | Y_reins |
| Y_risk1/2 | 0.0226 | | 0.140** | 0.132 | | 1.840*** |
| | (0.154) | | (0.0677) | (0.859) | | (0.473) |
| Y_reins | 0.000225 | 0.113*** | | –0.00457 | 0.0615*** | |
| | (0.0143) | (0.0346) | | (0.0419) | (0.0196) | |
| Y_capital | | 0.255*** | –0.0367* | | 0.152*** | –0.269*** |
| | | (0.0522) | (0.0221) | | (0.0296) | (0.0721) |
| Perf | 0.170*** | | | 0.160 | | |
| | (0.0425) | | | (0.101) | | |
| Underrisk | 0.00345 | –0.105 | 0.0283 | 0.00676 | –0.0501 | 0.0915** |
| | (0.0179) | (0.0705) | (0.0192) | (0.0360) | (0.0404) | (0.0384) |
| Assetr | –0.00688 | –0.250*** | | –0.00954 | –0.0436* | |
| | (0.0427) | (0.0668) | | (0.0180) | (0.0234) | |
| Stock | –0.0117 | –0.0777*** | 0.0164* | –0.0171 | 0.0304* | –0.0474** |
| | (0.0136) | (0.0283) | (0.00870) | (0.0248) | (0.0161) | (0.0189) |
| GeoC | 0.00560 | –0.0898*** | 0.00713 | 0.0131 | –0.0761*** | 0.126*** |
| | (0.0137) | (0.0301) | (0.00973) | (0.0567) | (0.0173) | (0.0353) |
| BusC | 0.00659 | –0.460*** | 0.0685** | 0.0206 | –0.197*** | 0.343*** |
| | (0.0638) | (0.0467) | (0.0305) | (0.151) | (0.0268) | (0.0857) |
| Lnsize | –0.00322 | 0.0674*** | –0.0122*** | –0.00528 | 0.0298*** | –0.0531*** |
| | (0.00978) | (0.00870) | (0.00449) | (0.0224) | (0.00495) | (0.0128) |
| Lnage | 0.000655 | –0.0236* | 0.00997*** | 0.00168 | –0.0119* | 0.0277*** |
| | (0.00360) | (0.0120) | (0.00361) | (0.0105) | (0.00685) | (0.00786) |
| Group | 0.0111* | 0.0196 | 0.0166** | 0.0126** | –0.0158 | 0.0332** |
| | (0.00611) | (0.0283) | (0.00766) | (0.00518) | (0.0162) | (0.0137) |
| Premp | 0.0535 | | –0.377 | –0.659 | | –11.96** |
| | (1.966) | | (0.915) | (9.111) | | (5.026) |
| Coml | 0.00946 | 0.00546 | 0.00739 | –0.00157 | 0.0936*** | –0.146*** |
| | (0.00633) | (0.0291) | (0.00796) | (0.0663) | (0.0167) | (0.0387) |
| FSR | –0.00412 | 0.0248 | –0.000368 | –0.00112 | –0.0172 | 0.0359** |
| | (0.00572) | (0.0279) | (0.00785) | (0.0164) | (0.0160) | (0.0159) |
| Y_capital_1 | 0.951*** | | | 0.938*** | | |
| | (0.0379) | | | (0.115) | | |
| Y_reins_1 | | | 0.947*** | | | 0.866*** |
| | | | (0.0126) | | | (0.0276) |
| Levg | | | 0.00791* | | | 0.00511 |
| | | | (0.00451) | | | (0.00502) |

*Table continues*

**Table 10.** (*continued*)

| Variables | Coefficient | | | Coefficient | | |
|---|---|---|---|---|---|---|
| | Y_capital | Y_risk1 | Y_reins | Y_capital | Y_risk2 | Y_reins |
| Constant | 0.0427 | –0.234* | 0.0379 | 0.0637 | –0.223*** | 0.387*** |
| | (0.0371) | (0.129) | (0.0384) | (0.168) | (0.0737) | (0.113) |
| Observations | 1,785 | 1,785 | 1,785 | 1,785 | 1,785 | 1,785 |
| Prob > chi2 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| R-squared | 0.926 | 0.225 | 0.912 | 0.915 | 0.120 | –0.277 |

Note: Mean and standard deviation (in parentheses). Y capital: ratio of surplus to assets. Y_risk1: risk undertaking; 1 if insurers write cyber insurance policy (standalone or packaged policy). Y_risk2: risk undertaking; 1 if insurers write standalone cyber insurance policy. Y_reins: reinsurance usage, premium ceded to total premium written. Y_capital, Y_risk1, and Y_reins are measured on current basis. The following variables are measured using lagged year data: Levg: leverage ratio, ratio of net premium to surplus; Assetr: asset risk, ratio of investment in common stock, mortgage, and real estate to net total assets; Perf: Performance, return of asset. *,**, and *** denote statistical significance at the 10, 5, and 1 percent levels, respectively. See Table 4 for the other variable definitions.

diversified policies are writing cyber insurance. Furthermore, stock companies write more standalone cyber policies.

## CONCLUSION

We test the relationship between insurers' financial, managerial, and underwriting characteristics and whether they write cyber insurance in the U.S. P&C industry. This is the first empirical study on the cyber insurance market; we interpret the activity of an insurer in this market as risk-taking behavior. As the global cyber insurance market is still underdeveloped, our research constitutes a fresh and tentative analysis of the cyber insurance market. We show what kind of insurers are offering cyber insurance products, which will help regulators and other market participants to better understand the market. Our research also makes a supplementary contribution to the research on risk taking from a different perspective: for example, considering the finite risk paradigm and the managerial discretion hypothesis.

The limitations of this research might provide avenues for future research. Due to the lack of data, we were unable to evaluate all characteristics. For instance, we do not analyze the factors that affect the number of policies or the amount of premiums written. Our results thus need to be confirmed by more data, with alternative measures and for other countries besides the U.S. It might also be interesting to compare the characteristics of newcomers to the cyber insurance market to those that are already there and the profitability or performance of insurers that write cyber insurance.

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# APPENDIX A

## Cybersecurity and Identity Theft Insurance Coverage Supplement

**Table A1.** Cybersecurity and Identity Theft Insurance Coverage Supplement Sample Page

SUPPLEMENT FOR THE YEAR 20__ OF THE XXX

**CYBERSECURITY AND IDENTITY THEFT INSURANCE COVERAGE SUPPLEMENT**

For the Year Ended December 31, 20__
(To Be Filed by April 1)

If the reporting entity writes any standalone cybersecurity insurance coverage, please provide the following:

**1.** Standalone Cybersecurity Insurance Policies

| Number of Claims Reported | | Direct Premiums | | Direct Losses | | Adjusting and Other Expenses | | Direct Defense and Cost Containment | | Number of Policies in Force | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1<br>First Party | 2<br>Third Party | 4<br>Written | 4<br>Earned | 5<br>Paid | 6<br>Incurred | 7<br>Paid | 8<br>Incurred | 9<br>Paid | 10<br>Incurred | 11<br>Claims-Made | 12<br>Occurrence |
| | | $ | $ | $ | $ | $ | $ | $ | $ | | |

If the reporting entity writes any standalone identity theft insurance coverage, please provide the following:

**2.** Standalone Identity Theft Insurance Policies

| 1 | Direct Premiums | | Direct Losses | | Adjusting and Other Expenses | | Direct Defense and Cost Containment | | 10 |
|---|---|---|---|---|---|---|---|---|---|
| Number of Claims Reported | 2<br>Written | 3<br>Earned | 4<br>Paid | 5<br>Incurred | 6<br>Paid | 7<br>Incurred | 8<br>Paid | 9<br>Incurred | Number of Policies in Force |
| | $ | $ | $ | $ | $ | $ | $ | $ | |

If the reporting entity writes any cybersecurity insurance coverage that is part of a package policy, please provide the following:

**3.** Cybersecurity insurance that is part of a package policy

| Number of Claims Reported | | Direct Losses | | Adjusting and Other Expenses | | Direct Defense and Cost Containment | | Number of Policies in Force | |
|---|---|---|---|---|---|---|---|---|---|
| 1<br>First Party | 2<br>Third Party | 3<br>Paid | 4<br>Case Reserves | 5<br>Paid | 6<br>Case Reserves | 7<br>Paid | 8<br>Case Reserves | 9<br>Claims-Made | 10<br>Occurrence |
| | | $ | $ | $ | $ | $ | $ | | |

3.1 Can the direct premium earned for the cybersecurity coverage provided as part of a package policy be quantified or estimated? Yes [ ] No [ ]

3.11 If the response to 3.1 is no, please fully explain why the insurer cannot quantify or estimate direct premiums earned:

3.2 If the response to question 3.1 is yes, provide the quantified or estimated direct premiums written and direct premium earned amount for cybersecurity insurance included in package policies:

| | Cybersecurity Insurance Direct Premiums Written | Cybersecurity Insurance Direct Premiums Earned |
|---|---|---|
| 3.21 Amount quantified: | $ | $ |
| 3.22 Amount estimated using reasonable assumptions: | $ | $ |

3.3 If the liability portion of a cybersecurity policy is a claims-made policy, is an extended reporting endorsement (tail coverage) offered? Yes [ ] No [ ]

## 4. Identity theft insurance that is part of a package policy

| | Direct Losses | | Adjusting and Other Expenses | | Direct Defense and Cost Containment | | |
|---|---|---|---|---|---|---|---|
| 1 Number of Claims Reported | 2 Paid | 3 Case Reserves | 4 Paid | 5 Case Reserves | 6 Paid | 7 Case Reserves | 8 Number of Policies in Force |
| | $ | $ | $ | $ | $ | $ | |

4.1 Can the direct premium earned for the identity theft coverage provided as part of a package policy be quantified or estimated? Yes [ ] No [ ]

4.11 If the response to 4.1 is no, please fully explain why the insurer cannot quantify or estimate direct premiums earned:

4.2 If the response to question 4.1 is yes, provide the quantified or estimated direct premiums written and direct premium earned amount for identity theft insurance included in package policies:

| | Identity Theft Insurance Direct Premiums Written | Identity Theft Insurance Direct Premiums Earned |
|---|---|---|
| 4.21 Amount quantified: | $ | $ |
| 4.22 Amount estimated using reasonable assumptions: | $ | $ |

# APPENDIX B
## Additional Statistics and Results

**Table B1.** Descriptive Statistics by Cyber Writer and Non-writer

| Variables | (1) Insurers writing cyber coverage (512 insurers) | | | | | (2) Insurers not writing cyber coverage (1,273 insurers) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | Median | Std. Dev. | Min | Max | Mean | Median | Std. Dev. | Min | Max |
| Capt | 0.525 | 0.446 | 0.242 | 0.112 | 0.999 | 0.520 | 0.483 | 0.220 | 0.112 | 0.999 |
| Assetr | 0.102 | 0.043 | 0.143 | 0.000 | 0.702 | 0.123 | 0.050 | 0.164 | 0.000 | 0.702 |
| Stock | 0.803 | 1.000 | 0.398 | 0.000 | 1.000 | 0.777 | 1.000 | 0.416 | 0.000 | 1.000 |
| GeoC | 0.388 | 0.215 | 0.367 | 0.040 | 1.000 | 0.594 | 0.610 | 0.385 | 0.040 | 1.000 |
| BusC | 0.364 | 0.290 | 0.214 | 0.126 | 1.000 | 0.618 | 0.535 | 0.300 | 0.126 | 1.000 |
| Lnsize | 12.125 | 12.294 | 1.523 | 8.986 | 13.997 | 11.189 | 11.132 | 1.558 | 8.986 | 13.997 |
| Lnage | 3.723 | 3.714 | 0.910 | 0.000 | 5.142 | 3.411 | 3.466 | 1.005 | 0.000 | 5.142 |
| Group | 0.900 | 1.000 | 0.300 | 0.000 | 1.000 | 0.673 | 1.000 | 0.469 | 0.000 | 1.000 |
| Reins | 0.611 | 0.660 | 0.348 | 0.000 | 1.000 | 0.464 | 0.386 | 0.357 | 0.000 | 1.000 |
| FSR | 0.918 | 1.000 | 0.275 | 0.000 | 1.000 | 0.641 | 1.000 | 0.480 | 0.000 | 1.000 |
| Coml | 0.148 | 0.000 | 0.356 | 0.000 | 1.000 | 0.405 | 0.000 | 0.491 | 0.000 | 1.000 |

*Note:* See Table 4 for the variable definitions.

**Table B2.** Descriptive Statistics by Standalone Cyber Writer and Non-writer

| Variables | (1) Insurers writing standalone cyber coverage (113 insurers) | | | | | (2) Insurers not writing standalone cyber coverage (1,672 insurers) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | Median | Std. Dev. | Min | Max | Mean | Median | Std. Dev. | Min | Max |
| Capt | 0.568 | 0.500 | 0.258 | 0.197 | 0.999 | 0.518 | 0.471 | 0.224 | 0.112 | 0.999 |
| Assetr | 0.117 | 0.064 | 0.164 | 0.000 | 0.702 | 0.117 | 0.046 | 0.158 | 0.000 | 0.702 |
| Stock | 0.973 | 1.000 | 0.161 | 0.000 | 1.000 | 0.772 | 1.000 | 0.420 | 0.000 | 1.000 |
| GeoC | 0.177 | 0.080 | 0.234 | 0.040 | 1.000 | 0.559 | 0.520 | 0.388 | 0.040 | 1.000 |
| BusC | 0.354 | 0.294 | 0.186 | 0.126 | 0.880 | 0.558 | 0.478 | 0.302 | 0.126 | 1.000 |
| Lnsize | 12.556 | 12.758 | 1.403 | 8.986 | 13.997 | 11.383 | 11.389 | 1.590 | 8.986 | 13.997 |
| Lnage | 3.591 | 3.584 | 0.855 | 0.693 | 5.142 | 3.494 | 3.526 | 0.997 | 0.000 | 5.142 |
| Group | 0.965 | 1.000 | 0.186 | 0.000 | 1.000 | 0.723 | 1.000 | 0.448 | 0.000 | 1.000 |
| Reins | 0.686 | 0.776 | 0.316 | 0.033 | 1.000 | 0.494 | 0.452 | 0.360 | 0.000 | 1.000 |
| FSR | 0.991 | 1.000 | 0.094 | 0.000 | 1.000 | 0.702 | 1.000 | 0.457 | 0.000 | 1.000 |
| Coml | 0.327 | 0.000 | 0.471 | 0.000 | 1.000 | 0.331 | 0.000 | 0.471 | 0.000 | 1.000 |

*Note:* See Table 4 for the variable definitions.