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The systemic and non-systemic liquidity risk in Taiwanese financial institutions
臺灣金融機構系統性與非系統性流動風險之研究

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Abstract: This paper explores the liquidity risk characteristics in the Taiwanese financial institutions, including domestic bank, financial holding, insurance, and securities subsectors. The liquidity indices used in this study are the Amihud index and liquidity discount. We find that the Amihud index reflects more information about macroeconomic conditions, while the liquidity discount reveals more signals concerning firm-specific liquidity risk. The financial holding companies have lower liquidity risk. The impact of systemic liquidity risk on financial holdings is less than that on the other financial subsectors. Furthermore, the non-systemic liquidity risk of financial holding strongly influences the other financial subsectors. The domestic bank and insurance subsectors are the cruxes in transferring non-systemic liquidity risk in the financial market.

Keywords: Systemic liquidity risk, non-systemic liquidity risk, amihud index, liquidity discount, financial institution.

摘要：本研究探討臺灣金融類股流動性風險的特徵，研究樣本包含本國銀行、金控、保險與證券產業，本研究採用 Amihud 流動性風險指標與流動性折扣率衡量每家金融機構的流動性風險。研究結果發現 Amihud 指標反映較多總

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體經濟訊息，流動性折扣率則包含較多屬於個別公司特質的風險訊息。相較於其他金融產業，金控公司的流動性風險較低，也較不易受到系統性流動風險所影響，此外，金控公司的非系統性流動風險則顯著影響其他金融機構的流動性。在金融市場中，本國銀行與保險公司是傳遞非系統性流動風險的關鍵產業。

關鍵詞：系統性流動風險、非系統性流動風險、Amihud 流動性指標、流動性折扣率、金融機構

1. Introduction

The previous literature relevant to systemic risk focuses on the interconnections in the banking industry. Allen and Gale (2000) and Allen *et al.* (2010) demonstrate that liquidity shock can easily trigger systemic risk in the banking industry because of the interconnection of short-term funding among banks. Kaminsky and Reinhart (1999) find that banking crises typically have spillover effects in financial markets. The 2007 subprime crisis is a classic example of the tight interaction in financial institutions that determines systemic risk and drives global financial crises (Allen and Carletti, 2013). Chen *et al.* (2016) find that systemic liquidity risk strongly influences most U.S. financial subsectors. Different from the prior studies emphasizing systemic risk, Chen *et al.* (2016) also explore the relationship of idiosyncratic liquidity risk among U.S. financial subsectors. Most of the related literature focuses on the U.S., which has lower market liquidity risk in the world. The interconnection of liquidity risk in emerging markets like Taiwan is rarely studied in previous research. Taiwan experienced financial reform between 2001 and 2008 for a more stable financial market. Therefore, we investigate the impact of systemic liquidity risk and transmission of non-systemic liquidity risk in Taiwanese financial institutions.

From 2015 through 2018, the financial industry accounted for the highest average net-profit margin in the Taiwan Capitalization Weighted Stock Index

(TAIEX)[2]. The financial institutions listed on the Taiwan Stock Exchange (TWSE) include domestic banks, financial holding, insurance, and securities companies. Domestic banks play a pivotal role in providing capital to Taiwanese small-medium entrepreneurs. Taiwanese financial holding companies feature more diversified businesses than domestic banks. Since 2001, insurance, and securities companies have been able to operate with each other by founding subsidiary companies controlled by a specific holding company[3]. For the top three financial holding companies, the primary source of profits comes from their banking and insurance subsidiaries[4]. Furthermore, the banking and insurance subsidiaries of financial holding companies have higher market shares than domestic banks and insurance companies. In this study, we offer a better understanding whether the non-systemic risks of financial holdings have a spillover effect on other financial subsectors. Regarding the characteristic of insurance subsectors, because the Taiwanese prefer to take out insurance, the 2017 insurance penetration of Taiwan is 21.32%, the highest level in the world[5]. In 2018, Taiwanese life insurance companies had the second highest percentage of asset values, 26.4%, among domestic banks, life insurance companies, and credit cooperatives.[6] It implies that the liquidity health of the insurance subsector is closely related to the stability of Taiwan's financial market.

Most of the previous studies focus on the systemic risk for a specific financial subsector; for example, banking or insurance industries. The above features of

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2 From 2015 through 2018, the average of net-profit margin for the financial industry is 21.54%. The semiconductor industry has the second highest average of net-profit margin, 20.87%. The data is obtained from Taiwan Economic Journal (TEJ) database.

3 To encourage diversified operations among the financial institutions, the Financial Holding Company Act was announced in July 2001.

4 In June 2018, the top three financial holding companies were Cathay Financial Holdings, Fubon Financial Holdings, and CTBC Financial Holdings.

5 Insurance penetration is the ratio of insurance premiums in a particular year to the gross domestic product. In 2017, the life insurance density for Taiwan is 47,195 U.S. dollars, ranked third highest in the world. The data is from the Swiss Reinsurance Company.

6 The data is obtained from the Life Insurance Association of the Republic of China. The financial institutions in this statistical data include the Central Bank of Taiwan, domestic banks, life insurance companies, credit cooperatives, and Chunghwa Post. In 2018, the domestic banks had the highest asset value among all financial institutions included in this statistical data.

Taiwan banking, financial holding, and insurance subsectors are important in analyzing the transmission of liquidity risk in a deeply interconnected financial system. Furthermore, we emphasize the magnitude of change in liquidity risk to the non-systemic risk among the financial subsectors, which is rarely studied in the related literature.

In this paper, we use the Amihud illiquidity index shown in Amihud (2002) and liquidity discount proposed by Chen (2012) to measure the liquidity risk for each individual financial institution. The Amihud index is defined as the ratio of the individual stock return to the dollar of trading volume. A higher Amihud measure implies that the stock is more exposed to illiquidity risk. The liquidity discount is defined as the shortfall between liquid and illiquid asset values of an individual firm. The higher the liquidity discount, the more illiquid is the corresponding firm.

Our study contributes to the related literature on liquidity risk in several ways. First, we investigate whether the Amihud index and liquidity discount can be warning signals of liquidity risk for Taiwanese financial institutions. Though the Amihud index is a well-documented proxy for measuring liquidity risk in developed stock markets, less literature focuses on its suitability for emerging markets. The liquidity discount is derived from a combination of the CAPM-based model devised by Chen (2012) and the capital structure model of Geske (1979). Chen *et al.* (2012) find that the liquidity discount model can provide a remarkable prediction ability concerning liquidity healthiness of the 23 largest U.S. financial institutions. Chen *et al.* (2017) and Yeh *et al.* (2014) demonstrate that the liquidity discount contains more signals about firms' credit risk. Chen *et al.* (2016) find that the liquidity discount can exactly reflect the liquidity crisis caused by credit risk. Yeh *et al.* (2017) find that the liquidity discount is more stable than the Amihud index for measuring the liquidity risk of Taiwan Emerging Stock Market. According to the arguments of Chen *et al.* (2016, 2017), and Yeh *et al.* (2014, 2017), we explore the applicability of the Amihud index and liquidity discount to the Taiwanese financial industry by using the vector autoregression model.

With the vector autoregression model, the Granger causality analysis suggests that the Amihud index provides more information about the market conditions than the liquidity discount, while the liquidity discount has a greater predictive ability on funding liquidity. Moreover, we use impulse response analysis to examine how these two indices respond to changes in economic conditions (represented by market returns and volatility), funding liquidity (represented by short-term interest rate and call-loan rate), and investor expectations and sentiment (represented by yield spread, VIX, and consumer confidence). We find that both the Amihud index and liquidity discount positively respond to market uncertainty. The Amihud index increases at the down market state; however, this phenomenon is trivial to the liquidity discount. The Amihud index is sensitive to the short-term interest rate, while the liquidity discount is more affected by the call-loan rate. Both the Amihud index and the liquidity discount rise for pessimistic investor expectations and sentiment. Furthermore, compared with liquidity discount, the Amihud index presents stronger responses to changes in market conditions, investor expectations, and consumer confidence. Our evidence indicates that the Amihud index reflects more information about the macroeconomic variables, while liquidity discount contains more information about firms' credit risk.

Our second contribution to the literature is that we provide evidence concerning the crucial role of the financial holding subsector in contributing to the systemic liquidity risk of the Taiwanese financial industry. By employing principal component analysis, our results show that financial holdings, domestic banks, and insurance companies are the main contributors to systemic liquidity risk[7]. This is because the banking and insurance subsidiaries are core businesses for most Taiwanese financial holding companies, which are involved in strong competition with other domestic banks and insurance companies. Because of interconnection, the variation in liquidity risk of the financial industry is driven by financial holding, domestic bank, and insurance subsectors. Moreover, by examining the influence of systemic liquidity risk across all financial subsectors, we find that systemic

[7] Several studies on systemic risk (Billio *et al.*, 2010; Chen *et al.*, 2014, 2017; Neale *et al.*, 2012) use principal component analysis to measure systemic risk of financial institutions.

liquidity risk has a greater impact on domestic banks, insurance, and securities subsectors and less impact on financial holdings. Therefore, based on the above analysis, we suggest that the financial holding subsector is a central factor in stabilizing the liquidity of Taiwanese financial market.

Our third contribution is to explore the dynamic transmission of non-systemic liquidity risk among financial institutions, which is still an open field in the related literature. Most studies (Allen and Gale, 2000; Allen *et al.*, 2010; Billio *et al*., 2010; Cai *et al.*, 2018; Chen *et al.*, 2014; Drehmann and Tarashev, 2013; Neale *et al*., 2012) focus on the interconnection of systemic risk among financial institutions. We follow Chen *et al.* (2016) to extract the non-systemic risk from two liquidity proxies: the Amihud index and the liquidity discount. Using the Granger causality test, we find that financial holding subsector's non-systemic risk estimated by the liquidity discount has a greater net influence on the domestic bank, securities, and insurance subsectors, while insurance companies are more dependent on other subsectors. However, the empirical evidence using the Amihud index shows lower interconnectivity of non-systemic risk among all financial subsectors. Therefore, our results lend support to Chen *et al.* (2016, 2017) and Yeh *et al.* (2014) who showed that the liquidity discount contains more signals about non-systemic liquidity risk.

Further, different from Chen *et al.* (2016), we use impulse response to evaluate the dynamic impact of liquidity shock from a specific financial subsector. We find that the financial holding subsector has a smaller and shorter response to the non-systemic liquidity shock from other financial subsectors. Conversely, the domestic bank, securities, and insurance subsectors have strong responses to the shock generated by the financial holding subsector. Our study has taken a step in the direction of investigating the relationship of firm-specific liquidity risk between financial holding firms and medium-sized financial institutions.

The remainder of this paper is organized as follows. Section 2 introduces the properties of sample data and the measure of the Amihud index and liquidity discount. Section 3 provides the empirical analysis concerning the systematic components of liquidity risk and the transmission of non-systemic liquidity risk.

Section 4 presents the conclusions.

2. Liquidity risk of the financial institutions

2.1 Data description

We study the financial institutions listed in the TWSE between December 2002 and June 2018. By the end of June 2018, there are 16 financial holding companies and 38 domestic banks in Taiwan. However, only 15 financial holding companies and 12 domestic banks are listed firms. Considering the availability of financial data across the sample period, we include 15 financial holding companies, 10 domestic banks, 12 securities companies, and 8 insurance companies in our data set . The characteristics of the domestic banking, financial holding, insurance, and securities subsectors are described in Table 1. The weight of market capitalization (market value) is defined as the percentage of an industry's market capitalization in the Taiwan Capitalization Weighted Stock Index. Table 1 shows that the market value of the financial holding industry is around five times that of the domestic banking, securities, and insurance subsectors. By comparing the trading value among the financial subsectors, we obtain results similar to those observed for the market value. Moreover, the financial holding subsector has much higher net profits and growth of cumulative revenue than other financial subsectors. This indicates that financial holding companies have advantages in competing with non-financial holding companies.

We adopt the daily return and daily trading volume dollar to calculate the Amihud index for each individual financial institution in our sample data. We use the following quarterly accounting variables to estimate the liquidity discount of Chen (2012), including current liabilities, non-current liabilities, adjusted and unadjusted stock prices, and outstanding shares. All daily data for each month and quarterly data are obtained from the TEJ database. The monthly macroeconomic variables including TAIEX market returns, market volatility, short-term interest rate , Taiwan's VIX, 20-year Treasury bond, 5-year Treasury bond, interbank call-loan rate, and Taiwanese Consumer Confidence Index (CCI) are also collected

Table 1
Characteristics of financial subsectors

Financial subsector	Domestic bank	Financial holding	Insurance	Securities
Market value (%)	0.1587	0.8980	0.0618	0.1995
Trading value (%)	0.1132	0.4976	0.0639	0.0723
Cumulative revenue growth rate (%)	4.1475	56.89	0.6913	12.16
Cumulative net profit (thousand dollars)	2,699,840	12,490,005	1,428,884	450,835

Table 1 shows the mean of market value, trading value, cumulative revenue growth rate, and cumulative net profit for the domestic bank, financial holding, insurance, and securities subsectors over the sample period between January 2003 and June 2018.

from the TEJ database.

2.2 The measurement of liquidity risk

According to Amihud (2002), the illiquidity level for individual stock is defined as the average ratio of the absolute individual stock return to the dollar of trading volume, as shown in Equation (1).

$$Amihud\ index_{i,t} = \frac{1}{D_{i,t}} \sum_{d=1}^{D_{i,t}} \frac{|R_{i,d,t}|}{VOL_{i,d,t}} \tag{1}$$

In Equation (1), $R_{i,d,t}$ and $VOL_{i,d,t}$ represent the return and dollar volume for the stock *i* on the date *d* of the month *t*; $D_{i,t}$ denotes the number of days with data available for the stock *i* in the month *t*. The Amihud index reflects the daily influence of order flow on stock returns. For a specific stock with higher liquidity risk, the response of stock price is more sensitive to the current order flow, which is represented by a higher level of the Amihud index.

Based on Chen (2012), we calculate the liquid and illiquid asset values to obtain the liquidity discount index. In the period *t*, a convex relationship between the asset value for a specific firm, A_t, and the economic fundamentals W_t, is represented by a call option with payoff $A_T = \max\{W_T - K, 0\}$. A higher strike price K implies a more illiquid state, which is calculated from the implied credit spreads of the Geske (1979) model. If the dynamic process of W_t satisfies a geometric Brownian movement with a mean μ_w and volatility σ_w, the liquid asset value A_t can be calculated using the binominal model of Cox *et al.* (1979). Because the liquid asset value A_t and the economic fundamentals W_t are unobservable, we estimate the liquid asset value via the firm's equity value by adopting the multi-period structural credit risk model proposed by Geske (1979). The debts in the liquidity discount model include the short-term and long-term debts with face values L_1 and L_2 that mature at time T_1 and T_2. The equity value can be regarded as the call option price on the asset value. Thus, the equity value E at time T_1 is formulated in the following equation:

$$E = A_t N_2\left(d_1^+, d_2^+; \sqrt{\frac{T_1 - t}{T_2 - t}}\right) - e^{-r(T_1-t)} L_1 N_1(d_1^-) - e^{-r(T_2-t)} L_2 N_2\left(d_1^-, d_2^-; \sqrt{\frac{T_1 - t}{T_2 - t}}\right) \quad (2)$$

In Equation (2), L_1 and L_2 symbolize the face values of short-term and long-term debts with maturity time T_1 and T_2. The probability function $N_2(d_1, d_2; \rho)$ is the bi-variate normal distribution with the correlation coefficient ρ and limits d_1 and d_2 shown in Equation (3).

$$d_i^{\pm} = \frac{\ln V_t - \ln X_i + (r \pm \sigma_A^2)(T_i - t)}{\sigma_A \sqrt{T_i - t}}, \qquad i = 1, 2 \quad (3)$$

In Equation (3) X_1 equals $\overline{V}_{T_1}$, X_2 equals $\overline{L}_2$, $\overline{V}_{T_1}$ is the total value of debts, and σ_A is the volatility of liquid asset value. We calculate the liquid asset value A_t based on Equations (2) and (3); moreover, we infer the economic fundamentals W_t through the convexity relationship.

We use Equation (4) to calculate the illiquid asset value, A_t^*.

$$A_t^* = \frac{1}{R(t,T)}\{E(A_T) - \beta^{\$}[E(W_T) - R(t,T)W_t]\} \quad (4)$$

In Equation (4), $E(A_T)$ and $E(W_T)$ are the expected values of the liquid asset and economic fundamentals; $R(t,T) = e^{r(T-t)}$ represents the compound risk-free interest rate r, and $\beta^{\$} = \frac{Cov[A_T, W_T]}{Var[W_T]}$ denotes the dollar beta. Finally, the liquidity discount in period t equals to $(A_t - A_t^*)/A_t$. A high value for the liquidity discount implies a more illiquid state for the corresponding firm.

In this study, for each financial subsector, we measure the monthly liquidity risk by calculating the equal-weighted average of each firm's liquidity risk index across financial institutions. Table 2 shows the summary statistics of liquidity risk in the domestic bank, financial holding, insurance, and securities subsectors. For financial holding firms, the mean of the Amihud index is 0.0096, with a median of 0.0077 and a standard deviation of 0.0103, all lower than those of other subsectors. Similar evidence is also observed for the liquidity discount. This indicates that, on average, financial holding companies have stable and better liquidity health than domestic banks, insurance, and securities companies. Regarding the liquidity risk of the financial market as a whole, the Amihud index is more volatile than the liquidity discount. One explanation is that the Amihud index reflects the sensitive response of stock price to current trading volume; thus, it is more likely to be influenced by the availability of transaction data.

Table 2
Descriptive statistics of liquidity risk for the financial subsectors

Panel A Amihud index

	Domestic bank	Financial holding	Insurance	Securities	Financial market
Mean	0.1255	0.0096	0.3249	0.4043	0.2161
Median	0.0689	0.0077	0.1340	0.2752	0.1468
Maximum	1.3589	0.0777	5.6508	2.8130	1.5632
Minimum	0.0017	0.0004	0.0006	0.0011	0.0011
Std. Dev.	0.1852	0.0103	0.6037	0.4328	0.2268
Observations	187	187	187	187	187

Panel B Liquidity discount

	Domestic bank	Financial holding	Insurance	Securities	Financial market
Mean	0.1105	0.0031	0.0400	0.0119	0.0414
Median	0.0154	5.00E-07	0.0041	1.00E-06	0.0059
Maximum	0.6859	0.0738	0.3093	0.2394	0.2473
Minimum	3.16E-07	3.13E-07	3.44E-07	3.18E-07	4.34E-07
Std. Dev.	0.1800	0.0116	0.0643	0.0445	0.0624
Observations	187	187	187	187	187

Table 2 reports the summary statistics of monthly liquidity risk for the domestic bank, financial holding, insurance, securities subsectors, and financial market. The liquidity risk indices are Amihud index and liquidity discount. The sample period is from December 2002 through June 2018.

Figure 1A and 1B depict the time-series of monthly equal-weighted Amihud index and liquidity discount for the domestic bank, financial holding, insurance, and securities subsectors. Both figures show that the liquidity risk of financial holdings is indeed lower in most periods than that of the domestic bank, insurance, and securities subsectors. The largest upward spike in the Amihud index series for the financial holding, bank, and insurance subsectors is observed during the 2008-2009 global financial crisis in which the financial market suffered a liquidity squeeze. The liquidity discount of domestic bank, financial holding, and insurance subsectors also significantly increase during this crisis period. It should be noted that the change in the Amihud index of the securities subsector does not exactly coincide with the occurrence of 2009 liquidity shocks in the financial market. The most severe liquidity crunch for the securities subsector was in 2003 rather than in 2008-2009. Moreover, the liquidity risk of the securities subsector is highly volatile during 2005-2006 and 2012-2013 when the financial market is stable. We also observe a sharp jump in the domestic bank's liquidity discount series between 2003 and 2004. We conjecture that non-systemic factors are important determinants of liquidity variation for the financial industry, given the dramatic changes in the liquidity risk during non-crisis periods.

In Figures A1A and A1B of the Appendix, we also provide the time-series of monthly market value-weighted Amihud index and liquidity discount for the domestic bank, financial holding, insurance, and securities subsectors[8]. The pattern of market value-weighted liquidity risk is similar to that of equal-weighted liquidity risk. The financial holdings still have lower liquidity risk relative to other subsectors. The value-weighted indices also demonstrate that financial institutions face a severe liquidity crunch from 2008 through 2010.

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8 In Table 1, the market value of financial holding subsector is much higher than that of domestic bank, insurance, and securities subsectors. In Table 2, the liquidity risk of financial holdings is much lower than that of other subsectors. To avoid overestimating (underestimating) the weighting of liquidity risk for large-size (small-size) companies, we adopt equal-weighted average rather than value-weighted average.

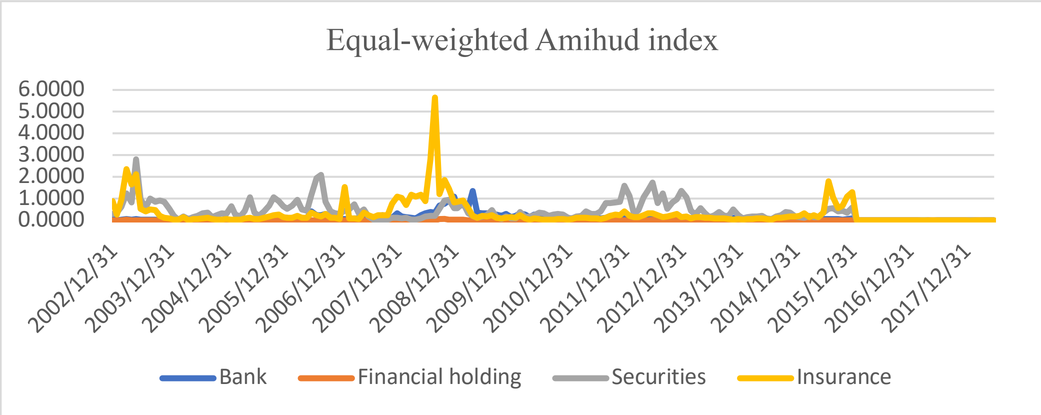

Figure 1A

Time-series monthly equal-weighted Amihud index of financial subsectors

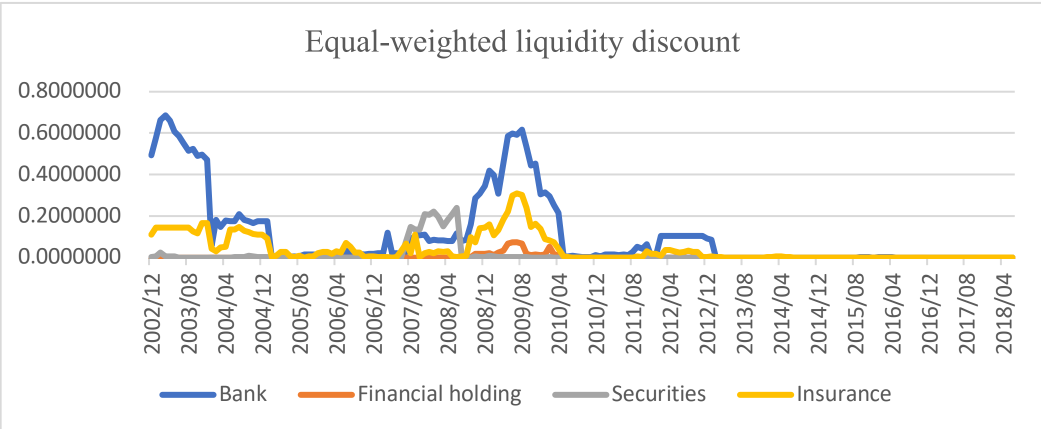

Figure 1B

Time-series monthly equal-weighted liquidity discount of financial subsectors

Figures 1A and 1B describe the time-series of monthly equal-weighted liquidity risk for the financial subsectors in Taiwan. The financial subsectors include the domestic bank, financial holding, insurance, and securities subsectors. The liquidity risk is measured by the Amihud index and liquidity discount. We calculate the liquidity risk proxy for each individual financial institution listed in the Taiwan Stock Exchange. The monthly liquidity risk for a financial subsector is the equal-weighted average of liquidity risk for each individual stock in this specific subsector over the sample period between December 2002 and June 2018.

3. Empirical analysis

3.1 Information contained in liquidity index

In this section, we explore whether the Amihud index and liquidity discount contain different information by studying the relationship between macroeconomic, financial variables and liquidity risk. Theoretical studies (Garleanu and Pedersen, 2007; Vayanos, 2004) predict that a greatly downward or highly uncertain market will make liquidity suppliers reduce the liquidity supply when their capital constraints are reached. In our paper, we use the returns and volatility of TAIEX to represent capital market conditions. Following Karolyi *et al.* (2012), we adopt short-term interest rate and interbank call-loan rate to symbolize the condition of funding liquidity. In addition, the yield spread (20-year Treasury bond minus 5-year Treasury bond) and Taiwan VIX are employed to represent the expectations for capital market conditions. The studies (Chen, 2011; Fisher and Statman, 2003; Jansen and Nahuis, 2003) suggest a strong relationship between consumer sentiment and stock returns. Therefore, we investigate the link between stock liquidity and consumer sentiment represented by CCI.

Table 3 shows the contemporaneous correlations between the macroeconomic conditions, financial variables, and liquidity risk of the financial market. We find that the Amihud index is moderately correlated with market conditions (market volatility), funding constraints (interest rate and call-loan rate), investor expectations (VIX), and consumer confidence (CCI), while the liquidity discount is modestly correlated with most variables except for market volatility and VIX. In addition, the correlation between the Amihud index and liquidity discount is 0.3436, indicating that these two liquidity indices are not highly correlated. This suggests that the Amihud index and liquidity discount may contain different information concerning liquidity risk.

We then explore the causal relationship between macroeconomic, financial variables and liquidity risk using the vector autoregression model shown in Equations (5) and (6).

$$Amihud\ index_t = c + \sum_{m=1}^{M} a_m Amihud\ index_{t-m} + \sum_{m=1}^{M} b_m X_{t-m} + \varepsilon_t \quad (5)$$

Table 3

Correlation analysis

	Market return	Market volatility	Interest rate	Call-loan rate	Yield spread	VIX	CCI
Amihud index	-0.1657*	0.5166*	0.4810*	0.3996*	-0.1959*	0.6273*	-0.4295*
Liquidity discount	0.0851	0.4764*	0.3669*	0.1430	0.3219*	0.6646*	-0.1465*

Table 3 shows the Pairwise correlation between macroeconomic, financial variables, and liquidity risk index measured by the Amihud index and liquidity discount. The variables include TAIEX return and volatility, short-term interest rate, interbank call-loan rate, yield spread, Taiwan VIX and consumer confidence index (CCI). The sample period is from January, 2003 through June, 2018. The data period for VIX is between December, 2006 and June, 2018. Superscript * indicates statistical significance at the 5%.

$$Liquidity\ discount_t = c + \sum_{m=1}^{M} c_m Liquidity\ discount_{t-m} + \sum_{m=1}^{M} d_m X_{t-m} + \eta_t \quad (6)$$

In Equations (5) and (6), $Amihud\ index_t$ and $Liquidity\ discount_t$ measure equal-weighted liquidity risk for the financial market in the month *t*; the variable X_t is the macroeconomic or financial variable. The lag length *M* is determined by the Akaike information criterion (AIC). Table 4 provides the results of the Granger causality test. We find that market return, market volatility, short-term interest rate, VIX, and CCI significantly Granger-cause liquidity risk as measured by the Amihud index. A similar result is observed for the liquidity discount. Furthermore, the variables relevant to credit risk represented by the call-loan rate and yield spread[9] significantly Granger-cause the liquidity discount, indicating that the liquidity discount reflects more credit risk information than the Amihud index.

On the other hand, the Amihud index significantly Granger-causes all of the macroeconomic variables, except for consumer confidence, indicating that Amihud index can serve as the indicator of future market conditions, funding liquidity, and investor expectations. The liquidity discount Granger-causes market volatility, the short-term interest rate, yield spread, and consumer confidence. Furthermore, we adopt the Diebold-Mariano test to investigate the prediction

[9] Yield spread is determined by the liquidity premium and credit spread. The higher credit risk makes investors require greater yield spread.

ability of the Amihud index and liquidity discount on the macroeconomic variables. The testing results present that compared with the liquidity discount, the Amihud index is the better forecast of market conditions (market return and market volatility) and investor expectations (yield spread) although the difference is insignificant. Moreover, the Amihud index is a significantly superior prediction of investor sentiment (consumer confidence). The liquidity discount has a greater ability in predicting funding liquidity (short-term interest rate) than the Amihud index[10].

In addition, the range of lag periods in our VAR models is from 1 to 8 which implies a short or long terms causality relationship. For example, the two-way causality relationship between market return and liquidity risk measured by liquidity discount maintains 8 months. However, the two-way causality relationship between market volatility and liquidity risk measured by Amihud index only preserves for 2 months.

Next, we explore the response of liquidity risk to the shocks from macroeconomic conditions, funding constraints, and investor expectations within 10 months. The results of the impulse response analysis are shown in Figure 2. Based on the results concerning positive and negative responses of the liquidity risk indices, we observe that the financial market becomes more illiquid under the following conditions: declining market returns, highly uncertain capital market, constrained funding liquidity, investors' pessimistic expectations, and lack of consumer confidence. A Comparison of the response magnitude between the Amihud index and liquidity discount suggests that the Amihud index presents a stronger and longer response to changes in market returns, market volatility, short-term interest rate, VIX, and consumer confidence than the liquidity discount. This is likely because the Amihud index is estimated by the stock return and trading volume, which is more likely to be influenced by the above macroeconomic variables. By contrast, the liquidity discount is inferred from the firm's liquid and illiquid asset values, which strongly responds to the changes in the interbank call-

[10] The detail results of Diebold-Mariano test are available upon request.

Table 4
Granger-causality relationship between macroeconomic variables and liquidity risk

Panel A Granger-causality relationship for Amihud index

	Financial variables Granger cause Amihud index						
	Market return	Market volatility	Interest rate	Call-loan rate	Yield spread	VIX	CCI
Chi-square	41.816	24.344	9.0796	0.20333	2.9439	20.674	7.2822
P-value	< 0.001***	< 0.001***	0.059*	0.977	0.4	<0.001***	0.007***
	Amihud index Granger causes Financial variables						
	Market return	Market volatility	Interest rate	Call-loan rate	Yield spread	VIX	CCI
Chi-square	18.717	7.6307	22.095	21.813	20.527	40.208	0.75124
P-value	0.009***	0.022**	< 0.001***	< 0.001***	< 0.001***	<0.001***	0.386
Lags number	7	2	4	3	3	4	1

Panel B Granger-causality relationship for liquidity discount

	Financial variables Granger cause liquidity discount						
	Market return	Market volatility	Interest rate	Call-loan rate	Yield spread	VIX	CCI
Chi-square	33.228	21.102	2.67	27.632	14.425	39.712	6.5993
P-value	< 0.001***	< 0.001***	0.102	< 0.001***	0.006***	<0.001***	0.086*
	Liquidity discount Granger causes Financial variables						
	Market return	Market volatility	Interest rate	Call-loan rate	Yield spread	VIX	CCI
Chi-square	10.594	15.065	11.874	5.3542	7.9582	6.0878	8.3709
P-value	0.226	0.002***	0.001***	0.374	0.093*	0.637	0.039**
Lags number	8	3	1	5	4	8	3

Table 4 shows the Granger-causality relationship between macroeconomic variables and liquidity risk. The liquidity risk indices are Amihud index and liquidity discount. The macroeconomic variables include TAIEX return and volatility, short-term interest rate, interbank call-loan rate, yield spread, Taiwan VIX and consumer confidence index (CCI). The sample period is from January, 2003 through June, 2018. The data period for VIX is between December, 2006 and June, 2018. The number of lag periods is based on Akaike information criterion (AIC). Superscript *, **, and *** indicate statistical significance at the 10%, 5%, and 1%.

loan rate and yield spread related to the credit risk information. In the Appendix, Tables A1-A7 provide the impact levels of macroeconomic variables on the

Amihud index and liquidity discount. Based on the 95% confidence interval, the impulse responses of liquidity risk within 10 months are significant.

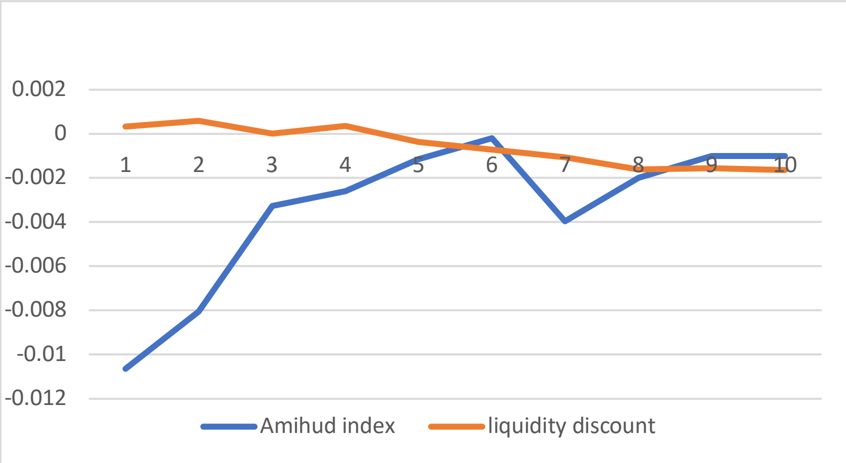

Figure 2A

Response of liquidity risk to market returns

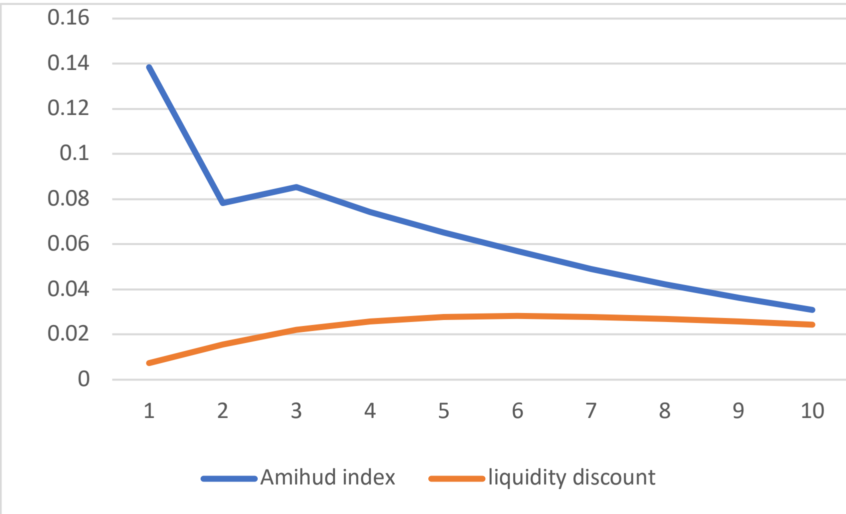

Figure 2B

Response of liquidity risk to market volatility

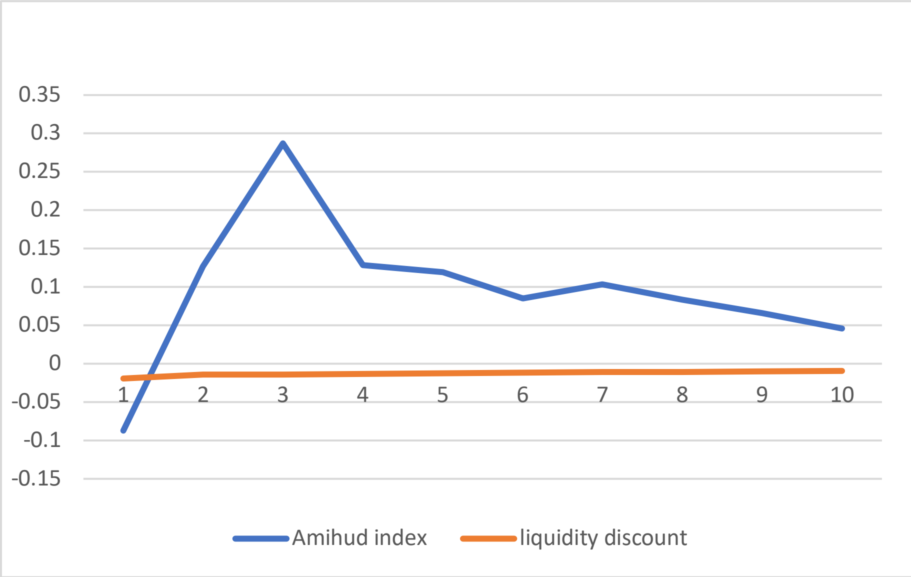

Figure 2C

Response of liquidity risk to short-term interest rate

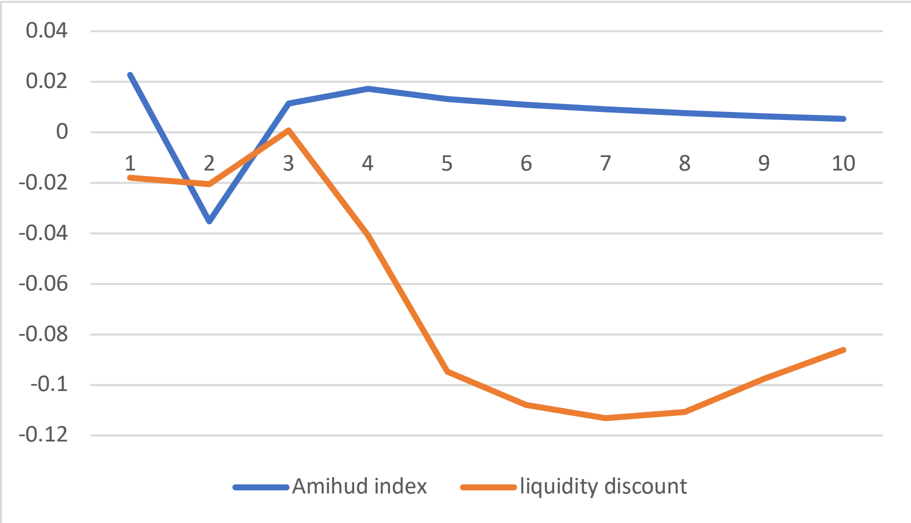

Figure 2D

Response of liquidity risk to interbank call-loan rate

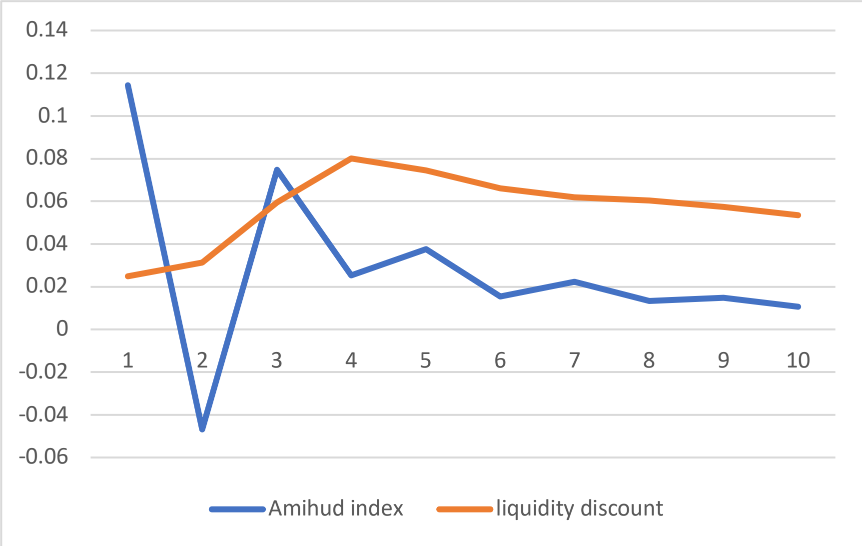

Figure 2E
Response of liquidity risk to yield spread

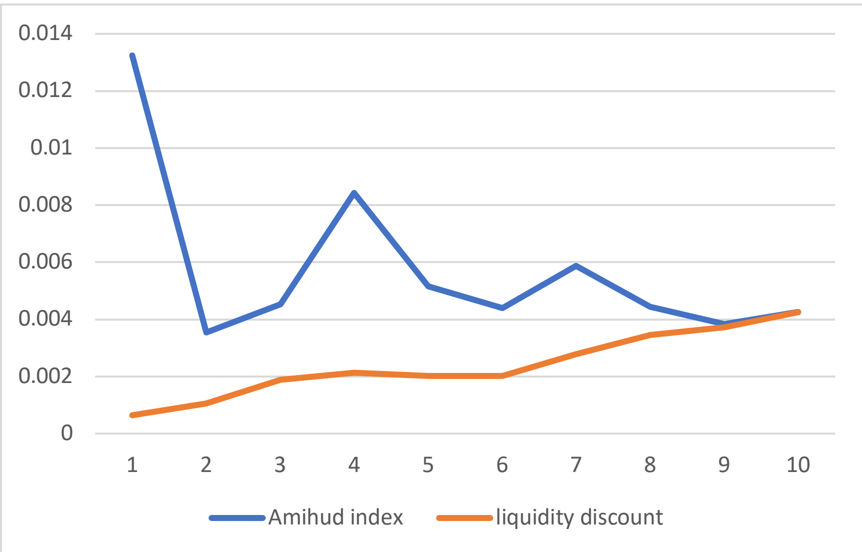

Figure 2F
Response of liquidity risk to VIX

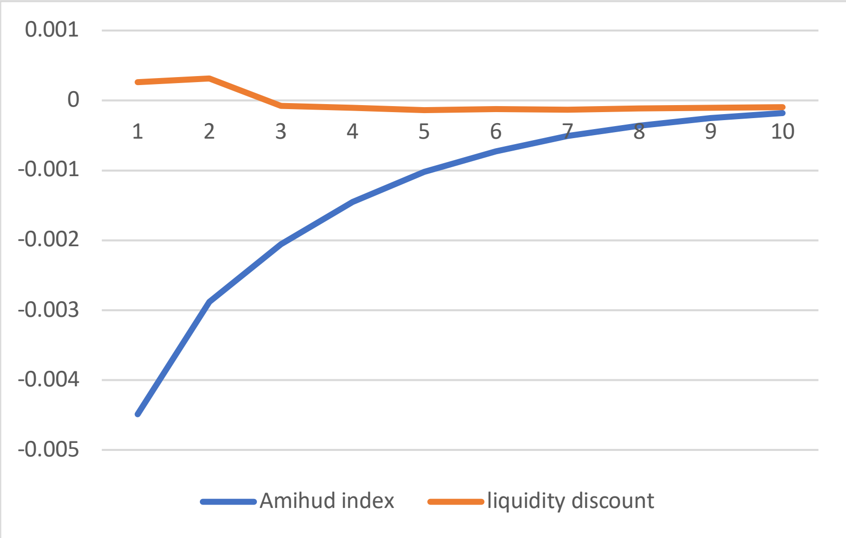

Figure 2G

Response of liquidity risk to consumer confidence

The series of Figure 2 show the impulse response of liquidity risk in the financial market to the changes in market returns, market volatility, short-term interest rate, interbank call-loan rate, yield spread, Taiwan VIX, and consumer confidence, respectively. The liquidity risk indices include the Amihud index and liquidity discount. The series of Figure 2 plot the response of liquidity risk during the following 10 periods when the shocks of macroeconomic variables occur in the period 0. The blue (red) line represents the Amihud index series (liquidity discount series). The sample period is between January 2003 and June 2018. The data period for Taiwan VIX is from December 2006 through June 2018.

3.2 Systemic factors of liquidity risk

Figure 1 shows how the liquidity risks of domestic bank, financial holding, insurance and securities subsectors fluctuate during stable and stressed market periods. In order to identify the contribution of each subsector's illiquidity to the financial market risk, we adopt the principal component analysis to extract the common factors of liquidity risks for the four financial subsectors between January 2003 and June 2018. For example, if the first 4 principal components explain most of the variability in liquidity risks for the four financial subsectors, the model is described in Equation (7):

$$PCj_t = c_{j1}L_{1t} + c_{j2}L_{2t} + c_{j3}L_{3t} + c_{j4}L_{4t} \quad \text{for } j = 1 \ldots 4 \tag{7}$$

In Equation (7), PCj_t is the jth principal component; L_{it} is the liquidity risk of the financial subsector i, i = 1…4 ; $c_{j1}, c_{j2}, c_{j3}, c_{j4}$ are the factor loadings, $c_{j1}^2 + c_{j2}^2 + c_{j3}^2 + c_{j4}^2 = 1$ and $c_{j1}c_{k1} + c_{j2}c_{k2} + c_{j3}c_{k3} + c_{j4}c_{k4} = 0$ for k = 1…4, $j \neq k$.

Table 5 presents the results of the principal component analysis for the Amihud index and liquidity discount. Panel A1 of Table 5 provides 4 principal components explaining the proportions of variation in financial market liquidity as measured by the Amihud index. The results show that the first principal component, PC1, explains the largest proportion of volatility, 56.44%, in the liquidity risks of the four financial subsectors, and the second principal component, PC2, explains the second highest proportion of variation, 21.12%. The cumulative percentage of variation explained by the first and second components is 77.57%, indicating that the first and second principal components dominate the evolution of liquidity risk as measured by the Amihud index. Panel A2 of Table 5 reports the loading values of the domestic bank, financial holding, insurance, and securities subsectors to the variation of the four principal components. The results for the Amihud index shown in Panel A2 show that the domestic bank and financial holding subsectors dominate the first principal component, indicating that the systemic liquidity risk of the financial market is highly correlated with the liquidity risks in the domestic bank and financial holding subsectors. The insurance subsector is the third contributor to the first principal component. The securities subsector has the lowest contribution to the first principal component, yet is the top contributor to the second principal component.

We also observe evidence for the liquidity discount similar to that found for the Amihud index. Panel B1 of Table 5 shows that the first and second principal components together explain 85.64% of the variation in liquidity risk as measured by the liquidity discount. The results shown in panel B2 suggest that, in addition to domestic banks and financial holdings, the insurance subsector is also a significant contributor to the first principal component derived from liquidity discount. This result may be attributed to the Taiwanese's high insurance penetration and prevalence. Therefore, insurance companies serve as important liquidity suppliers in Taiwan's financial markets. For the contribution of the securities subsector, the result is similar to that found on Amihud index.

Table 5

Principal component analysis

Panel A Principal component analysis for Amihud index

Panel A1 Proportion of variations explained by principal components			
Number	Value	Proportion	Cumulative proportion
PC1	2.2577	0.5644	0.5644
PC2	0.8450	0.2112	0.7757
PC3	0.6814	0.1704	0.9460
PC4	0.2159	0.0540	1

Panel A2 Loading values of each variable in the principal component				
Variable	PC 1	PC 2	PC 3	PC 4
Domestic bank	0.5193	-0.4606	-0.4637	0.5507
Financial holding	0.6132	-0.0462	-0.1793	-0.7679
Insurance	0.4569	-0.1448	0.8605	0.1726
Securities	0.3815	0.8745	-0.1121	0.2780

Panel B Principal component analysis for liquidity discount

Panel B1 Proportion of variations explained by principal components			
Number	Value	Proportion	Cumulative proportion
PC1	2.4235	0.6059	0.6059
PC2	1.0021	0.2505	0.8564
PC3	0.4901	0.1225	0.9790
PC4	0.0841	0.0210	1

Panel B2 Loading values of each variable in the principal component				
Variable	PC 1	PC 2	PC 3	PC 4
Domestic bank	0.5881	0.0712	-0.5011	0.6308
Financial holding	0.5200	-0.0508	0.8330	0.1829
Insurance	0.6187	0.0090	-0.2185	-0.7540
Securities	-0.0349	0.9957	0.0852	-0.0122

Table 5 presents the results of principal component analysis concerning the liquidity risk indices. Panels A and B show the results of principal component analysis for the Amihud index and liquidity discount. Panels A1 and B1 describe the proportions of variation of liquidity risks in each financial subsector explained by 4 principal components from the Amihud index and liquidity discount. The first (fourth) principal component, PC1 (PC4), explains the largest (smallest) proportion of volatility in liquidity risks. Panels A2 and B2 show the loading values of domestic bank, financial holding, insurance and securities subsectors in 4 principal components for the Amihud index and liquidity discount. The sample period is from January, 2003 through June, 2018.

To explore the influence of systemic liquidity risk on each financial subsector, we decompose the liquidity risk indices into systemic and non-systemic components. The regression models are described in Equations (8) and (9).

$$Amihud\ index_{i,t} = \alpha_{i,0} + \alpha_{i,1}PC1_{t-1} + \alpha_{i,12}PC1_{t-2} + \alpha_{i,2}PC2_{t-1} + \alpha_{i,22}PC2_{t-2} + \varepsilon_{i,t} \quad (8)$$

$$Liquidity\ discount_{i,t} = \beta_{i,0} + \beta_{i,1}PC1_{t-1} + \beta_{i,12}PC1_{t-2} + \beta_{i,2}PC2_{t-1} + \beta_{i,22}PC2_{t-2} + \eta_{i,t} \quad (9)$$

In Equations (8) and (9), $Amihud\ index_{i,t}$ and $Liquidity\ discount_{i,t}$ denote the financial subsector *i*'s liquidity risk in the month *t* measured by the Amihud index and liquidity discount. The first and second principal components represent the systemic liquidity risk; $PC1_{t-1}$ and $PC1_{t-2}$ denote the first principal component in the month *t-1* and *t-2*; $PC2_{t-1}$ and $PC2_{t-2}$ denote the second principal component in the month *t-1* and *t-2*. According to Chen *et al.* (2016), the residual $\varepsilon_{i,t}$ and $\eta_{i,t}$ reflect the non-systemic risk in the month *t* for the financial subsector *i*.

Table 6 provides the results for the systemic liquidity risk models (8) and (9). Our findings in Panel A of Table 6 show that the Amihud index of the domestic bank, financial holding, and insurance subsectors are significantly and positively related to primary systemic liquidity risk in the last month, $PC1_{t-1}$. The impact of primary systemic risk lagged two months, $PC1_{t-2}$, is still significant for domestic banks and financial holding firms, but not for the securities and insurance subsectors. All subsectors more weakly respond to the second primary systemic risk *PC2* than *PC1*, except for the securities subsector. Furthermore, a comparison of the estimated coefficients of $PC1_{t-1}$ shows that primary systemic liquidity risk lagged one period has a higher impact on the domestic banking, securities, and insurance subsectors than financial holdings, implying that small-medium companies are more likely to be influenced by systemic risk than larger companies. Because the financial holding subsector is one of the main contributors to the variation in the systemic liquidity risk, as shown in Table 5, the financial holding subsector plays an important role in stabilizing the liquidity of the Taiwanese financial market. In addition, the R-square of the regression models for the

Amihud index is larger than 50% in the domestic banking, financial holdings, and securities subsectors, indicating that the systemic liquidity risk explains high proportions of variation in the Amihud index for these three subsectors.

In Panel B of Table 6, the liquidity discount of the domestic banking, financial holding, and insurance subsectors significantly and positively responds to primary systemic liquidity risk lagged one month, consistent with the results for the

Table 6

Influence of systemic components on liquidity risk

Panel A Amihud index

	Domestic bank	Financial holding	Securities	Insurance
Constant	0.0421***	0.0028***	0.0974***	0.0798*
	(3.36)	(-4.35)	(2.84)	(1.94)
$PC1_{t-1}$	0.1343**	0.0094***	0.2359***	0.9292*
	(2.27)	(2.93)	(3.07)	(1.9)
$PC1_{t-2}$	0.2307***	0.0136***	0.1658	0.0621
	(3.56)	(3.31)	(1.5)	(0.23)
$PC2_{t-1}$	-0.0881	-0.0001	0.6285***	-0.4675
	(-1.52)	(-0.04)	(3.78)	(-1.3)
$PC2_{t-2}$	-0.1213**	-0.0079**	-0.0072	-0.0639
	(-2.53)	(-2.07)	(-0.05)	(-0.32)
R^2	0.5287	0.6576	0.5095	0.4020

Panel B Liquidity discount

	Domestic bank	Financial holding	Securities	Insurance
Constant	0.0010	-0.0007	0.0015*	0.004***
	(0.4)	(-1.52)	(1.83)	(2.69)
$PC1_{t-1}$	1.1232***	0.1017***	-0.111***	0.5133***
	(7.15)	(2.64)	(-4.01)	(6.88)
$PC1_{t-2}$	0.0052	-0.0527	0.0217	-0.1075
	(0.03)	(-1.63)	(0.82)	(-1.56)
$PC2_{t-1}$	0.0318	-0.0212*	0.9147***	0.0399
	(0.42)	(-1.8)	(5.14)	(0.43)
$PC2_{t-2}$	0.0879	0.0017	-0.0303	-0.0913
	(1.3)	(0.16)	(0.34)	(-1.23)
R^2	0.9170	0.3894	0.7923	0.8343

Table 6 provides the results of systemic regression model. The model of Panel A is $Amihud\ illiquidity_{i,t} = \alpha_{i,0} + \alpha_{i,1}PC1_{t-1} + \alpha_{i,12}PC1_{t-2} + \alpha_{i,2}PC2_{t-1} + \alpha_{i,22}PC2_{t-2} + \varepsilon_{i,t}$. The model of Panel B is $Liquidity\ discount_{i,t} = \beta_{i,0} + \beta_{i,1}PC1_{t-1} + \beta_{i,12}PC1_{t-2} + \beta_{i,2}PC2_{t-1} + \beta_{i,22}PC2_{t-2} + \eta_{i,t}$. In the Amihud index and liquidity discount models, $PC1_{t-1}$ and $PC1_{t-2}$ represent the first principal component in the month *t-1* and *t-2*; $PC2_{t-1}$ and $PC2_{t-2}$ represent the second principal component in the month *t-1* and *t-2*. The coefficient estimates are corrected for heteroscedasticity and autocorrelation. The values in parentheses are t-statistics. Superscript *, **, and *** indicate statistical significance at the 10%, 5%, and 1%. The sample period is from January 2003 through June 2018.

Amihud index[11]. The result that financial holding firms are less influenced by primary systemic risk is also observed with the liquidity discount. A large difference between these two liquidity risk indices is that the R-square of liquidity discount model for the financial holding subsector (39%) is much lower than those for other subsectors (from 79% to 92%). Thus, we conclude that, for the domestic banking, securities, and insurance subsectors, the variations in the liquidity risk measured by liquidity discount are adequately explained by systemic liquidity risk. By contrast, for the financial holding subsector, the systemic liquidity risk only explains 39% of variation in the liquidity discount, implying that the liquidity discount for the financial holding subsector contains more signals about the non-systemic liquidity risk.

3.3 Interconnection of non-systemic liquidity risk

In this section, we analyze the influence and dependence of non-systemic liquidity risk among the domestic bank, financial holding, securities, and insurance subsectors by employing the following vector autoregression model.

$$\varepsilon_{i,t} = c + \sum_{m=1}^{M} a_{i,m}\varepsilon_{i,t-m} + \sum_{j=1,j\neq i}^{4}\sum_{m=1}^{M} b_{j,m}\varepsilon_{j,t-m} + \delta_{i,t} \tag{10}$$

$$\eta_{i,t} = c + \sum_{m=1}^{M} f_{i,m}\eta_{i,t-m} + \sum_{j=1,j\neq i}^{4}\sum_{m=1}^{M} g_{j,m}\eta_{j,t-m} + \zeta_{i,t} \tag{11}$$

In Equation (10), $\varepsilon_{i,t}$ denotes the non-systemic liquidity risk for the financial subsector i extracted from the Amihud index. In Equation (11), $\eta_{i,t}$ denotes the non-systemic liquidity risk for the financial subsector *i* extracted from the liquidity discount. The lag length *M* is determined by the AIC[12].

With the Granger causality test, Chen *et al.* (2016) propose a simple method to measure whether the non-systemic liquidity risk of a financial subsector influences or connects with the non-systemic liquidity risk in other subsectors. They define the influence of a given financial subsector as the number of other

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[11] The liquidity discount of the securities subsector is negatively related with primary systemic liquidity risk $PC1_{t-1}$, but it highly and positively responds to the second primary systemic risk $PC2_{t-1}$. This result can be explained by the finding shown in Panel B of Table 5. The securities subsector has an adverse contribution to the first principal component of market liquidity risk, and plays as the main contributor to the second principal component.

[12] For the Amihud index, the lag length of the vector autoregression model is 8 periods. For the liquidity discount, the lag length of the vector autoregression model is 2 periods.

financial subsectors that are Granger-caused by the given financial subsector. The dependence of a specific financial subsector is the number of other financial subsectors that Granger-cause liquidity shocks to this financial subsector. For a specific subsector, the connection with other subsectors is the sum of its influence and dependence numbers and its net influence is the difference between influence and dependence. Table 7 describes the results of the Granger causality test for all financial subsectors, while Panels A and B present the non-systemic liquidity risk extracted from the Amihud index and liquidity discount. For example, in Panel A of Table 7, the non-systemic liquidity risk of financial holding subsector Granger-causes liquidity shocks only to the domestic bank subsector, and is Granger-caused by the insurance subsector. Thus, for financial holding subsector, its influence and dependence are both equal to 1, the number of connections with other subsectors is 2, and the net influence is 0.

The results for the Amihud index and liquidity discount show that the securities subsector has less connection with the other financial subsectors. This is because, for most Taiwanese financial holding firms, the banking and insurance subsidiaries are the main subsidiaries, meaning that they contribute greater capital than other subsidiaries. Domestic banks and medium-sized insurance companies are involved in fierce competition with financial holding firms. Therefore, non-systemic liquidity risk is tightly connected across the domestic banking, financial holding, and insurance subsectors. It is noteworthy that the magnitude of the interconnected relationship derived from the liquidity discount is apparently higher than that extracted from the Amihud index, which provides additional evidence that the liquidity discount reflects more firm-specific liquidity risk. Thus, in the following analysis, we focus on the non-systemic liquidity risk extracted from the liquidity discount.

Our findings concerning the liquidity discount, shown in Panel B of Table 7, indicate that the non-systemic liquidity risk of financial holdings has a greater net influence (net influence number of 1) on the other subsectors. Thus, the financial holding subsector serves as the trigger of non-systemic liquidity risk in the

Table 7
Interconnection of non-systemic liquidity risk

Panel A Non-systemic liquidity risk extracted from Amihud index

	Domestic bank	Financial holding	Securities	Insurance
Influence	0	1	1	2
Dependence	3	1	0	0
Interconnection	3	2	1	2
Net influence	-3	0	1	2

Panel B Non-systemic liquidity risk extracted from liquidity discount

	Domestic bank	Financial holding	Securities	Insurance
Influence	2	2	1	2
Dependence	2	1	1	3
Interconnection	4	3	2	5
Net influence	0	1	0	-1

Table 7 shows the results of Granger causality test concerning the non-systemic liquidity risk of the domestic bank, financial holding, securities, and insurance subsectors. Panels A and B provide the results for the non-systemic risk extracted from Amihud index and liquidity discount. The influence of a specific financial subsector is that the financial subsector's liquidity shock Granger-causes other financial subsectors' non-systemic liquidity risk. The dependence of a specific financial subsector is that the non-systemic liquidity risk of the financial subsector is Granger-caused by the liquidity shocks of other financial subsectors. The interconnection of a specific financial subsector is the sum of influence and dependence for the financial subsector. The net influence of a specific financial subsector is the difference in the number of influence and dependence for the financial subsector. The sample period is between January 2003 and June 2018.

financial market. The insurance subsector is more dependent (dependence number of 3) on the other financial subsectors than the domestic bank, financial holding, and securities subsectors. Furthermore, the domestic bank and insurance subsector are highly connected with other subsectors (connection numbers 4 and 5), implying that the domestic bank and insurance subsectors are the media for distributing the non-systemic liquidity risk among the financial institutions.

As a robustness check, we use the regression model shown in Equation (9) to examine the impact of systemic liquidity risk on each financial subsector in the period of the 2007-2009 financial crisis. In Panel A of Table 8, the results are consistent with our findings for the whole sample period presented in Panel B of

Table 6. During the financial crisis period, the liquidity risk of the domestic banking, financial holding, and insurance subsectors are significantly and positively related to the systemic liquidity risk. The impact of systemic liquidity risk on the financial holdings is still lower than that on other subsectors. Furthermore, the estimated coefficients of the variable $PC1_{t-1}$ during this subsample period are larger than those estimated from the whole sample. The 2007-2009 crisis is characteristic of the systemic risks in the financial market; therefore, the liquidity risks among the financial institutions are highly explained by the systemic risk.

Panel B of Table 8 presents the influence, dependence, and interconnection of non-systemic liquidity risk among the financial subsectors during the financial crisis period. We find that the net influence of the insurance subsector is higher than other subsectors. The reasonable explanation is that small and medium-size companies become more likely to trigger non-systemic liquidity risk among the financial institutions between 2007 and 2009. Moreover, compared with the whole sample, the non-systemic liquidity risks of financial subsectors are more closely interconnected in the financial crisis.

Finally, we employ impulse response analysis to investigate the transmission process of non-systemic liquidity risk extracted from liquidity discount among the financial subsectors. The series of Figure 3 plot how financial institutions respond to shocks generated from the domestic bank, financial holding, insurance, and securities subsectors within 10 months[13]. For example. Figure 3A shows the responses of the financial holding, securities, and insurance subsectors to shocks coming from domestic banks. Our observations concerning the transmission of non-systemic liquidity risk are as follows. First, during the earlier periods, most financial subsectors clearly and positively respond to firm-specific liquidity risk occurring in a specific subsector[14]. Second, the results shown in Figures 3A, 3C,

[13] Based on 95% confidence interval, impulse responses are significant. The result is available upon request.

[14] Regarding the shock coming from insurance subsector shown in Figure 3D, the securities subsector represents the positive response. The response of financial holding companies is trivial. The domestic banks negatively respond to the non-systemic liquidity risk of insurance

Table 8

Systemic and non-systemic liquidity risk during the crisis period

Panel A Influence of systemic components on liquidity risk

	Domestic bank	Financial holding	Securities	Insurance
Constant	0.0541**	-0.0057	0.0266	0.0132
	(2.46)	(-1.61)	(1.95)	(1.04)
$PC1_{t-1}$	1.2162***	0.2154***	-0.4121***	0.5883***
	(5.19)	(4.50)	(-4.56)	(4.56)
$PC2_{t-1}$	0.1959	0.0325	0.7235***	0.0596
	(1.62)	(1.67)	(4.01)	(0.81)
R^2	0.9167	0.7259	0.7331	0.8614

Panel B Interconnection of non-systemic liquidity risk

	Domestic bank	Financial holding	Securities	Insurance
Influence	3	2	2	3
Dependence	4	3	4	2
Interconnection	7	5	6	5
Net influence	-1	-1	-2	1

Table 8 shows the impact of systemic liquidity risk and the interconnection of non-systemic liquidity risk between January 2007 and December 2009. The liquidity risk is measured by the liquidity discount. The model of Panel A is $Liquidity\ discount_{i,t} = \beta_{i,0} + \beta_{i,1}PC1_{t-1} + \beta_{i,12}PC1_{t-2} + \beta_{i,2}PC2_{t-1} + \beta_{i,22}PC2_{t-2} + \eta_{i,t}$ where $PC1_{t-1}$ and $PC1_{t-2}$ represent the first principal component in the month *t-1* and *t-2*; $PC2_{t-1}$ and $PC2_{t-2}$ represent the second principal component in the month *t-1* and *t-2*. The results for the estimated coefficients of $PC1_{t-2}$ and $PC2_{t-2}$ are omitted in this table. The coefficient estimates are corrected for heteroscedasticity and autocorrelation. The values in parentheses are t-statistics. Superscript **, and *** indicate statistical significance at the 5%, and 1%. Panel B provides the results of Granger causality test concerning the non-systemic liquidity risk of the domestic bank, financial holding, securities, and insurance subsectors. The definitions of influence, dependence, interconnection, and net influence are the same as those described in Table 7.

and 3D indicate that the response of financial holding subsector is trivial relative to the other financial subsectors. Moreover, it approximates 0 during the earlier periods, implying that the impact of non-systemic liquidity risk from the other

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subsector. Our conjecture is that the domestic banks are allowed to have insurance business; therefore, the medium or small-size insurance companies are in competition with the banks. Thus, the shock of insurance companies negatively affects the non-systemic liquidity risk of domestic banks.

subsectors on the financial holding subsector is temporary. Third, by comparing the magnitudes of the response in Figure 3B with those in Figures 3A, 3C, and 3D, we find that the responses of the domestic bank, securities, and insurance subsectors to the shock from financial holdings are stronger than those to shocks from the other financial subsectors. This result indicates that the non-systemic liquidity risk of financial holdings is more influential on the other financial subsectors.

4. Conclusions

This paper shows how liquidity shocks are transmitted across the domestic bank, financial holding, insurance, and securities subsectors in Taiwan. We employ the Amihud index and the liquidity discount to measure the liquidity risk for each individual financial institution. The Amihud index and liquidity discount reflect different information concerning liquidity risk in the financial market. Our findings suggest that the Amihud index contains more information about the relationship between liquidity risk and macroeconomic variables, including capital market conditions, investor expectations, and consumer sentiment, than the

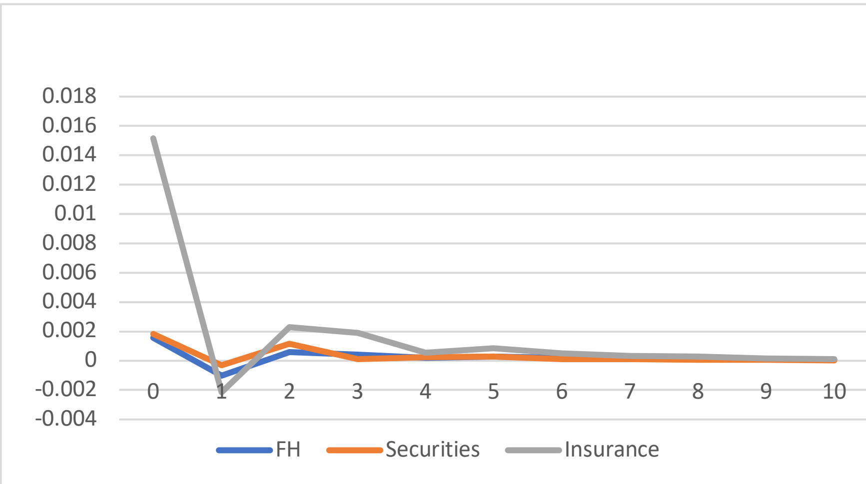

Figure 3A

The non-systemic liquidity risk from the domestic bank subsector

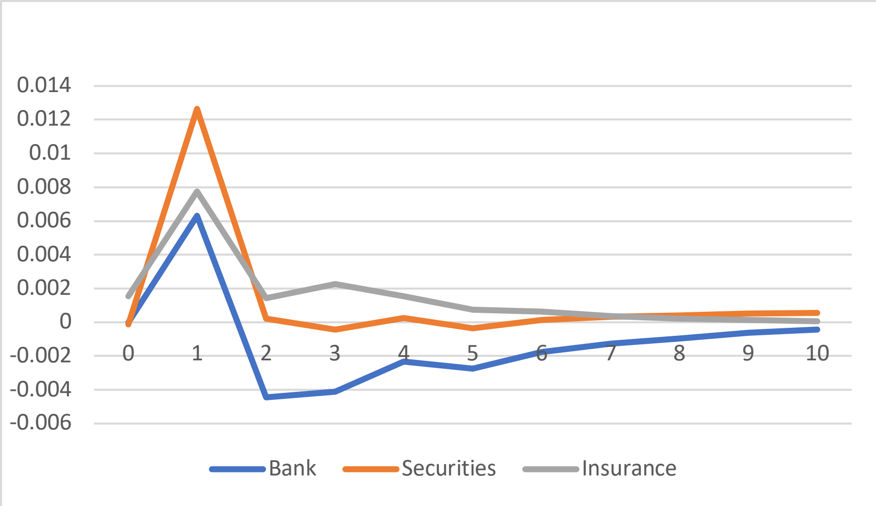

Figure 3B

The non-systemic liquidity risk from the financial holding subsector

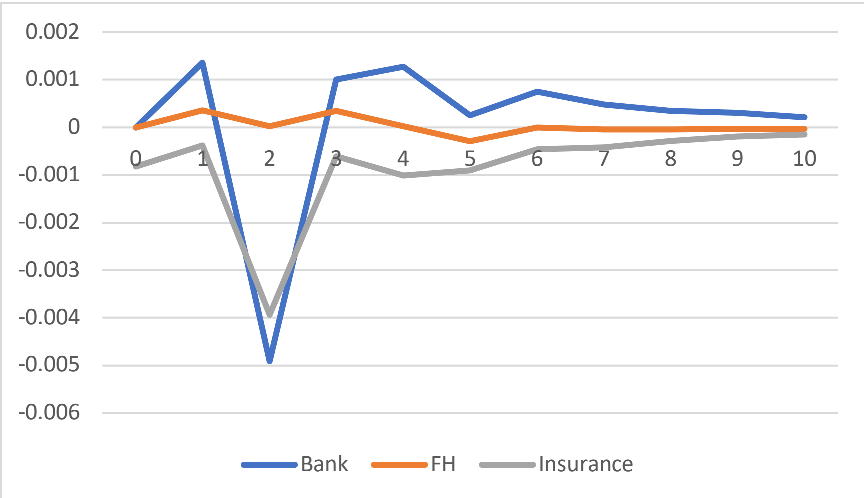

Figure 3C

The non-systemic liquidity risk from the securities subsector

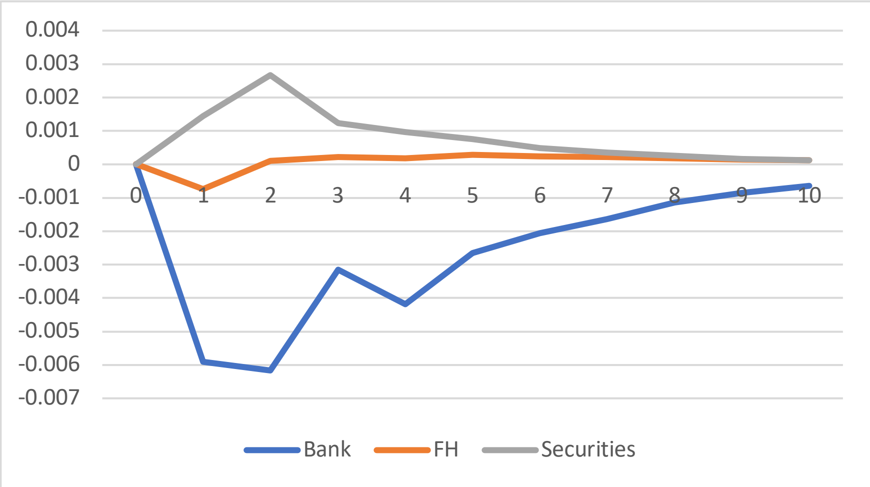

Figure 3D

The non-systemic liquidity risk from the insurance subsector

The series of Figure 3 describe the impulse response of financial subsectors to the non-systemic liquidity risk occurred in a specific financial subsector. The liquidity risk is measured by liquidity discount. The number of response period is 10 months. Figure 3A plots the responses of financial holding, securities, and insurance to the shock from the domestic bank subsector. Figure 3B plots the responses of domestic bank, securities, and insurance to the shock from the financial holding subsector. Figure 3C plots the responses of domestic bank, financial holding, and insurance to the shock from the securities subsector. Figure 3D plots the responses of domestic bank, financial holding, and securities to the shock from the insurance subsector. The sample period is between January 2003 and June 2018.

liquidity discount. This study shows the applicability of the Amihud index and liquidity discount in measuring different aspects of liquidity risk. In addition, we use principal component analysis to separate the systemic and non-systemic liquidity risk from the Amihud index and liquidity discount. We find that the domestic bank, financial holding, and insurance subsectors are important contributors to the variation in the systemic liquidity risk. Moreover, the financial holding subsector is less influenced by systemic liquidity risk.

Further, we show evidence that the non-systemic liquidity risk derived from liquidity discount follows tight interconnections between the domestic banking, financial holding, and insurance subsectors. The financial holding firms are the trigger of non-systemic liquidity risk, and domestic bank and insurance subsectors serve as the critical centers for transferring non-systemic liquidity risk in the financial market. Moreover, the domestic banking, securities, and insurance subsectors are sensitive to the shock generated by the financial holding subsector. Our results show that the financial holding firms are characteristic of too-big-to-fail.

The implications of our empirical results are as follows. For investors, our comparison of liquidity risks among the domestic banks, financial holding, insurance, and securities subsectors can serve as available guidance in constructing safe and profitable investment portfolios. For financial institutions and regulatory authorities, our model provides reasonable tools for measuring different types of liquidity risk. The Amihud index can serve as a better measurement of systemic liquidity risk, and liquidity discount is predictive in firm-specific liquidity risk. For financial institution regulators, the method proposed here is easy to calculate the systemic risk in the financial system and their specific liquidity risk based on their data of asset and debt values. Moreover, our results show the causality relationship between the liquidity risk indices and macroeconomic variables. Accordingly, policy makers can design specific financial policies to control systemic risks in the financial markets. Furthermore, we provide evidence concerning the influence and dependence of firm-specific liquidity risk among the financial subsectors. Therefore, we suggest that regulatory authorities can adopt the vector autoregression model used in this paper to monitor the liquidity healthiness of individual financial institutions and stabilize the liquidity risk of the entire financial system.

Appendix A

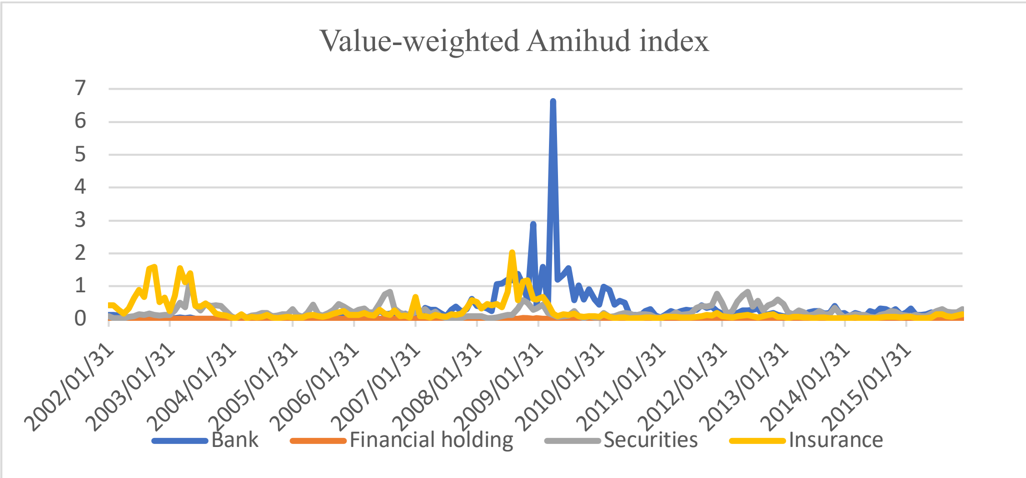

Figure A1A

Time-series monthly market value-weighted Amihud index of financial subsectors

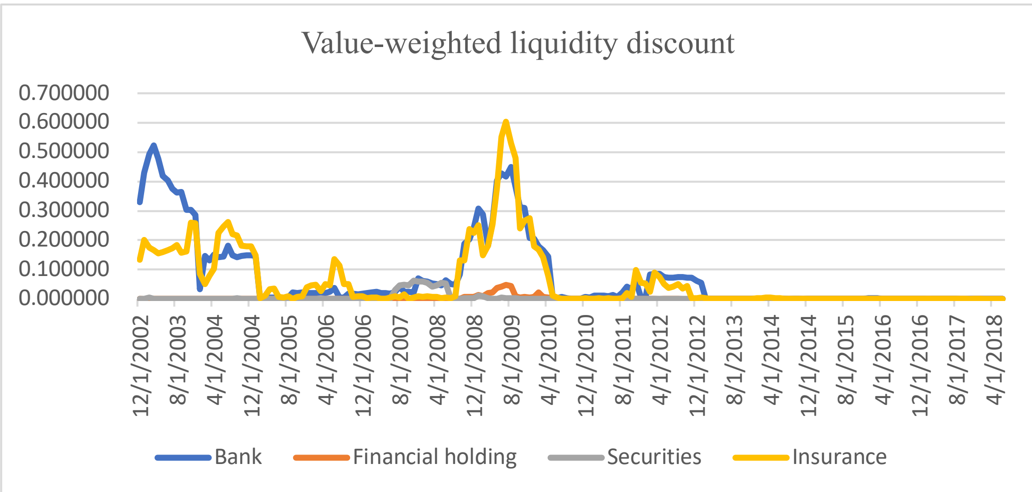

Figure A1B

Time-series monthly market value-weighted liquidity discount of financial subsectors

Figures A1A and A1B describe the time-series of monthly market value-weighted liquidity risk for the financial subsectors in Taiwan. The financial subsectors include the domestic bank, financial holding, insurance, and securities subsectors. The liquidity risk is measured by the Amihud index and liquidity discount. We calculate the liquidity risk proxy for each individual financial institution listed in the TWSE. The monthly liquidity risk for a financial subsector is the market value-weighted average of liquidity risk for each individual stock in this specific subsector over the sample period between December 2002 and June 2018.

Appendix B

Table A1

Impulse response of liquidity risk to market returns

Panel A	Response of Amihud index	
Period	Amihud index response	95% confidence interval
1	-0.0106	(-0.0143, -0.0070)
2	-0.0080	(-0.0125, -0.0036)
3	-0.0033	(-0.0079, 0.0014)
4	-0.0026	(-0.0074, 0.0022)
5	-0.0011	(-0.0061, 0.0038)
6	-0.0020	(-0.0054, 0.0050)
7	-0.0040	(-0.0091, 0.0011)
8	-0.0020	(-0.0063, 0.0023)
9	-0.0010	(-0.0047, 0.0027)
10	-0.0010	(-0.0042, 0.0022)
Panel B	Response of liquidity discount	
Period	Liquidity discount response	95% confidence interval
1	0.0003	(-0.0002, 0.0008)
2	0.0006	(-0.0001, 0.0013)
3	0.0000	(-0.0008, 0.0008)

4	0.0004	(-0.0005, 0.0012)
5	-0.0004	(-0.0012, 0.0005)
6	-0.0007	(-0.0016, 0.0002)
7	-0.0011	(-0.0021, -0.0001)
8	-0.0016	(-0.0027, -0.0005)
9	-0.0016	(-0.0027, -0.0005)
10	-0.0016	(-0.0027, -0.0006)

Table A1 describes the impulse response of liquidity risk to the changes in market returns. The liquidity risk is measured by the Amihud index (Panel A) and liquidity discount (Panel B). This table presents the response of liquidity risk during the following 10 periods when the shock of market returns occurs in period 0. The 95% confidence interval is shown in the table. The sample period is between January 2003 and June 2018.

Table A2

Impulse response of liquidity risk to market volatility

Panel A	Response of Amihud index	
Period	Amihud index response	95% confidence interval
1	0.1384	(0.0832, 0.1936)
2	0.0783	(0.0211, 0.1356)
3	0.0853	(0.0303, 0.1403)
4	0.0743	(0.0181, 0.1305)
5	0.0652	(0.0101, 0.1203)
6	0.0569	(0.0044, 0.1094)
7	0.0491	(-0.0003, 0.0985)
8	0.0422	(-0.0038, 0.0882)
9	0.0362	(-0.0063, 0.0787)
10	0.0309	(-0.0081, 0.0700)
Panel B	Response of liquidity discount	
Period	Liquidity discount response	95% confidence interval
1	0.0074	(0.0009, 0.0138)
2	0.0155	(0.0068, 0.0242)

3	0.0222	(0.0129, 0.0316)
4	0.0258	(0.0149, 0.0367)
5	0.0277	(0.0157, 0.0397)
6	0.0283	(0.0155, 0.0410)
7	0.0279	(0.0148, 0.0411)
8	0.027	(0.0136, 0.0404)
9	0.0258	(0.0123, 0.0393)
10	0.0244	(0.0110, 0.0379)

Table A2 describes the impulse response of liquidity risk to the changes in market volatility. The liquidity risk is measured by the Amihud index (Panel A) and liquidity discount (Panel B). This table presents the response of liquidity risk during the following 10 periods when the shock of market volatility occurs in period 0. The 95% confidence interval is shown in the table. The sample period is between January 2003 and June 2018.

Table A3

Impulse response of liquidity risk to short-term interest rate

Panel A	Response of Amihud index	
Period	Amihud index response	95% confidence interval
1	-0.0872	(-0.2880, 0.1135)
2	0.1266	(-0.1013, 0.3545)
3	0.2871	(0.0433, 0.5309)
4	0.1284	(-0.1179, 0.3748)
5	0.1192	(-0.0467, 0.2851)
6	0.0849	(-0.0751, 0.2450)
7	0.1037	(-0.0036, 0.2439)
8	0.0833	(-0.0402, 0.2067)
9	0.0661	(-0.0352, 0.1673)
10	0.0458	(-0.0353, 0.1269)
Panel B	Response of liquidity discount	
Period	Liquidity discount response	95% confidence interval
1	-0.0193	(-0.0424, 0.0038)

2	-0.0142	(-0.0315, 0.0031)
3	-0.0142	(-0.0314, 0.0029)
4	-0.0133	(-0.0294, 0.0028)
5	-0.0126	(-0.0278, 0.0027)
6	-0.0119	(-0.0263, 0.0026)
7	-0.0112	(-0.0250, 0.0026)
8	-0.0106	(-0.0237, 0.0025)
9	-0.0100	(-0.0224, 0.0025)
10	-0.0094	(-0.0213, 0.0025)

Table A3 describes the impulse response of liquidity risk to the changes in short-term interest rate. The liquidity risk is measured by the Amihud index (Panel A) and liquidity discount (Panel B). This table presents the response of liquidity risk during the following 10 periods when the shock of short-term interest rate occurs in period 0. The 95% confidence interval is shown in the table. The sample period is between January 2003 and June 2018.

Table A4

Impulse response of liquidity risk to interbank call-loan rate

Panel A	Response of Amihud index	
Period	Amihud index response	95% confidence interval
1	0.0227	(-0.2514, 0.2968)
2	-0.0353	(-0.3423, 0.2717)
3	0.0113	(-0.2859, 0.3086)
4	0.0173	(-0.2474, 0.2819)
5	0.0131	(-0.2021, 0.2283)
6	0.0109	(-0.1699, 0.1916)
7	0.0090	(-0.1425, 0.1604)
8	0.0076	(-0.1188, 0.1340)
9	0.0064	(-0.0982, 0.1109)
10	0.0053	(-0.0809, 0.0914)
Panel B	Response of liquidity discount	
Period	Liquidity discount response	95% confidence interval

1	-0.0179	(-0.0048, 0.0121)
2	-0.0206	(-0.0616, 0.0203)
3	0.0007	(-0.0482, 0.0497)
4	-0.0409	(-0.0954, 0.0136)
5	-0.0946	(-0.1528, -0.0365)
6	-0.1079	(-0.1694, -0.0465)
7	-0.1131	(-0.1756, -0.0507)
8	-0.1107	(-0.1730, -0.0484)
9	-0.0974	(-0.1592, -0.0356)
10	-0.0861	(-0.1474, -0.0248)

Table A4 describes the impulse response of liquidity risk to the changes in interbank call-loan rate. The liquidity risk is measured by the Amihud index (Panel A) and liquidity discount (Panel B). This table presents the response of liquidity risk during the following 10 periods when the shock of interbank call-loan rate occurs in period 0. The 95% confidence interval is shown in the table. The sample period is between January 2003 and June 2018.

Table A5

Impulse response of liquidity risk to yield spread

Panel A	Response of Amihud index	
Period	Amihud index response	95% confidence interval
1	0.1143	(-0.0935, 0.3221)
2	-0.0468	(-0.2821, 0.1884)
3	0.0746	(-0.1753, 0.3246)
4	0.0254	(-0.1236, 0.1743)
5	0.0376	(-0.0819, 0.1571)
6	0.0153	(-0.0760, 0.1067)
7	0.0224	(-0.0630, 0.1079)
8	0.0135	(-0.0561, 0.0830)
9	0.0148	(-0.0482, 0.0777)
10	0.0106	(-0.0413, 0.0624)
Panel B	Response of liquidity discount	

Period	Liquidity discount response	95% confidence interval
1	0.0249	(0.0009, 0.0488)
2	0.0313	(-0.0016, 0.0643)
3	0.0596	(0.0204, 0.0987)
4	0.0800	(0.0358, 0.1243)
5	0.0744	(0.0313, 0.1175)
6	0.0662	(0.0237, 0.1087)
7	0.0620	(0.0193, 0.1046)
8	0.0605	(0.0174, 0.1036)
9	0.0574	(0.0156, 0.0991)
10	0.0534	(0.0132, 0.0936)

Table A5 describes the impulse response of liquidity risk to the changes in yield spread. The liquidity risk is measured by the Amihud index (Panel A) and liquidity discount (Panel B). This table presents the response of liquidity risk during the following 10 periods when the shock of yield spread occurs in period 0. The 95% confidence interval is shown in the table. The sample period is between January 2003 and June 2018.

Table A6

Impulse response of liquidity risk to VIX

Panel A	Response of Amihud index	
Period	Amihud index response	95% confidence interval
1	0.0132	(0.0068, 0.0197)
2	0.0035	(-0.0041, 0.0112
3	0.0045	(-0.0036, 0.0127)
4	0.0084	(0.0012, 0.0157)
5	0.0052	(-0.0019, 0.0122)
6	0.0044	(-0.0030, 0.0118)
7	0.0059	(-0.0018, 0.0135)
8	0.0045	(-0.0033, 0.0122)
9	0.0038	(-0.0039, 0.0116)
10	0.0043	(-0.0035, 0.0120)

Panel B	Response of liquidity discount	
Period	Liquidity discount response	95% confidence interval
1	0.0006	(0.0001, 0.0012)
2	0.0011	(0.0002, 0.0019)
3	0.0019	(0.0009, 0.0029)
4	0.0021	(0.0010, 0.0033)
5	0.0020	(0.0008, 0.0032)
6	0.0020	(0.0008, 0.0033)
7	0.0028	(0.0015, 0.0041)
8	0.0035	(0.0021, 0.0048)
9	0.0037	(0.0023, 0.0052)
10	0.0043	(0.0027, 0.0058)

Table A6 describes the impulse response of liquidity risk to the changes in Taiwan VIX. The liquidity risk is measured by the Amihud index (Panel A) and liquidity discount (Panel B). This table presents the response of liquidity risk during the following 10 periods when the shock of Taiwan VIX occurs in period 0. The 95% confidence interval is shown in the table. The sample period is between December 2006 and June 2018.

Table A7

Impulse response of liquidity risk to consumer confidence

Panel A	Response of Amihud index	
Period	Amihud index response	95% confidence interval
1	-0.0045	(-0.0078, -0.0012)
2	-0.0029	(-0.0052, -0.0006)
3	-0.0021	(-0.0037, -0.0004)
4	-0.0015	(-0.0027, -0.0002)
5	-0.0010	(-0.0020, -0.0001)
6	-0.0007	(-0.0015, 0.00001)
7	-0.0005	(-0.0011, 0.00006)
8	-0.0004	(-0.0008, 0.00008)
9	-0.0003	(-0.0006, 0.00009)

10	-0.0002	(-0.0005, 0.00008)
Panel B	Response of liquidity discount	
Period	Liquidity discount response	95% confidence interval
1	0.0003	(-0.0001, 0.0006)
2	0.0003	(-0.0002, 0.0008)
3	-0.00008	(-0.0007, 0.0006)
4	-0.00011	(-0.0007, 0.0005)
5	-0.00014	(-0.0008, 0.0005)
6	-0.00012	(-0.0007, 0.0004)
7	-0.00013	(-0.0007, 0.0004)
8	-0.00011	(-0.0006, 0.0004)
9	-0.00010	(-0.0005, 0.0003)
10	-0.00009	(-0.0005, 0.0003)

Table A7 describes the impulse response of liquidity risk to the changes in consumer confidence. The liquidity risk is measured by the Amihud index (Panel A) and liquidity discount (Panel B). This table presents the response of liquidity risk during the following 10 periods when the shock of consumer confidence occurs in period 0. The 95% confidence interval is shown in the table. The sample period is between January 2003 and June 2018.

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