Theoretical Economics Letters, 2021, 11, 522-539
https://www.scirp.org/journal/tel
ISSN Online: 2162-2086
ISSN Print: 2162-2078

Systemic Risk between Carry Trade and Stock Market

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How to cite this paper: Yang, H.-F., Liu, C.-L., & Liu, H.-M. (2021). Systemic Risk between Carry Trade and Stock Market. *Theoretical Economics Letters, 11,* 522-539.
https://doi.org/10.4236/tel.2021.113035

Received: April 22, 2021
Accepted: June 19, 2021
Published: June 22, 2021

Abstract

In this paper, we exploit the impacts of extreme asset prices (high-low ranges) on multiple horizons and use a conditional value-at-risk (*CoVaR*) model to evaluate the degree of risk contagion between stock markets and carry-trade markets. We associate the systemic risk of a financial market with conditions in related markets during periods of crisis. The model can be empirically applied to diversified portfolio strategies, but the systemic risk involved is conditional on closely related financial markets. Most notably, our evidence shows that this propagating effect was significant during the 2000-2001 tech bubble and 2007-2009 global financial crisis periods and not reveal negligible risk spillover effect during the 2015-2016 Brexit (British exit from European Union) and potential possible Grexit (Greece's potential exit from European Union) periods. Moreover, the *CoVaR* value is shown to be a strong alternative indicator of risk management and asset allocation, especially for investments in carry-trade and stock markets.

Keywords

High-Low Range, Carry-Trade, Systemic Risk, *CoVaR*, Risk Contagion

1. Introduction

The investment strategies of financial market usually balance risk and rewards by adjusting asset allocation that is highly related to the investment holding period. For example, Lan et al. (2018) suggest that stocks held primarily by long-horizon funds outperform stocks held mainly by short-horizon funds. Cella et al. (2013) suggest that investors with short horizons amplify the effects of market-wide negative shocks by demanding capital liquidity. Beber et al. (2021) also show that risk premiums in financial markets depend on variations in holding horizons and allocation of assets. Therefore, these results highlight the importance of the investment horizon in determining risk exposure and the asset pricing effects of liquidity (Beber et al., 2021; Kamara et al., 2016).

The field of studies in ordinary volatility spillover between carry-trade and stock markets has been explored previously, in addition, a variety of interpretations of risk measures have been developed (Cassino & Wallis, 2010; Melvin & Taylor, 2009). Some studies adopt vector autoregressive models and bivariate EGARCH models to determine whether there is a lead-lag causal relationship between returns from carry-trade and stock markets (Tse & Zhao, 2012; Lee & Chang, 2013; Fung et al., 2013). While these studies have effectively detected volatility spillover, their findings do not address the tail risk conditional on extreme events in other markets. To advance our theoretical understanding about conditional tail risk on extreme events in other financial markets, we adopt a $CoVaR$ model proposed by Adrian & Brunnermerier (2016) to explore systemic contagion between carry-trade portfolios and stock markets. The $CoVaR$ is a methodology using quantile regression for identifying extreme events without the restrictions of distributional assumption. Furthermore, it focuses on the tail risk conditional on extreme distress in other markets in excess of ordinary volatility-risk spillover. Therefore, to explore the effect of different measures of asset price and varied horizons on risk spillover, the systemic contagions between carry-trade and stock markets (i.e., U.S. and European) is measured using a $CoVaR$ model in different periods (2000-2001 dot-com bubble, 2002-2006 non-crisis, 2007-2009 credit crisis, 2010-2012 European debt crises, 2013-2014 non-crisis, 2015-2016 Brexit and potential possible Grexit periods).

Our empirical results contribute to the literature in the following ways. First, our study employs a more appropriate approach to evaluate systemic contagions in multicurrency portfolios with varied horizons in carry-trade and stock markets. Second, a risk measure by using H-L Range model (High-Low stock price range) compared with general model (Close-Close stock price range) in both crisis and non-crisis periods. By providing a $CoVaR$ value estimated with extreme asset prices on multiple horizons, this study finds extra evidence to clarify the controversy of financial volatility with these two range-based data in stock markets (Chou et al., 2010). The results suggest that H-L Range model should contain additional information and imply far more uncertain metaphor than general model. Thirdly, an ex-ante analysis of systemic contagion across different markets provides an alternative indicator for investors to understand the manner in which risks spill over across markets over time and how they are interrelated and can be hedged (Ebrahim, 2000; Araç & Yalta, 2015), especially in carry-trade and stock markets.

The remainder of the paper is organized as follows. Section 2 develops the $CoVaR$ model to capture the contagion of systemic risk and introduces the data. Section 3 provides our empirical results, and Section 4 offers our concluding remarks.

2. Literature Review

Considerable literature on currency markets has focused on currency-specific strategies. Such currency portfolios have become a popular speculative strategy for pursuing higher-yielding assets. High-yielding currencies are known to "go up by the stairs and down by the elevator," implying that the carry trade has substantial crash risk spillover from external markets (Dumas & Solnik, 1995; De Santis & Gerard, 1997; Darvas, 2009). For instance, carry trades experienced large losses during the global financial crisis of the late 2000s, with the unwinding of many carry trades overlapping the drop in U.S. stock markets (Melvin & Taylor, 2009; Cassino & Wallis, 2010). Garnham (2009) note that when global stock markets rebounded, carry-trade profits began to show a returning trend. Melvin and Taylor (2009) also observe that the volatility in currency markets was accompanied with an increase in the risk of other asset classes and its time-varying risk exposure in times of greater uncertainty (Christiansen et al., 2011).

Previous studies have indicated that carry-trade portfolios are profitable but usually accompanied by uncertain market risk (Darvas, 2009; Gyntelberg & Remolona, 2007; Rendon, 2011). For instance, Fung et al. (2013) find that volatility creates spillover effects between the carry-trade and stock markets. The mechanism through which carry-trade and stock markets are highly related is that funds move to global high-yielding assets (Brunnermeier & Pedersen, 2009; Fong, 2010; Fernández-Avilés et al., 2012; Alemany et al., 2015). When there are substantial losses in stock markets, capital outflows from currency portfolios are inevitable. Hartmann et al. (2004) and Brunnermeier et al. (2009) note that volatility risks from stock market downturns lead to higher risks in carry-trade markets. The investment currency therefore appreciates against the funding currency due to a demand and supply imbalance (Ranaldo & Soderlind, 2010; Tse & Zhao, 2012). By contrast, except for the risk spillover from stock market downturns, as capital flows into high-yielding stock markets, the value of the currencies of countries that are net capital recipients' increases, leading to more volatile carry-trade portfolios (Fung et al., 2013). Thus, capital flows contribute to closer links between carry-trade and stock markets that trade a range of different currencies, causing systemic risk contagion (Boudreault et al., 2014). Therefore, apart from the uncertainty of markets risk in exchange rate movements (Darvas, 2009; Rendon, 2011), there are some issues need to be further considered including whether the asset allocation of currency portfolios with multiple horizons can take on different burdens of risk spillover effects, whether to use traditional risk estimators can help investors or institutions to adjusting their asset positions appropriately, and whether adopting diversified carry-trade strategies can be profitable and reduce risk contagion from other financial markets simultaneously. These questions could further deepen the understanding of the issue of uncertainty of markets risk.

The way to calculate stock return usually uses the data of close-to-close asset price, however, these data do not account for price fluctuation, especially close to the closing price on two trading days (Chou et al., 2010). Beckers (1983) shows that the daily price range contains important information on stock price variability. That the high-low range is likely to provide a more reliable indication of stock price variability than close-to-close change has already been theoretically shown, as it is easier to calculate asset price volatility with high and low ranges. A high-low estimator is not ad hoc and can be applied to a variety of markets with different market structures (Corwin & Schultz, 2012). Moreover, a range-based measure of financial market risk is shown to be theoretically, numerically, and empirically superior to other measures of volatility (Blau & Whitby, 2017). This study extends this line of literature by adopting asset price extremes (high and low ranges) as the scale of asset return variability to measure systemic contagions from other major stock markets. Our model constructs a multicurrency portfolio (high-low interest rate strategy) with multiple horizons. Although the related literature suggests that the risk contagions between stock and carry-trade markets are bilateral (Fung et al., 2013; Liu & Yang, 2017), the contagion from major stock markets is more influential than that from carry-trade markets (Liu & Yang, 2017). Our study therefore focuses on a unidirectional systemic risk effect from these major stock markets (U.S. and European).

3. Research Methodology

3.1. Data and Variables

To measure risk-propagated effects between stock markets and carry-trade markets, this study uses the most liquid currencies from developed countries: Australian dollar (AUD), Canadian dollar (CAD), Swiss franc (CHF), Danish krone (DKK), Euro (EUR), British pound (GBP), Japanese yen (JPY), Norwegian krone (NOK), New Zealand dollar (NZD), Swedish krona (SEK), and US dollar (USD). Although Jurek (2014) uses interest rate spreads as an alternative portfolio weight, carry-trade returns may vary substantially between different base currencies. We address the multicurrency position on carry-trade portfolios with multiple horizons and follow previous studies in using equally weighted baskets with USD as the base currency to allocate carry-trade portfolios (Burnside et al., 2011). An equally weighted carry-trade portfolio is designed that allocates a long position (investing) to the currencies with the highest interest rates (high-yielding currencies) and a short position (funding) to the currencies with the lowest interest rates (low-yielding currencies) with different holding frequencies (quarterly, monthly, weekly, and daily) from January 1999 through December 2016. We collect the daily nominal exchange rates to the US dollar (USD) and three-month interbank interest rates from the DataStream database.

Following previous studies, we calculate carry-trade returns using a high-minus-low strategy, constructing a long position in currencies with higher interest rates and a short position in other currency with lower interest rates (Brunnermeier et al., 2009; Christiansen et al., 2011; Lustig et al., 2011; Tse & Zhao, 2012). The carry-trade return of investing in a foreign currency by borrowing other currencies are constructed as $R_t^c \equiv \left(i_{t-1}^* - i_{t-1}\right) - \Delta f_t$, where f_t is the logarithm of the nominal exchange rate (in units of foreign currency per dollar), and $\Delta f_t \equiv f_t - f_{t-1}$ is the depreciation of the foreign currency; i_{t-1} is the logarithm of the U.S. interest rate at time $t-1$, and i_{t-1}^* is the logarithm of the foreign interest rate. R_t^c is the abnormal return for a carry-trade strategy of investing in a foreign currency and funding it through the other currency.

The one-pair currency portfolios are denoted as $CT^{1\times1}$ (one long, one short). To diversify the currency portfolio, this study encompasses multiple currencies in asset allocation including $CT^{2\times2}$ (two long, two short), and $CT^{3\times3}$ (three long, three short). The carry-trade portfolio allocates a long position in the *j* currencies (*j* = 1, 2, and 3) with the highest interest rates at the beginning of each trading date and a short position in the remaining *k* (*k* = 1, 2 and 3) currencies with the lowest interest rates, where each currency is weighted equally and carry-trade returns rely on these most liquid currencies from developed countries.

3.2. Model

A useful model for measuring systemic risk is the conditional value-at-risk (*CoVaR*) and $\Delta CoVaR$ measurement proposed by Adrian & Brunnermeier (2016). The model is defined as the difference between *VaR* conditional on the institution being in a normal state and *VaR* conditional on the institution being in distress. Specifically, capture the ex-ante risk contagion effect for reducing problems from model of ex-post realized losses (Saunders & Allen, 2002). To measure downside risk, the unconditional *VaR* of financial market *i* at the *q* percentile is defined as $\Pr\left(X^i \le VaR_q^i\right) = q$. The *VaR* of market *i*, VaR_q^i, typically a negative number, is determined by the asset return value of market *i* (X^i) and quantile *q*. To measure the downside risk caused by risk contagion, $CoVaR_q^{j|C\left(x^i\right)}$ is the *VaR* of market *j* and is conditional on market *i*'s event $C\left(X^i\right)$; that is, when market *i*'s asset-return attains its VaR value { $X^i = VaR_q^i$ },

$$\Pr\left(X^j \le CoVaR_q^{j|C\left(X^i\right)} \mid C\left(X^i\right)\right) = q$$

Market *i*'s contribution to the risk of market *j* can be further defined as: $\Delta CoVaR_q^{j|i} = CoVaR_q^{j|X^i = VaR_q^i} - CoVaR_q^{j|X^i = Median^i}$, where $CoVaR_q^{j|X^i = Median^i}$ denotes the *VaR* of market *j*'s asset returns when market *i*'s returns are normally distributed (e.g. 50% percentile), and $CoVaR_q^{j|i}$ is market *j*'s *VaR* when market *i*'s returns are in a distressed or extremely poor state, such as during a crisis period. Moreover, $\Delta CoVaR$ measure of systemic risk indicates the difference between the *VaR* of market *j* conditional on the distress of another market *i* and the *VaR* of market *j* conditional on the normal state of market *i*. This *CoVaR* quantifies the extent to which a financial market adds to another market's risk, and the estimate of $\Delta CoVaR$ are based on *CoVaR* model, where market *i*'s *Co-*

VaR relative to the system is define as the VaR of the market $j's$ asset returns conditional on market i being in a particular state.

We employ the asymmetric model proposed by Lopez-Espinosa et al. (2012) and measure the predicted value from the quantile regression by taking the VaR of a carry-trade portfolio conditional on the VaR of the stock market. Within the quantile regression framework, our time-varying $CoVaR$ can now be formally specified as:

$$CT_t^{CT|R} = \alpha_{t,q}^{i|s} + \beta_{1,q}^{i|s} R_t^s I_{\left(R_t^S<0\right)} + \beta_{2,q}^{i|s} R_t^s I_{\left(R_t^S\geq 0\right)} + \beta_{3,q}^{i|s} CT_{t-1}^i + \mathbf{M}_{t-1}\gamma_q^{i|s} + \varepsilon_{t,q}^{i|s}, \quad (1)$$

$$CoVaR_t^{CT|R}(q) = C\hat{T}_t^{CT|R}(q), \quad (2)$$

where $I_{(.)}$ is an indicator function taking a value of one if the condition in the subscript is true and zero otherwise (Lopez-Espinosa et al., 2012), CT_t^i is the return of currency portfolios (one long, one short; two long, two short; three long, three short). Following previous studies, **M** variables are the common risk factors that affect interest rate and currency risk, such as TED, VIX GOLD, and OIL (Saleem & Vaihekoski, 2010; Yang et al., 2014). R_t^s denotes the H-L Range and C_t-C_{t-1} Range (Close-Close) stock returns of the U.S. or Eurozone markets. The range of the logarithm of prices is defined as the difference between the daily highest and lowest price on a logarithmic scale. H-L Range for stock indices are calculated as $100\times\log\left(p_t^{\text{high}}/p_t^{\text{low}}\right)$, where the closing price is higher than the opening price, or $100\times\log\left(p_t^{\text{low}}/p_t^{\text{high}}\right)$, where the closing price is lower than the opening price, and C_t-C_{t-1} Range returns for stock indices are calculated by $100\times\log\left(p_t^{\text{close}}/p_{t-1}^{\text{close}}\right)$, respectively.

Related studies indicate that the volatility index (VIX) is useful to measure volatility risk and market uncertainty, particularly during financial crises (Collin-Dufresne et al., 2001). For instance, Clarida et al. (2009) find a strong relationship between the excess returns of a carry trade and volatility. Similarly, Pan and Singleton (2008) find that the VIX index and risk premiums in sovereign credit default swaps are closely related. Therefore, since our study covers both U.S. and European stock markets, additional volatility indices apart from the VIX variable are employed in our dataset, such as the V2TX index, which is based on 50 real-time EURO STOXX option prices. Because the TED spread can serve as an illiquidity measure (Brunnermeier et al., 2009) and is considered a useful index of funding in carry-trades market (Menkhoff et al., 2012), we also incorporated it as a proxy for funding liquidity. The data on the TED spread is defined as the interest rate difference between three-month London interbank offered rates (LIBOR) and three-month Treasury bills obtained from Federal Reserve Board's H.15 Releases and Datastream databases.

After risk spillover from stock markets to carry-trade markets was quantified, the systemic risk was further measured by the difference in $CoVaR$ values between normal periods (with a 50% critical value of VaR) and distressed periods with an extreme q% critical value of VaR (q = 1% and q = 5%). The systemic risk contagion from the stock markets is measured as follows:

$$\Delta CoVaR_t^{CT|S}(q) = CoVaR_t^{CT|S}(q) - CoVaR_t^{CT|S}(50\%), \quad (3)$$

4. Empirical Results

In this study, we assess an equally-weighted portfolio of ten developed-market currencies that yield an excess return that encompasses a long position of one currency with a short position of another currency (include extreme asset prices of one long, one short; two long, two short; and three long, three short currency portfolios), with a series of higher kurtosis with multicurrency portfolios as shown in Table 1. This evidence is consistent with the literature, indicating that a fat-tail distribution of asset prices is closely related to market liquidity risk. Moreover, two kind of stock returns, the H-L Range (using the highest and lowest prices from U.S and European stock markets) and the C_t-C_{t-1} Range (using the closing prices from U.S and European stock markets) are calculated to estimate the time varying volatility needed in easting value-at-risk (VaR). Main market risk factors, such as the European volatility index (V2TX) for the euro market, and Europe's leading blue-chip index (STOXX) for the euro, are not available before January 1, 1999. Due to limited data availability, our study encompasses carry-trade portfolios, stock returns, and market risk factors for the period spanning 1999-2016, when available (Table 1).

Table 1. Descriptive summary.

Range Model	$CT^{1\times1}$	$CT^{2\times2}$	$CT^{3\times3}$	S & P		STOXX		TED	VIX	V2TX	GOLD	OIL
				C_t-C_{t-1}	H-L	C_t-C_{t-1}	H-L					
Mean	6.04	9.52	11.43	0.01	−0.01	0.00	−0.03	0.46	20.73	25.20	0.00	0.00
Median	5.89	9.35	10.78	0.02	0.19	0.01	0.21	0.31	18.97	23.18	0.00	0.00
Maximum	8.65	13.46	17.15	4.53	4.74	5.62	4.14	4.51	80.86	87.51	0.08	0.29
Minimum	3.15	5.38	6.79	−4.11	−4.73	−3.91	−5.17	0.09	9.89	11.60	−0.09	−0.16
Std. Dev.	1.02	1.69	2.07	0.56	0.75	0.68	0.92	0.44	8.63	9.56	0.01	0.03
Skewness	0.37	0.32	0.50	−0.21	−0.27	−0.05	−0.16	3.36	2.05	1.62	0.01	0.41
Kurtosis	1.86	1.90	1.98	10.32	6.07	7.78	3.86	19.55	9.97	6.55	8.43	10.46
No. of Obs.	4227	4227	4227	4227	4098	4227	4098	4227	4227	4227	4227	4227

Note: the carry-trade portfolio $CT^{1\times1}$ is designed for a long position in the currency with the highest interest rate, combined with a short position for the currency with the lowest interest rate. $CT^{2\times2}$ encompasses a long position for two currencies with a short position for another two currencies, while $CT^{3\times3}$ represents a long position for three currencies with a short position for another three currencies. H-L Ranges (using the highest, lowest, opening, and closing prices) and C_t-C_{t-1} Range (using the opening and closing prices) for stock indices are calculated by $100\times\log\left(p_t^{high}/p_t^{low}\right)$ or $100\times\log\left(p_t^{low}/p_t^{high}\right)$ where the closing price is less than the opening price, and $100\times\log\left(p_t^{close}/p_{t-1}^{close}\right)$, respectively. The TED spread is the difference between the three-month LIBOR Eurodollar rate and the three-month U.S. Treasury bill rate. VIX mean the option-implied volatility index acquired from the Chicago Board Option Exchange. V2TX means the Euro stock volatility index; GOLD means the returns of the gold price index acquired from Chicago Board Option Exchange; OIL means the returns of West Texas Intermediate crude oil price. These evidences in Table 1 show the return value of the major stock markets in the United States and Europe, and this paper use two kinds of models (H-L & C-C) to calculate stock return. In the carry-trade market, we use multi-currency to calculate portfolio profit. Moreover, the primary market variables also involved in this study (during 1999-2016).

In addition, Table 1 shows that the return value of the major stock markets in the United States and Europe was between 5.62 and −5.17, indicating that changes in the stock market are greatly affected by external market factors. This paper uses the high-low model to calculate stock returns, which is different from the return value calculated using the closing price model, indicating that there appears to be hidden information that has not been disclosed. Besides, in the carry-trade market, although the multi-currency investment will bring higher returns, the difference in profit (maximum-minimum) will increase with the diversification of currency investment portfolios, indicating that there is still a risk of diversified portfolio. Moreover, the volatility index of the US and European stock markets were between 87.51 and 9.89, indicating that there are potential risks and uncertainties in the stock market during this study period.

The use of *CoVaR* model based on range data is similarly as the heterogeneous autoregressive quantile regression model (HAR-QREG model) can capture the shapes of the conditional return distribution and isolate the effect from short-, medium-, and long-term volatility (Haugom et al., 2016). Our empirical analysis is consistent with the risk contagions that were prevalent among global financial markets and varied between different periods of time. For example, Brunnermeier & Pedersen (2009) reveal that market liquidity and funding illiquidity are connected and their co-movement is positively associated with volatility risk. The *CoVaR* model is particularly useful for capturing systemic risk contagion between different financial sectors (Adrian & Brunnermeier, 2016). The magnitude of the downside risk of a carry-trade portfolio is propagated from a stock market and is in excess of $q\%$ *VaR* when the stock market falls into distress. Moreover, $CoVaR_t^{CT|S}(q\%)$ is greater than the magnitude of contagion during normal periods, $CoVaR_t^{CT|S}(50\%)$, and the difference between the two values, $\Delta CoVaR$, is expected to be negative (Liu & Yang, 2017).

A reasonable inference we draw from the $\Delta CoVaR$ value is that the percentage change in risk conditional on the external financial sector shifting from a normal state toward a severely risky state and the increased magnitude of the $\Delta CoVaR$ measure can be taken as an increase in additional systemic risk contagion incurred from a carry-trade market when the stock market undergoes turbulence (Liu & Yang, 2017). To provide more convincing evidence, we provide the $\Delta CoVaR$ value for different years, covering the dot-com bubble, the 2007-2009 global financial crisis, the Eurozone debt crisis periods, and the Brexit and potential possible Grexit periods (Table 2 and Table 3). Two types of stock returns measures, including H-L Range and C_t-C_{t-1} Range models are considered in this study, and multicurrency allocation is also included for diversified carry-trade portfolios. Moreover, to explore the systemic risk between stock markets and carry-trade markets, the $\Delta CoVaR$ values (1% and 5% quantiles) are estimated using models with different year horizons (from 1999 to 2016) and multiple frequencies (daily, weekly, monthly, and quarterly).

Table 2. Systemic contagion (1%) from U.S. stock markets to carry-trade markets.

Holding Periods Portfolio	Daily Returns			Weekly Returns			Monthly Returns			Quarterly Returns		
	$CT^{1\times1}$	$CT^{2\times2}$	$CT^{3\times3}$	$CT^{1\times1}$	$CT^{2\times2}$	$CT^{3\times3}$	$CT^{1\times1}$	$CT^{2\times2}$	$CT^{3\times3}$	$CT^{1\times1}$	$CT^{2\times2}$	$CT^{3\times3}$
$\Delta CoVaR_t^{CT\|S}$ (1%) Panel A: H-L Range based model												
1999	−1.53	−3.24	−3.39	−2.37	−0.81	−4.97	−16.43	−1.83	−0.26	−2.87	5.48	4.05
2000	−1.49	−3.17	−3.32	−2.31	−0.78	−4.88	−17.38	−1.94	−0.29	−2.76	5.39	4.04
2001	−1.24	−2.64	−2.76	−1.90	−0.64	−4.02	−19.18	−2.18	−0.34	−2.54	5.00	3.76
2002	−1.08	−2.30	−2.41	−1.65	−0.57	−3.42	−15.27	−1.58	−0.16	−1.73	4.09	3.36
2003	−1.09	−2.32	−2.43	−1.66	−0.57	−3.47	−15.38	−1.64	−0.19	−1.74	4.33	3.63
2004	−1.11	−2.37	−2.48	−1.67	−0.58	−3.48	−14.45	−1.46	−0.13	−1.84	4.47	3.72
2005	−1.24	−2.65	−2.77	−1.88	−0.64	−3.94	−16.25	−1.75	−0.22	−1.96	4.74	3.94
2006	−1.30	−2.75	−2.89	−2.00	−0.68	−4.21	−16.19	−1.81	−0.26	−2.17	4.49	3.46
2007	−1.66	−3.51	−3.67	−2.59	−0.88	−5.48	−16.02	−1.74	−0.23	−2.27	4.72	3.65
2008	−2.18	−4.62	−4.81	−3.37	−1.11	−7.26	−22.25	−2.77	−0.56	−3.52	5.94	4.06
2009	−1.35	−2.87	−3.01	−2.12	−0.73	−4.44	−15.41	−1.75	−0.27	−3.98	6.08	3.86
2010	−1.09	−2.32	−2.44	−1.67	−0.57	−3.48	−15.53	−1.64	−0.19	−1.69	3.97	3.26
2011	−1.15	−2.45	−2.57	−1.77	−0.61	−3.70	−15.90	−1.66	−0.18	−1.68	4.38	3.74
2012	−1.20	−2.55	−2.67	−1.83	−0.62	−3.85	−17.18	−1.91	−0.27	−2.09	4.33	3.35
2013	−1.08	−2.31	−2.43	−1.62	−0.56	−3.38	−17.77	−1.91	−0.24	−1.87	4.67	3.93
2014	−1.09	−2.31	−2.43	−1.64	−0.56	−3.46	−18.33	−1.99	−0.26	−1.74	4.37	3.68
2015	−1.13	−2.41	−2.53	−1.73	−0.59	−3.63	−19.36	−2.15	−0.31	−1.85	4.17	3.36
2016	−1.24	−2.64	−2.77	−1.90	−0.65	−3.99	−16.56	−1.83	−0.26	−2.04	4.27	3.32
2000-2001	−1.37	−2.90	−3.04	−2.11	−0.71	−4.45	−18.28	−2.06	−0.31	−2.65	5.19	3.90
2002-2006	−1.16	−2.48	−2.60	−1.77	−0.61	−3.70	−15.51	−1.65	−0.19	−1.89	4.42	3.62
2007-2009	−1.73	−3.67	−3.83	−2.69	−0.91	−5.73	−17.89	−2.09	−0.35	−3.26	5.58	3.86
2010-2012	−1.15	−2.44	−2.56	−1.76	−0.60	−3.68	−16.20	−1.74	−0.22	−1.82	4.23	3.45
2013-2014	−1.09	−2.31	−2.43	−1.63	−0.56	−3.42	−18.05	−1.95	−0.25	−1.81	4.52	3.80
2015-2016	−1.19	−2.52	−2.65	−1.82	−0.62	−3.81	−17.96	−1.99	−0.28	−1.95	4.22	3.34
$\Delta CoVaR_t^{CT\|S}$ (1%) Panel B: C_t-C_{t-1} Range based model												
1999	−1.32	−0.38	−2.42	−0.29	−0.79	−2.66	−1.76	−1.09	−0.73	−4.04	−3.14	−1.61
2000	−1.28	−0.37	−2.34	−0.28	−0.78	−2.63	−1.77	−1.10	−0.74	−6.23	−5.41	−2.84
2001	−1.05	−0.31	−1.93	−0.23	−0.68	−2.27	−1.79	−1.02	−0.80	−5.74	−4.77	−2.48
2002	−0.91	−0.27	−1.67	−0.18	−0.59	−1.95	−1.56	−0.89	−0.70	−4.76	−2.87	−1.37
2003	−0.91	−0.27	−1.68	−0.20	−0.60	−1.99	−1.58	−0.90	−0.71	−5.44	−3.94	−1.99
2004	−0.94	−0.28	−1.72	−0.19	−0.60	−1.99	−1.53	−0.89	−0.68	−5.55	−4.14	−2.10
2005	−1.06	−0.31	−1.94	−0.22	−0.66	−2.20	−1.64	−0.95	−0.72	−5.01	−3.76	−1.91
2006	−1.10	−0.32	−2.02	−0.24	−0.69	−2.32	−1.77	−1.06	−0.76	−7.67	−6.20	−3.21

Continued

2007	−1.44	−0.42	−2.63	−0.31	−0.85	−2.86	−1.86	−1.15	−0.77	−5.85	−4.62	−2.38
2008	−1.90	−0.55	−3.47	−0.44	−1.11	−3.75	−2.33	−1.52	−0.91	−8.99	−8.49	−4.54
2009	−1.17	−0.34	−2.14	−0.26	−0.71	−2.39	−1.88	−1.19	−0.76	−9.08	−8.96	−4.83
2010	−0.92	−0.27	−1.68	−0.19	−0.60	−1.98	−1.63	−0.92	−0.73	−5.92	−3.99	−1.97
2011	−0.97	−0.28	−1.78	−0.19	−0.63	−2.08	−1.66	−0.94	−0.74	−6.14	−4.76	−2.44
2012	−1.01	−0.30	−1.86	−0.22	−0.65	−2.19	−1.66	−0.96	−0.73	−4.48	−2.70	−1.29
2013	−0.91	−0.27	−1.66	−0.18	−0.60	−2.00	−1.51	−0.83	−0.70	−2.68	−1.35	−0.60
2014	−0.90	−0.27	−1.66	−0.18	−0.61	−2.02	−1.60	−0.87	−0.74	−5.34	−3.92	−1.98
2015	−0.94	−0.28	−1.73	−0.17	−0.63	−2.08	−1.71	−0.93	−0.79	−4.00	−2.33	−1.10
2016	−1.06	−0.31	−1.94	−0.23	−0.66	−2.20	−1.73	−1.00	−0.76	−6.86	−5.48	−2.83
2000-2001	−1.17	−0.34	−2.14	−0.25	−0.73	−2.45	−1.78	−1.06	−0.77	−5.98	−5.09	−2.66
2002-2006	−0.98	−0.29	−1.81	−0.21	−0.63	−2.09	−1.62	−0.94	−0.71	−5.69	−4.18	−2.12
2007-2009	−1.50	−0.44	−2.75	−0.34	−0.89	−3.00	−2.02	−1.29	−0.81	−7.97	−7.36	−3.92
2010-2012	−0.97	−0.28	−1.77	−0.20	−0.63	−2.08	−1.65	−0.94	−0.73	−5.51	−3.82	−1.90
2013-2014	−0.90	−0.27	−1.66	−0.18	−0.61	−2.01	−1.56	−0.85	−0.72	−4.01	−2.64	−1.29
2015-2016	−1.00	−0.29	−1.84	−0.20	−0.65	−2.14	−1.72	−0.97	−0.77	−5.43	−3.91	−1.96

Table 3. Systemic contagion (1%) from European stock markets to carry-trade markets.

$\Delta CoVaR_t^{CT\|S}$ (1%) Panel A: H-L Range based Model												
Holding Periods Portfolio	Daily			Weekly			Monthly			Quarterly		
	$CT^{1\times1}$	$CT^{2\times2}$	$CT^{3\times3}$	$CT^{1\times1}$	$CT^{2\times2}$	$CT^{3\times3}$	$CT^{1\times1}$	$CT^{2\times2}$	$CT^{3\times3}$	$CT^{1\times1}$	$CT^{2\times2}$	$CT^{3\times3}$
1999	−1.21	−3.87	−2.63	−2.72	−1.78	−5.26	−16.28	−12.99	−0.78	8.64	−17.09	−13.48
2000	−1.19	−3.81	−2.59	−2.67	−1.77	−5.15	−17.00	−13.50	−0.78	8.20	−16.22	−12.80
2001	−1.05	−3.39	−2.25	−2.32	−1.70	−4.25	−14.59	−11.99	−0.85	7.01	−13.89	−10.97
2002	−0.95	−3.10	−2.03	−2.04	−1.64	−3.52	−11.93	−10.09	−0.82	1.44	−1.58	−0.91
2003	−0.95	−3.11	−2.04	−2.05	−1.63	−3.57	−10.61	−9.03	−0.75	1.84	−2.67	−1.85
2004	−0.97	−3.16	−2.07	−2.07	−1.64	−3.61	−11.63	−9.80	−0.78	2.52	−4.18	−3.09
2005	−1.05	−3.39	−2.25	−2.26	−1.68	−4.09	−12.99	−10.77	−0.80	3.18	−5.52	−4.15
2006	−1.08	−3.47	−2.32	−2.38	−1.71	−4.38	−12.53	−10.23	−0.70	4.62	−8.54	−6.57
2007	−1.28	−4.08	−2.80	−2.90	−1.83	−5.69	−15.08	−12.00	−0.71	5.32	−10.23	−7.99
2008	−1.61	−5.00	−3.53	−3.72	−2.03	−7.75	−23.94	−18.13	−0.72	13.19	−26.86	−21.39
2009	−1.10	−3.55	−2.38	−2.45	−1.72	−4.58	−13.44	−10.61	−0.59	16.32	−33.97	−27.23
2010	−0.95	−3.12	−2.04	−2.05	−1.64	−3.57	−10.86	−9.23	−0.76	1.54	−1.97	−1.27
2011	−0.99	−3.23	−2.13	−2.16	−1.67	−3.82	−12.04	−10.15	−0.81	1.58	−2.19	−1.48
2012	−1.02	−3.30	−2.19	−2.24	−1.68	−4.04	−12.98	−10.72	−0.78	3.91	−6.98	−5.31
2013	−0.95	−3.12	−2.04	−2.07	−1.64	−3.62	−13.77	−11.58	−0.91	2.44	−3.94	−2.88
2014	−0.96	−3.14	−2.05	−2.09	−1.66	−3.65	−13.46	−11.36	−0.91	1.90	−2.90	−2.06

Continued

2015	−0.98	−3.20	−2.10	−2.15	−1.67	−3.80	−13.58	−11.39	−0.89	2.37	−3.81	−2.77
2016	−1.04	−3.37	−2.24	−2.26	−1.68	−4.10	−12.14	−10.07	−0.75	4.12	−7.85	−6.11
2000-2001	−1.12	−3.60	−2.42	−2.50	−1.74	−4.70	−15.79	−12.74	−0.82	7.60	−15.06	−11.88
2002-2006	−1.00	−3.25	−2.14	−2.16	−1.66	−3.84	−11.94	−9.99	−0.77	2.72	−4.50	−3.31
2007-2009	−1.33	−4.21	−2.90	−3.02	−1.86	−6.01	−17.49	−13.58	−0.67	11.61	−23.69	−18.87
2010-2012	−0.99	−3.22	−2.12	−2.15	−1.66	−3.81	−11.96	−10.03	−0.78	2.34	−3.71	−2.69
2013-2014	−0.95	−3.13	−2.05	−2.08	−1.65	−3.63	−13.61	−11.47	−0.91	2.17	−3.42	−2.47
2015-2016	−1.01	−3.29	−2.17	−2.20	−1.68	−3.95	−12.86	−10.73	−0.82	3.24	−5.83	−4.44
$\Delta CoVaR_t^{CT\|S}$ (1%) Panel B: C_t-C_{t-1} Range based Model												
1999	−0.29	−0.35	−1.87	−0.89	−0.26	−5.49	−2.73	−3.39	−1.81	−3.79	−2.84	−1.35
2000	−0.28	−0.35	−1.84	−0.90	−0.27	−5.55	−2.74	−3.38	−1.81	−7.03	−5.15	−2.76
2001	−0.26	−0.32	−1.67	−0.91	−0.27	−5.58	−2.94	−3.61	−1.94	−5.38	−3.99	−2.00
2002	−0.24	−0.29	−1.56	−0.88	−0.26	−5.36	−2.46	−3.06	−1.64	−2.81	−2.23	−0.72
2003	−0.24	−0.29	−1.56	−0.87	−0.25	−5.31	−2.44	−3.01	−1.61	−3.58	−2.72	−1.17
2004	−0.24	−0.30	−1.58	−0.87	−0.25	−5.31	−2.33	−2.90	−1.55	−4.34	−3.25	−1.55
2005	−0.26	−0.32	−1.67	−0.89	−0.26	−5.42	−2.56	−3.16	−1.70	−3.72	−2.78	−1.33
2006	−0.26	−0.32	−1.71	−0.90	−0.26	−5.51	−2.69	−3.31	−1.78	−8.68	−6.40	−3.32
2007	−0.30	−0.37	−1.96	−0.92	−0.27	−5.66	−2.71	−3.37	−1.80	−5.59	−4.15	−2.07
2008	−0.36	−0.44	−2.31	−1.02	−0.30	−6.26	−3.60	−4.41	−2.37	−13.76	−9.96	−5.67
2009	−0.27	−0.33	−1.75	−0.86	−0.25	−5.29	−2.68	−3.30	−1.77	−13.26	−9.62	−5.43
2010	−0.24	−0.29	−1.56	−0.88	−0.26	−5.36	−2.50	−3.10	−1.66	−5.57	−4.18	−1.95
2011	−0.25	−0.30	−1.60	−0.90	−0.26	−5.50	−2.59	−3.22	−1.72	−4.57	−3.41	−1.64
2012	−0.25	−0.31	−1.64	−0.89	−0.26	−5.43	−2.62	−3.21	−1.73	−4.03	−3.08	−1.30
2013	−0.24	−0.29	−1.56	−0.88	−0.26	−5.37	−2.54	−3.13	−1.68	0.79	0.44	0.63
2014	−0.24	−0.29	−1.56	−0.92	−0.27	−5.59	−2.68	−3.30	−1.77	−3.39	−2.57	−1.12
2015	−0.24	−0.30	−1.58	−0.91	−0.27	−5.57	−2.83	−3.47	−1.87	−0.97	−0.90	0.05
2016	−0.26	−0.31	−1.67	−0.88	−0.26	−5.35	−2.67	−3.29	−1.77	−6.29	−4.68	−2.30
2000-2001	−0.27	−0.33	−1.75	−0.91	−0.27	−5.56	−2.84	−3.50	−1.88	−6.20	−4.57	−2.38
2002-2006	−0.25	−0.30	−1.62	−0.88	−0.26	−5.38	−2.50	−3.09	−1.65	−4.63	−3.48	−1.62
2007-2009	−0.31	−0.38	−2.01	−0.93	−0.27	−5.74	−3.00	−3.69	−1.98	−10.87	−7.91	−4.39
2010-2012	−0.25	−0.30	−1.60	−0.89	−0.26	−5.43	−2.57	−3.18	−1.70	−4.72	−3.56	−1.63
2013-2014	−0.24	−0.29	−1.56	−0.90	−0.26	−5.48	−2.61	−3.21	−1.72	−1.30	−1.07	−0.24
2015-2016	−0.25	−0.31	−1.63	−0.90	−0.26	−5.46	−2.75	−3.38	−1.82	−3.63	−2.79	−1.12

Note: $CT^{1\times1}$, $CT^{2\times2}$, and $CT^{3\times3}$ indicate that the carry-trade portfolio allocates a long position in the j currencies (j = 1, 2, and 3) with the highest interest rates at the beginning of each trading date and a short position in the remaining k (k = 1, 2, and 3) currencies with the lowest interest rates, where each currency is weighted equally and carry-trade returns rely on these most liquid currencies from developed countries. Moreover, to explore the systemic risk between stock markets and carry-trade markets, the $\Delta CoVaR$ values (1% and 5% quantiles) are estimated using models with different year horizons (from 1999 to 2016, including financial crisis and non-financial crisis periods) and multiple frequencies (daily, weekly, monthly, and quarterly).

Table 2 and **Table 3** provide the empirical results of the analysis with an extreme 1% quantile regression on the systemic contagion from U.S. and European stock markets to carry-trade markets. These evidences are consistent with previous studies indicating that tail risk in carry trade portfolios is related to risk spillover from stock markets and there exist a significant volatility spillover effects between the carry trade and stock markets (Tse & Zhao, 2012; Lee & Chang, 2013; Fung et al., 2013). Moreover, our empirical results can explain that if the leading stock prices declines resulted in investors quit the market or reset their assets position, the whole market or the indexes will go down. The mechanism through which carry trade portfolios and stock markets are highly related is that funds move globally to seek high-yielding assets (Brunnermeier & Pedersen, 2009; Fong, 2010; Fernández-Avilés et al., 2012; Alemany et al., 2015). When there are substantial losses in stock markets, capital outflows was inevitable to currency portfolios. In addition, the volatility risk from stock market downturn incurs higher risk in carry-trade markets (Brunnermeier et al., 2009; Hartmann et al., 2004). The investment currency, therefore, appreciates against the funding currency due to the imbalance of demand and supply (Ranaldo & Soderlind, 2010; Tse & Zhao, 2012). Moreover, our empirical result does coincide with related studies indicating that the $CoVaR$ model can successfully measure the amount of systemic risk contagion between different markets (Adrian & Brunnermeier, 2016) and is easily comparable with the risk impacts from external markets obtained using the $\Delta CoVaR$ values (Yang et al., 2014). The magnitude of $\Delta CoVaR$ values reveals clear differences between using H-L Range models and using C_t-C_{t-1} Range (ordinal close-to-close stock prices) models. Especially compared with other stable periods, our results show that the $\Delta CoVaR$ values are excessively large during financial crises, including the dot-com bubble in 2000-2001, and the U.S. credit crisis during 2007-2009. In addition, the $\Delta CoVaR$ values calculated with the data of Brexit and potential possible Grexit periods implicate that risk contagions between different markets cannot be disregarded during 2015-2016. Since Gregori & Sacchi (2019) showed that increased intensity of Grexit news contributed to affect other euro area countries' sovereign bond yields on Grexit between December 2014 and October 2015. This analyzed on potential possible Grexit and financial market activity and revealed a consistent result with related studies provided that between media and financial market activity exist a significant correlation (Engelberg & Parsons, 2011; Peress, 2014; Tetlock, 2007). In additional, Bouoiyour and Selmi (2019) provided that the great uncertainty over Brexit generates significant volatility spillovers of Credit Default Swaps (CDSs) across the UK and European,and find that the CDS spreads with the growing attention given to Brexit, reaching its highest level in the day relative to the announcement of Brexit (i.e., June 23rd, 2016).This spread of the damage done by Grexit and Brexit possibly favored a widespread anxiety and bring different impacts on traders and investors. We therefor infer these spread effects are result in ΔCoVaR value in 2015-2016 are not less than the ones during non-crisis periods and Eurozone debt crisis periods.

Furthermore, the magnitude of the $\Delta CoVaR$ value calculated with a multicurrency portfolio over a short-term holding period show a tendency to uptrend (with a more negative value indicating a higher risk contagion) when an external stock market is in distress. This means that more diversified carry-trade strategies suffer greater risk impacts from the stock market. Unlike short-term investment strategies, holding a one-pair currency portfolio (one long, one short) over a long horizon (one month or greater) cannot reduce risk contagion impacts from stock markets, and more diversified currency allocations exhibited downtrends in the $\Delta CoVaR$ value compared with the $\Delta CoVaR$ value of a one-pair currency portfolio held long-term (as shown in **Table 2** and **Table 3**). To an extent, investors adopting currency-diversified strategies spread the risk of asset allocation for investment. For robust testing, we involved European leading stock index to evaluated risk spillover effects. We compare the U.S and European stock sample and our empirical exhibit similar risk impacts using varied carry-trade strategies with a multicurrency portfolio over a multi holding period. This phenomenon suggests that investors, traders, financial regulators, and risk managers should be concerned with currency allocation with varied holding time frequencies and the turbulence of external markets.

We further use a 5% quantile regression for robustness and these results shows that systemic risks measures were also severe during the dot-com bubble, U.S. credit crunch and over the Brexit and Grexit potential periods. Besides, the more multi-currency portfolio subject to the greater the risk in the short-term investment period. Conversely, the use of a multi-currency portfolio can reduce risk in the long-term investment period. The annual distribution of $\Delta CoVaR$ value capturing systemic risks from stock markets for carry-trade markets are similar to the results obtained using an extreme 1% quantile regression model. Although the carry-trade strategies grows diversify the risk contagion is not decline, the strategies with multicurrency allocation is better than a simple pair of currencies held in long-term. Another concern is that the systemic risk to carry-trade markets from the U.S. and European markets continuously increased for investments with diversified currencies in the short-term investment period. This evidence is consistent with the literature, demonstrating that more diversified asset allocation can lead to rapid capital transfer, market instability, and systemic risk spillover while external financial markets are in turmoil (Brunnermeier & Petersen, 2009). In addition, these empirical results suggest that although adopting multiple-currency strategies is usually profitable or spread risk in a carry-trade market, investing with a simple currency allocated holding for short-term horizons is preferable, especially while external stock markets are undergoing turbulence.

Compared with $\Delta CoVaR$ value calculated using H-L Range and C_t-C_{t-1} Range models, we find that these carry-trade portfolios suffer from varied risk effects and significant differences between short-term (a week or less) and long-term (a month or more) holding periods. Moreover, unlike C_t-C_{t-1} Range models, systemic risk contagion in carry-trade markets is particularly pronounced when using H-L Range-based models. The fact provides support that the *CoVaR* model satisfies the modeling purpose of clarifying systemically important financial markets (Liu & Yang, 2017).

Since Garman & Klass (1980) indicated that the opening and closing prices, are merely "snapshots" of the process during the trading interval, high-low prices during the trading interval contain more information regarding volatility than traditional used general prices model (Beckers, 1983; Chou et al., 2010; Garman & Klass, 1980).

The magnitude of the $\Delta CoVaR$ value calculated using H-L Range model is more negative than the C_t-C_{t-1} range model used during short-term horizon periods, we can infer that the $\Delta CoVaR$ value measured using H-L Range stock prices should contain more uncertain metaphor than using C_t-C_{t-1} Range stock prices. Especially while external markets are in turmoil, the information of the market is chaotic and lack of countermeasures, resulting in high uncertainty in the investment markets. Our empirical results reveal significant risk contagion effects during Brexit and Greece's potential exit from European Union. The results coincides with financial markets' varied tendency as shown Euro countries' sovereign bound yields and credit default swaps with growing risk impacts (Gregori & Sacchi, 2019; Bouoiyour & Selmi, 2019). Moreover, searching for possible hidden information and how to measure on systemic risk between carry-trade and stock markets is therefore essential.

These facts confirm that the *CoVaR* model is an appropriate methodology to successfully measure the amount of systemic contagion among different markets. Besides, the economic inference of the $\Delta CoVaR$ value indicates the percentage change in risk conditional on an external financial sector shifting from a normal state toward a severely risky state. The increased magnitude of the $\Delta CoVaR$ measure can be taken as an increase in additional risk contagion incurred from a carry-trade market when the stock market is undergoing turbulence.

5. Conclusion

This study complements relevant literature by showing that systemic contagion affects currency portfolio strategies including currencies allocated in the short and long terms investment, and the holding horizon of highly liquid assets selected in carry-trade markets. Results of this study contribute to existing knowledge in several ways. One contribution of our study is its attempt to confirm that the *CoVaR* model is an effective approach to capture systemic risk contagion between different financial sectors (Adrian & Brunnermeier, 2016). By using CoVaR model, the tail risk conditional on extreme events in other markets can be measured by quantifying the magnitude of additional exposure to risk contagion without considering the restrictions of distributional assumption. A second contribution of this study is that the extension of systemic contagion into using H-L Range data encompasses more market's uncertainty and unexposed information. In particular, systemic contagions are particularly severe during periods of financial distress, such as the tech bubble and U.S. credit crisis periods. In addition, there are not exist disregarded risk spillover effect during the Brexit and potential possible Grexit Periods. Moreover, our evidence on systemic contagion can help investors, trader, financial regulators, and risk managers understand the risks of international capital flows, especially when related markets are exposed to extreme distress.

Therefore, the results suggest that the combination of high-low range model and a *CoVaR* approach can be applied to quantify risk propagation at the multi-industry or multi-firm level on related financial markets undergoing turmoil, such as bond or insurance markets, leading to better capacity to detect risk and its spillover and construct superior investment strategies and portfolios in a volatile environment. Finally, the limitation and future research should be considered in regards to this study. Other potential risk factors affecting the difference (i.e. unexposed information) between using high-low range and close-close range data to measure systemic risk should be considered. Another area for further study is investing over different time horizons and with multicurrency allocations in carry-trade markets, especially when related markets are exposed to extreme distress.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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