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ARTICLE



## Triangular arbitrage across forex and cryptocurrency markets during the COVID-19 crisis: a MRS-AR approach

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### ABSTRACT

This article employs a Markovian regime-switching autoregressive approach to examine triangular arbitrage across forex and cryptocurrency markets during the coronavirus disease 2019 crisis. The findings suggest the following: (1) profitable triangular arbitrage tends to occur in the turbulent period during the crisis, significantly outperforming cryptocurrency investments; and (2) the persistent profitability of triangular arbitrage ensues from strong memory of high returns, low risk, and shock response to global quantitative monetary easing policy. Regulatory authorities should consolidate cryptocurrency supervision systems and establish cross-border coordination mechanisms to stabilize exchange rates and enhance market efficiency.

### KEYWORDS

Triangular arbitrage; forex; cryptocurrency; COVID-19; Markovian regime-switching autoregressive approach

### JEL CLASSIFICATION

C32; F31; G15

### 1. Introduction

Cryptocurrencies have recently become an increasingly attractive asset class in global portfolios because of their soaring prices, heavy trading, and huge market capitalization. Waves of money have flown through the cryptocurrency market for seeking a safe haven and an efficient store of value under increasing risk aversion during the coronavirus disease 2019 (COVID-19) pandemic crisis. This may cause asynchronous fluctuations in values of fiat currencies and cryptocurrencies and then discrepancies in official and cryptocurrency price-implied exchange rates. Attention should be drawn to triangular arbitrage across forex and cryptocurrency markets during the crisis.

Preliminary studies of triangular arbitrage (e.g. Goldstein 1964; Grubel 1964) regard the arbitrage as a fundamental aspect of exchange rate theory and a tool for establishing consistent exchange rates. Recent studies (e.g. Herwartz 2001; Gradojevic, Erdemlioglu, and Gencay 2020) analyse arbitrage opportunities and ultra-short-term profit fluctuations by using vector error correction model with exponential and logarithmic smooth transition functions and wavelet technique based on ultra-high-frequency data. In the latest work, Makarov and Schoar (2020) focus mainly on statistical analysis of opportunities and profits for

arbitrage across countries and between cryptocurrencies from 2016 to 2018. However, there has not been a systematic consideration of the mechanism of the global crisis induced short- and medium-term profit variation for triangular arbitrage related to cryptocurrencies.

This article aims to examine triangular arbitrage across forex and cryptocurrency markets during the COVID-19 crisis. Hence, it contributes to the literature in two ways. First, I investigate unexploited opportunities and the dynamics of potential profits for triangular arbitrage from a cross-market perspective, considering forty arbitrage strategies among fiat currencies and cryptocurrencies during the crisis as a case study. Second, I analyse the adjustment mechanism of arbitrage profits in the crisis with a Markovian regime-switching autoregressive (MRS-AR) approach, which can better capture crisis-induced structural change and adjustment of arbitrage profits in comparison with the commonly used methods including the threshold autoregressive and error-correction models (e.g. Forbes, Kalb, and Kofman 1999) as well as the exponential smooth transition autoregressive and the arbitrage consistent smooth transition models (e.g. Peel and Venetis 2005).

The article provides a new perspective on international portfolio management during the crisis for cryptocurrency investors and a scientific basis of cryptocurrency supervision and exchange rate stabilization for regulatory authorities. Furthermore, the investigation can theoretically enrich triangular arbitrage in the digital circumstance and stimulate a rethinking of the international monetary system in the crisis and beyond. Therefore, this research has considerable implications for international practice and economic theory.

## II. Analytical approach and data

Triangular arbitrage tends to be a self-eliminating process, implying the adjustment of deviations from triangular parity or potential profits. Besides, major events such as global crises, policy shifts, and factionalism (e.g. Su et al. 2021) may cause structural change and shock uncertainty. Hence, a MRS-AR approach to analysis of profit dynamics for triangular arbitrage across forex and cryptocurrency markets can be expressed as follows:

$$Y_t - \mu_s = \sum_{i=1}^n \phi_{s,i} (Y_{t-i} - \mu_s) + \varepsilon_{s,t} \quad (1)$$

$$P[a < Y_t \leq b | Y_1, Y_2, \dots, Y_{t-1}] = P[a < Y_t \leq b | Y_{t-1}] \quad (2)$$

where  $Y_t$  denotes the potential triangular arbitrage profits across forex and cryptocurrency markets at time  $t$ ;  $\mu_s$  represents the average profits (returns) in state  $s$ ;  $(Y_{t-i} - \mu_s)$  is the deviations from the average profits in state  $s$  at time  $(t-i)$ , herein  $i = 1, 2, \dots, n$ ;  $\phi_{s,i}$  is the autoregressive coefficients of arbitrage profits, signifying memory strength;  $\varepsilon_{s,t} \sim N(0, \sigma_{s,t}^2)$  denotes the standardized residuals, reflecting the innovation or shock;  $\sigma_{s,t}$  is the cross-market volatility;  $P$  is the conditional probabilities;  $a$  and  $b$  are the minimum and maximum profits, respectively.

The daily data on Investing.com trading platform before and during the crisis from 1 May 2019 to 31 March 2021 are employed in the article. The data set includes the closing exchange rates

among the US dollar, the euro, the British pound, the Japanese yen, the Chinese yuan, bitcoin and ethereum. The sample size is fixed at 495 after deducting common closing days. Triangular arbitrageurs synchronously conduct three transactions in the clockwise or anticlockwise direction among fiat currencies and cryptocurrencies (see Figure 1 for an example).

In Table 1, I make comparisons of unexploited opportunities, average profits or returns (Avg.), standard deviations (Std.) for 40 arbitrage strategies with those for cryptocurrency investments. The five cases of 'CNY-USD-BTC', 'CNY-EUR-BTC', 'CNY-GBP-BTC', 'CNY-JPY-BTC', and 'CNY-ETH-BTC' seem to be of more opportunities, higher returns (much higher than transaction costs in practice), and lower risk, significantly outperforming all of cryptocurrency investments. The finding strongly supports Makarov and Schoar (2020)'s opinion on arbitrage across countries and between cryptocurrencies and the influence of capital restrictions on trade direction.

Figure 2 depicts trends in potential profits for the five lucrative strategies in the sampling period. Sustainable profits have emerged since 31 October 2019, close to the outbreak of the pandemic. The profits reached a short-term peak in rapid response to a new round of global quantitative monetary easing policy (QE) announced on March 16<sup>th</sup> 2020. The findings suggest that triangular arbitrage for the five profitable strategies tends to occur in the turbulent period during the crisis, instead of the tranquil period before the crisis. These results coincide with Taylor (1989)'s

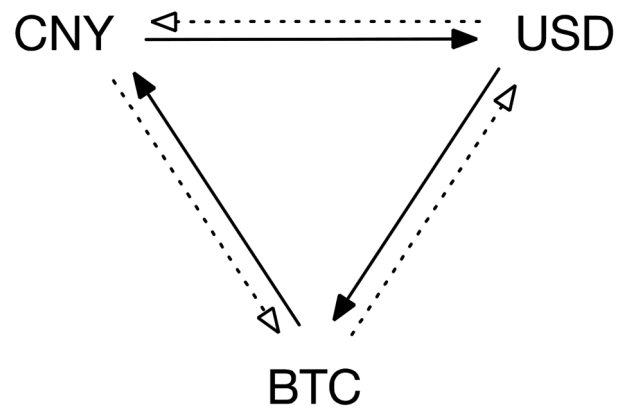
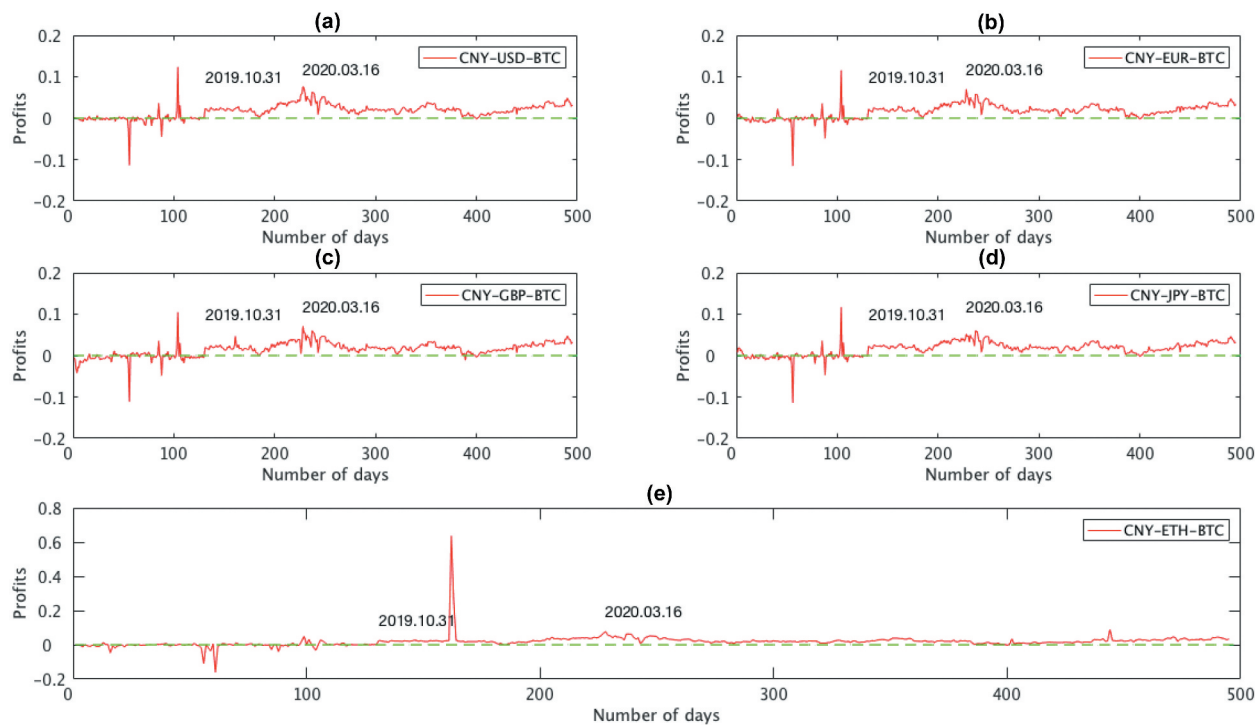


Figure 1. Diagrammatic sketch of triangular arbitrage across forex and cryptocurrency markets.

**Table 1.** Comparisons of triangular arbitrage across forex and cryptocurrency markets with cryptocurrency investments from May 2019 to March 2021.

Arbitrage strategies	Frequency of profitable arbitrage	Avg.	Std.	Arbitrage strategies	Frequency of profitable arbitrage	Avg.	Std.
USD-EUR-BTC	25.05%	-0.0011	0.0032	EUR-USD-BTC	74.95%	0.0011	0.0032
USD-GBP-BTC	17.78%	-0.0024	0.0051	GBP-USD-BTC	82.22%	0.0024	0.0053
USD-JPY-BTC	35.56%	-0.0006	0.0038	JPY-USD-BTC	64.44%	0.0006	0.0038
USD-CNY-BTC	17.37%	-0.0166	0.0168	CNY-USD-BTC	82.63%	0.0172	0.0173
EUR-GBP-BTC	23.23%	-0.0015	0.0043	GBP-EUR-BTC	76.77%	0.0015	0.0044
EUR-JPY-BTC	62.42%	0.0004	0.0025	JPY-EUR-BTC	37.58%	-0.0004	0.0025
EUR-CNY-BTC	19.80%	-0.0157	0.0163	CNY-EUR-BTC	80.20%	0.0162	0.0166
GBP-JPY-BTC	73.13%	0.0018	0.0055	JPY-GBP-BTC	26.87%	-0.0017	0.0054
GBP-CNY-BTC	19.39%	-0.0144	0.0168	CNY-GBP-BTC	80.61%	0.0149	0.0171
JPY-CNY-BTC	17.98%	-0.0160	0.0161	CNY-JPY-BTC	82.02%	0.0165	0.0163
USD-EUR-ETH	28.89%	-0.0011	0.0033	EUR-USD-ETH	71.11%	0.0012	0.0033
USD-JPY-ETH	39.60%	-0.0006	0.0041	JPY-USD-ETH	60.40%	0.0006	0.0041
USD-CNY-ETH	55.15%	-0.0006	0.0120	CNY-USD-ETH	44.85%	0.0007	0.0135
EUR-JPY-ETH	58.59%	0.0004	0.0035	JPY-EUR-ETH	41.41%	-0.0004	0.0034
EUR-CNY-ETH	63.64%	0.0003	0.0121	CNY-EUR-ETH	36.36%	-0.0002	0.0134
JPY-CNY-ETH	61.82%	0.0001	0.0123	CNY-JPY-ETH	38.18%	0.0001	0.0136
ETH-USD-BTC	45.86%	-0.0017	0.0189	USD-ETH-BTC	54.14%	0.0022	0.0287
ETH-EUR-BTC	34.34%	-0.0016	0.0188	EUR-ETH-BTC	65.66%	0.0022	0.0287
ETH-JPY-BTC	39.60%	-0.0016	0.0190	JPY-ETH-BTC	60.40%	0.0022	0.0288
ETH-CNY-BTC	13.74%	-0.0175	0.0269	CNY-ETH-BTC	86.26%	0.0188	0.0354
Cryptocurrency investments	Frequency of profitable investment	Avg.	Std.	Cryptocurrency investments	Frequency of profitable investment	Avg.	Std.
BTCCUSD	53.33%	0.0061	0.0490	ETHUSD	53.74%	0.0070	0.0613
BTCEUR	53.54%	0.0059	0.0486	ETHEUR	53.13%	0.0069	0.0612
BTCGBP	54.34%	0.0059	0.0483	ETHJPY	52.93%	0.0069	0.0618
BTCJPY	53.94%	0.0061	0.0490	ETHCNY	52.93%	0.0069	0.0617
BTCCNY	54.95%	0.0060	0.0478	ETHBTC	46.67%	0.0012	0.0469

Source: Author's calculations based on data from the website of Investing.com.



**Figure 2.** Trends in potential triangular arbitrage profits across forex and cryptocurrency markets from May 2019 to March 2021.

viewpoint about arbitrage and market turbulence. Moreover, the results indicate obvious inconsistencies between direct and cross exchange rates, which can induce exchange rate instability and market inefficiency.

### III. Results

The MRS-AR approach for the five remunerative strategies is performed with the switching regression technique after conducting the ADF test of

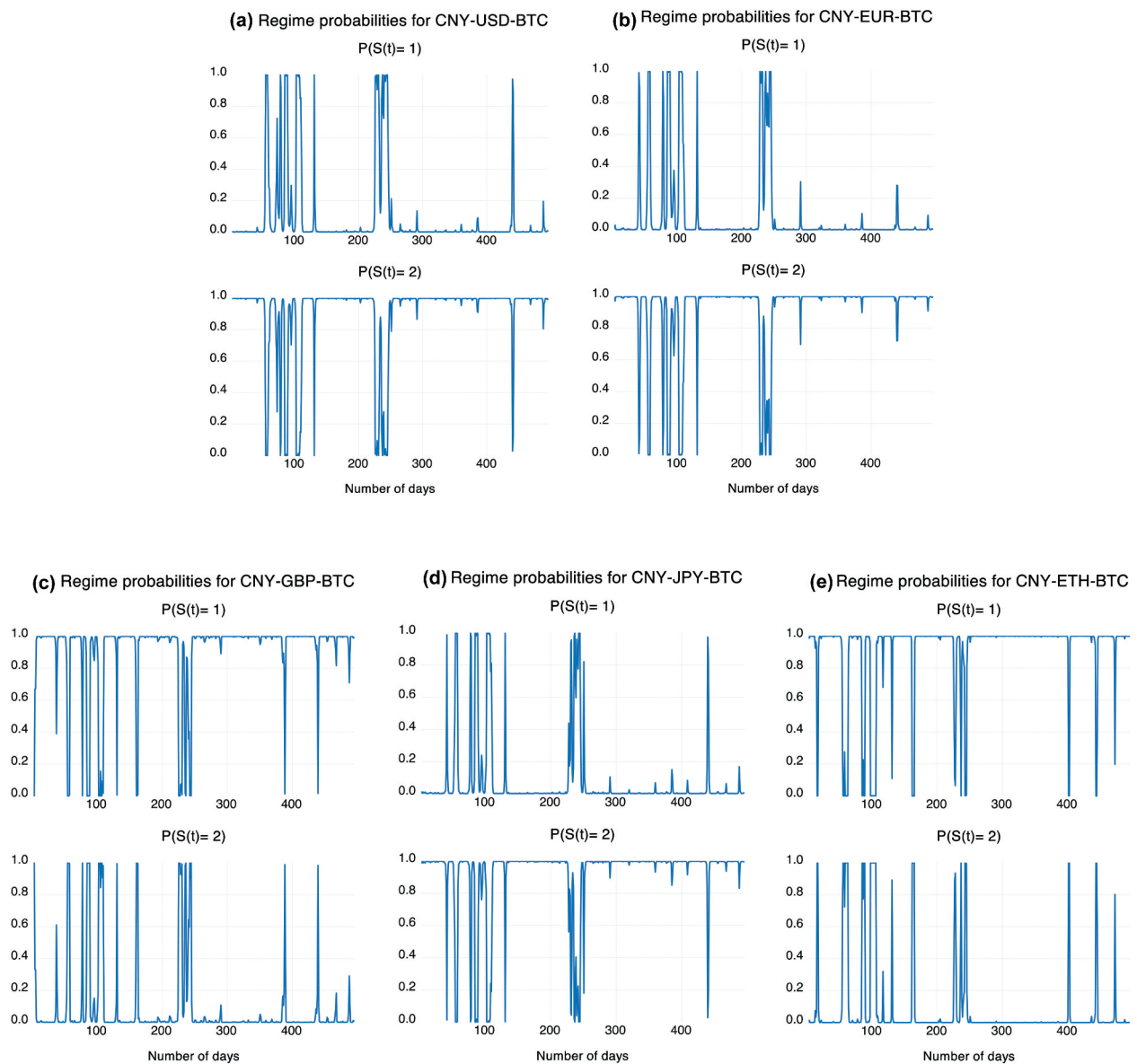
stationarity for potential profits. Table 2 reports the estimation results and the regime probabilities of arbitrage profits are plotted in Figure 3.

It can be seen from Table 2 and Figure 3 that the low volatility regime with high average returns has steadily dominated the slow adjustment process of arbitrage profits during the crisis. The first-order autoregressive coefficients in the AR equation are close to one, indicating a strong memory of past profits and sluggish self-correction in the markets in response to the COVID-19 shock. These

**Table 2.** Estimation results: MRS-AR.

Arbitrage strategies	CNY-USD-BTC	CNY-EUR-BTC	CNY-GBP-BTC	CNY-JPY-BTC	CNY-ETH-BTC
Parameters					
$\mu_1$	0.054***	0.318***	0.208***	0.422***	0.225***
$\mu_2$	0.441**		0.092*		
$\sigma_1$	0.031***	0.035***	0.004***	0.035***	0.005***
$\sigma_2$	0.004***	0.004***	0.033***	0.004***	0.115***
$\phi_{1,1}$	0.368**	0.758***	0.687***	0.768***	0.726***
$\phi_{1,2}$	0.290**	0.189***	0.242***	0.187***	0.196***
$\phi_{2,1}$	0.768***				
$\phi_{2,2}$	0.190***				
$\rho_{1,1}$	0.765	0.743	0.966	0.694	0.971
$\rho_{2,2}$	0.976	0.977	0.686	0.972	0.704
Log likelihood	1878.461	1864.152	1818.985	1876.232	1697.827
AIC	-7.584	-7.534	-7.347	-7.583	-6.859
SC	-7.507	-7.474	-7.279	-7.523	-6.800

Note: \*\*\*, \*\* and \* denote the 1%, 5% and 10% significance levels, respectively.



**Figure 3.** Markovian switching smoothed regime probabilities of potential triangular arbitrage profits across forex and cryptocurrency markets from May 2019 to March 2021.

findings imply that sustainable arbitrage profits are probably caused by strong memory of high returns and low risk during the crisis.

However, regime shifts have frequently occurred between high and low volatility for a short period after the announcement of global QE, which may result from the spillover of currency turmoil to the cryptocurrency market due to the sudden shock of global QE. These results are in coincidence with Huang and Lu (2019)'s view on the formation mechanism of potential arbitrage profits to some extent.

#### IV. Conclusions

This article has examined triangular arbitrage across forex and cryptocurrency markets during the COVID-19 crisis with the MRS-AR approach. The findings suggest the following: first, profitable triangular arbitrage tends to occur in the turbulent period during the crisis, significantly outperforming cryptocurrency investments; second, the persistent profitability of triangular arbitrage ensues from strong memory of high returns and low risk as well as shock response to global QE. The article

paves the way for further analysis of cryptocurrency-based triangular arbitrage in subsequent stages of the crisis in consideration of cross-border financial regulation, transaction costs, liquidity, and algorithmic trading (e.g. Tao et al. 2021) using tick data.

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## Disclosure statement

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