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Cryptocurrencies and Gold - Similarities and Differences

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Abstract

This article investigates similarities and differences between gold and four cryptocurrencies (Bitcoin, Ethereum, Bitcoin Cash and Litecoin). To do so, we estimate a system-GARCH-in-mean with respect to four determinants for the period starting 7/18/2014 at earliest until 7/12/2021. We find that, first, liquidity premia are less important. Second, volatility premia exist in either gold and cryptocurrencies. Third, the response of cryptocurrencies to exchange rate changes is more pronounced than for gold at least if developing countries are included. Fourth, gold exhibits a safe haven status, while cryptocurrencies do not. So those cannot be seen as a store of value but rather as speculative assets.

Keywords: Cryptocurrencies, Gold, System-GARCH-in-mean

JEL classification: E42, G15, C58

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1 Introduction

The use of cryptocurrencies has increased rapidly in recent years. Because of its independence of national monetary policies and the technology limiting the supply of cryptocurrencies, some see them as a safe haven asset just like gold, typically seen as an asset to store value, i.e. in times of turmoil.

The economic role of cryptocurrencies has been investigated extensively in recent years in different dimensions. In especially three of those are directly connected to the research question tackled in this article: First, the interconnectedness of different cryptocurrencies. Analysis in this context focus mainly on volatility spillovers between the different cryptocurrencies.[1] Corbet et al. (2018) find a strong linkage of Bitcoin, Ripple and Litecoin in prices and volatility but almost no connection to other financial assets. Katsiampa (2018) investigate the volatility interconnectedness of Bitcoin and Ether using a diagonal BEKK model. Indeed a significant degree of interconnectedness of those two cryptocurrencies could be verified. Katsiampa et al. (2019) extend this analysis using a BEKK MGARCH model and adding Litecoin as a third cryptocurrency. They also find strong linkages between those three cryptocurrencies. Andrada-Felix et al. (2020) investigate the role of volatility connectedness of various cryptocurrencies and traditional currencies. They find that connectedness is high between the different cryptocurrencies but they are almost unconnected to traditional currencies.

The second strand of literature investigates the relationship of cryptocurrencies to global uncertainty or crises. Akyildirim et al. (2020) estimate for various cryptocurrencies the correlations with the VIX or VSTOXX. It is shown that there is a correlation, and it increases in times of heightened financial stress. Corbet et al. (2020) focus on the role of cryptocurrencies in the COVID-19 pandemic. Using social media data, they show that returns as well as volumes traded increase during

[1] Of course the role of volatility in cryptocurrencies has also been investigated without the focus on interconnectedness of the various cryptocurrencies. See e.g. Katsiampa (2017), Baur and Dimpfl (2018), Chaim and Laurini (2018,2019) and Troster et al. (2019), Ardia et al. (2019)

the pandemic, concluding that cryptocurrencies are a store of value if uncertainty is high. Demir et al. (2020) do a wavelet exercise and focus on COVID-19 cases or deaths instead of social media data. I.e. for Bitcoin, a spread of the pandemic reduced the returns on impact but increased it afterwards.

Third, the performance of cryptocurrencies is compared to the one of gold as the classic safe-haven asset in order to find out whether cryptocurrencies exhibit the same properties. Dyhrberg (2016) is one of the first to do so for Bitcoin. He finds out that Bitcoin can be classified in between the US-dollar and gold as the extremes of medium of exchange and store of value. Baur and Dimpfl (2018) replicate and extent the study and come to the result that Bitcoin returns volatility are distinctly different from gold as well as the US-dollar. Corbet et al. (2020a) investigate correlations of Chinese stock markets to either Bitcoin and gold. At least if high-frequency data is used, the correlation of both to stock prices is increasing in the COVID-19 pandemic and therefore possibly also between Bitcoin and gold itself. Finally, Hassan et al. (2021) use a DCC-GJR-GARCH model to estimate the cryptocurrency uncertainty on precious metals. They find that only gold has a consistent and reliable safe-haven status in this setting.

This article merges all three strands of literature, thus we estimate empirically volatility spillovers of four different cryptocurrencies (Bitcoin, Ethereum, Bitcoin Cash and Litecoin), the role of global uncertainty and the differences to gold simultaneously. Moreover, we add two more variables which to the best of our knowledge have not been investigated so far with respect to cryptocurrencies: First, the role of liquidity and second, the impact of a multilateral exchange rate. To do so, we estimate a system-GARCH-in-mean model, which additionally allows us to find significant differences between cryptocurrencies and gold. Closest to this approach is possibly Liu and Serletis (2019), who estimate a VARMA GARCH-in-mean model with respect to volatility and stock prices or interest rates. Our set of variables will be different but we will also allow for volatility spillovers among the different

cryptocurrencies and gold.

The remainder of the article is organized as follows: Section 2 develops the estimation model, Section 3 describes the data used, Section 4 presents the results and Section 5 finally concludes.

2 The model

The model used in this article rests on a standard portfolio model, according to which certain determinants influence the price of an asset. This can be written as:

$$p_t = \alpha \cdot ex_t + \beta \cdot l_t + \gamma \cdot r_t + \delta \cdot v_t \tag{1}$$

In equation (1), the asset price (p_t) is either the price of gold or a cryptocurrency. Four determinants explain the price level while α, β, γ and δ determine the quantitative effect of those on asset prices: First, since cryptocurrencies, as well as gold, have currency-like properties, they should vary with the exchange rate (ex_t), i.e. the prices should rise if the underlying currency is depreciating and vice versa.

Second, the price of an asset is driven by its liquidity (l_t), meaning that investors demand a higher liquidity premium the more illiquid the asset.

Third, assets are influenced by global risk aversion (r_t). On the one hand, investors could demand an additional premium if the assets are presumed to be less safe if global risks rise. On the other hand also a discount is possible for assets viewed as safe havens in crisis periods as it should be the case for gold.

Fourth, a volatility premium is demanded by investors, meaning that assets with higher volatility (v_t) need to come up with higher prices all else being equal in order to compensate the investors for the higher uncertainty in future returns. Volatility premia in high-frequency data are typically modeled by adding a GARCH-in-mean term (Bollerslev, 1986) to the equation (see, e.g. Klose and Weigert, 2014). So as an

econometric specification the volatility premium in equation (1) can be substituted by the GARCH-in-mean term:

$$p_t = \alpha \cdot ex_t + \beta \cdot l_t + \gamma \cdot r_t + \delta \cdot \sigma_t^2 + \varepsilon_t \tag{2}$$

In equation (2) σ_t^2 signals the GARCH term and ε_t the residuals. In line with the literature on cryptocurrency estimation, we use a standard GARCH (1,1) model (see Dyhrberg, 2016, Baur and Dimpfl,2018, Corbet et al., 2020, 2020a, Akyildirim et al., 2020):

$$\sigma_t^2 = \zeta + \eta \cdot \varepsilon_{t-1}^2 + \theta \cdot \sigma_{t-1}^2 \tag{3}$$

However, we want to estimate equations (2) and (3) not only for just one asset but for five different assets being gold as well as the four cryptocurrencies Bitcoin, Ethereum, Bitcoin Cash and Litecoin. This being said, we do not only account for the volatility of each asset separately but allow for cross-correlation of the various assets. This leads to the following to system:

$$\mathbf{p_t} = \mathbf{a}\ \mathbf{ex_t} + \mathbf{L_t}\ \mathbf{b} + \mathbf{c}\ \mathbf{r_t} + \mathbf{s_t'}\ \mathbf{D}\ \mathbf{s_t} + \mathbf{e_t} \tag{4}$$

$$\text{,with } \mathbf{a} = \begin{pmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \\ \alpha_4 \\ \alpha_5 \end{pmatrix}, \mathbf{b} = \begin{pmatrix} \beta_1 \\ \beta_2 \\ \beta_3 \\ \beta_4 \\ \beta_5 \end{pmatrix}, \mathbf{c} = \begin{pmatrix} \gamma_1 \\ \gamma_2 \\ \gamma_3 \\ \gamma_4 \\ \gamma_5 \end{pmatrix}, \mathbf{p_t} = \begin{pmatrix} p_{1t} \\ p_{2t} \\ p_{3t} \\ p_{4t} \\ p_{5t} \end{pmatrix}, \mathbf{s_t} = \begin{pmatrix} \sigma_{1t} \\ \sigma_{2t} \\ \sigma_{3t} \\ \sigma_{4t} \\ \sigma_{5t} \end{pmatrix},$$

$$\mathbf{e_t} = \begin{pmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \\ \varepsilon_{3t} \\ \varepsilon_{4t} \\ \varepsilon_{5t} \end{pmatrix}, \mathbf{ex_t} = \begin{pmatrix} ex_t \end{pmatrix}, \mathbf{r_t} = \begin{pmatrix} r_t \end{pmatrix}, \mathbf{L} = \begin{pmatrix} l_{1t} & 0 & 0 & 0 & 0 \\ 0 & l_{2t} & 0 & 0 & 0 \\ 0 & 0 & l_{3t} & 0 & 0 \\ 0 & 0 & 0 & l_{4t} & 0 \\ 0 & 0 & 0 & 0 & l_{5t} \end{pmatrix},$$

$$\mathbf{D} = \begin{pmatrix} \delta_{11} & \delta_{12} & \delta_{13} & \delta_{14} & \delta_{15} \\ \delta_{21} & \delta_{22} & \delta_{23} & \delta_{24} & \delta_{25} \\ \delta_{31} & \delta_{32} & \delta_{33} & \delta_{34} & \delta_{35} \\ \delta_{41} & \delta_{42} & \delta_{43} & \delta_{44} & \delta_{45} \\ \delta_{51} & \delta_{52} & \delta_{53} & \delta_{54} & \delta_{55} \end{pmatrix}.$$

Please note, that ex_t and r_t are simple scalars as those variables are the same for all assets.

The variances and covariances are estimated using a diagonal-BEKK-GARCH (Engle and Kroner, 1995). Thus, those have the following form:

$$\mathbf{S_{ij\ t}} = \mathbf{F}' \ \mathbf{F} + \mathbf{G}' \ \mathbf{e_{t-1}} \ \mathbf{e'_{t-1}} \ \mathbf{G} + \mathbf{H}' \ \mathbf{S_{ij\ t-1}} \ \mathbf{H} \tag{5}$$

$$\text{, with } \mathbf{S_{ij\ t}} = \begin{pmatrix} \sigma_{1t}^2 & \sigma_{1t} \cdot \sigma_{2t} & \sigma_{1t} \cdot \sigma_{3t} & \sigma_{1t} \cdot \sigma_{4t} & \sigma_{1t} \cdot \sigma_{5t} \\ \sigma_{1t} \cdot \sigma_{2t} & \sigma_{2t}^2 & \sigma_{2t} \cdot \sigma_{3t} & \sigma_{2t} \cdot \sigma_{4t} & \sigma_{2t} \cdot \sigma_{5t} \\ \sigma_{1t} \cdot \sigma_{3t} & \sigma_{2t} \cdot \sigma_{3t} & \sigma_{3t}^2 & \sigma_{3t} \cdot \sigma_{4t} & \sigma_{3t} \cdot \sigma_{5t} \\ \sigma_{1t} \cdot \sigma_{4t} & \sigma_{2t} \cdot \sigma_{4t} & \sigma_{3t} \cdot \sigma_{4t} & \sigma_{4t}^2 & \sigma_{4t} \cdot \sigma_{5t} \\ \sigma_{1t} \cdot \sigma_{5t} & \sigma_{2t} \cdot \sigma_{5t} & \sigma_{3t} \cdot \sigma_{5t} & \sigma_{4t} \cdot \sigma_{5t} & \sigma_{5t}^2 \end{pmatrix},$$

$$\mathbf{F} = \begin{pmatrix} \zeta_{11} & \zeta_{12} & \zeta_{13} & \zeta_{14} & \zeta_{15} \\ 0 & \zeta_{22} & \zeta_{23} & \zeta_{24} & \zeta_{25} \\ 0 & 0 & \zeta_{33} & \zeta_{34} & \zeta_{35} \\ 0 & 0 & 0 & \zeta_{44} & \zeta_{45} \\ 0 & 0 & 0 & 0 & \zeta_{55} \end{pmatrix}, \mathbf{G} = \begin{pmatrix} \eta_{11} & 0 & 0 & 0 & 0 \\ 0 & \eta_{22} & 0 & 0 & 0 \\ 0 & 0 & \eta_{33} & 0 & 0 \\ 0 & 0 & 0 & \eta_{44} & 0 \\ 0 & 0 & 0 & 0 & \eta_{55} \end{pmatrix},$$

$$\mathbf{H} = \begin{pmatrix} \theta_{11} & 0 & 0 & 0 & 0 \\ 0 & \theta_{22} & 0 & 0 & 0 \\ 0 & 0 & \theta_{33} & 0 & 0 \\ 0 & 0 & 0 & \theta_{44} & 0 \\ 0 & 0 & 0 & 0 & \theta_{55} \end{pmatrix}.$$

3 Data

In this section, we describe the data used. Throughout the article, we make use of daily data, excluding weekends and holidays. Given the model of the previous section, we have five dependent variables in our system. These are the prices for gold, Bitcoin, Ethereum, Bitcoin Cash and Litecoin. In order to compare the prices, they are all denominated in US-dollar.

The prices are collected together with the liquidity indicator for those five assets. As frequently used in the literature, liquidity is measured by the underlying bid-ask-spread of the asset (see, e.g. Bernoth and Erdogan, 2012, Afonso et al., 2015 or Klose, 2021). Thus, a higher bid-ask spread signals lower liquidity of the asset, which should lead to a higher liquidity premium demanded by the investors. The availability of the various bid-ask spreads is determining our sample period. For cryptocurrencies there are no corresponding long-term data. Thus, the first data are available for Bitcoin on 7/18/2014, for Bitcoin Cash on 2/12/2018 for Ethereum and Litecoin on 11/01/2018. The end of the sample is for all assets 7/12/2021.

As the asset prices are denominated in US-dollar, this is also the one currency the exchange rate is based on. However, it makes no sense to use a bilateral exchange rate, e.g. towards the Euro, as this may not represent the overall evolution of the US-dollar. Therefore, we use the effective exchange rate. Those are used in nominal terms as also the asset prices are nominal. The Bank of International Settlements (BIS) collects two types of daily effective exchange rates. The first one

is a narrow effective exchange rate towards 24 other economies.[2] The second one is a broad effective exchange rate covering the 24 economies of the narrow aggregate and adds 34 other economies.[3] So in total 58 economies are covered by the broad effective exchange rate. We will use both effective exchange rate as there may be differences between the country samples, i.e. as the broad effective exchange rates adds especially developing and transition countries which may behave differently from developed countries when it comes to the use of cryptocurrencies.

To cover global uncertainty, two variables are frequently used: The first one is the volatility index (VIX) covering the implied volatility of the S&P 500. Thus, higher volatility signals a higher degree of global stress. The second one is the US corporate BBB government bond spread. A rising spread is here the indicator for increasing global uncertainty. We will use both measures but expect the qualitatively same influence on our asset prices.

Please note, that there were no data collected for the (cross-) volatility, as these variables are estimated within the system via GARCH.

In order to evaluate whether our model can be estimated in levels, augmented Dickey-Fuller-tests are performed. The results are presented in Table 1. Obviously, i.e. the five asset prices as well as the effective exchange rates appear to be non-stationary. Therefore, we follow the same procedure as frequently used in cryptocurrency estimations and build daily growth rates, thus e.g. asset returns, with respect to all variables.[4] When applying this transformation, all variables are stationary.

[2] The 24 economies covered in the narrow exchange rate towards the US-dollar are: Australia, Austria, Belgium, Canada, Chinese Taipei, Denmark, Finland, France, Germany, Greece, Hong Kong, Ireland, Italy, Japan, Korea, Netherlands, New Zealand, Norway, Portugal, Singapore, Spain, Sweden, Switzerland and United Kingdom.

[3] The additional 34 economies covered in the broad effective exchange rate are: Algeria, Argentina, Brazil, Bulgaria, Chile, China, Colombia, Croatia, Cyprus, Czech Republic, Estonia, Hungary, Iceland, India, Indonesia, Israel, Latvia, Lithuania, Luxembourg, Malaysia, Malta, Mexico, Peru, Philippines, Poland, Romania, Russia, Saudi Arabia, Slovak Republic, Slovenia, South Africa, Thailand, Turkey and United Arab Emirates.

[4] See e.g. Ardia et al., 2019, Liu and Seletis, 2019, Akyildirim, 2020, Corbet et al., 2020a, Liu and Tsyvinski, 2021.

4 Results

This section presents our estimation results. Since we are mainly interested in the differences between gold and the various cryptocurrencies, we follow a two-step procedure. In the first step, we estimate a bivariate system consisting of the asset prices gold and only one cryptocurrency. This leads to pairwise comparisons of the different cryptocurrencies with gold. In a second step, we estimate the model as described in section 2, thus including gold and the four cryptocurrencies in one system. In order to save space in the tables, we do not show the constants of the covariance equations as they are mostly insignificant and sum the individual cross volatilities of cryptocurrencies up to one coefficient. More detailed results in both dimensions are available upon request.

Using a system estimator has the advantage that significant differences in the estimated coefficients can be detected via Wald-tests. Thus, we will use those in order to find the differences between gold and the four cryptocurrencies.

The results when using the VIX as a global risk indicator are presented in Table 2, while the corresponding Wald-tests for statistically different coefficients are shown in Table 3. The tables show two sets of estimates, one using the broad effective exchange rate and one using the narrow aggregate. We can draw several conclusions from these results: First, the liquidity premium seems to be hardly relevant for either gold or cryptocurrencies. The only exception is Litecoin, where indeed the significant negative coefficient can be found, while for all other assets the result is insignificant. Therefore, it does not come as a surprise that the only significant differences between gold and a cryptocurrency with respect to the liquidity premium can be found vis-a-vis Litecoin, thus for Litecoin, the response to liquidity issues is significantly more pronounced than for gold.

Second, the response to the effective exchange rate is for all assets found to be negative as expected, and it turns out to be mainly significant. However, the coefficients differ on the one hand with respect to the different assets and on the other

hand between the broad and narrow effective exchange rate. While the coefficients are of almost the same size with about -0.5 for gold in all specifications, the response coefficients turn out to be higher for Ethereum, Bitcoin Cash and Litecoin with levels exceeding -1. Even more important, the estimates for those three cryptocurrencies tend to be higher when using the broad effective exchange rate instead of the narrow aggregate. This leads to the result that only for the broad aggregate, we identify significant differences between gold and the three cryptocurrencies, i.e. that those three react stronger to changes in the exchange rate than gold. The result that those three cryptocurrencies show a stronger response to the broad effective exchange rate is reasonable since the difference between the broad and narrow aggregate includes i.e. developing and transition countries with overall a less credible central bank than developed countries forming the narrow index. As the domestic central bank is less credible private cryptocurrencies are presumably a more relevant alternative in those countries than in developed countries.

Third, there are significant differences between all four cryptocurrencies and gold regarding the impact of global risk. While for gold the response is (if anything) significantly positive underlining the role of gold as a safe-haven asset, the coefficients turn out to be significantly negative for all cryptocurrencies in all specifications. Thus, the cryptocurrencies cannot be viewed as a safe-haven in times of financial stress. It does thus not come as a surprise that compared to gold, the difference with respect to global risk is significantly lower for all four cryptocurrencies.

Fourth, concerning volatility, investors indeed tend to demand a premium. This holds for either gold and cryptocurrencies. Quite astonishingly, the premium tends to be higher for gold than for Ethereum, Bitcoin Cash and Litecoin, even though only in a few of those specifications the difference is significantly different. However, this effect is partly offset by the higher response coefficients if gold and the cryptocurrencies move in tandem, even though only for Bitcoin Cash these differences turn out to be significantly different.

Finally, if the volatility among cryptocurrencies moves in tandem there is no additional liquidity premium demanded, possibly because risks with respect to the different cryptocurrencies is viewed as being equal.

When using the corporate BBB government bond spread instead of the VIX as indicator for global risk, the results are mainly reinforced (see Tables 4 and 5), i.e. with respect to the liquidity premium, exchange rate and liquidity premia. Although the global risk premium's coefficient size differs from the previous estimate, the very same conclusion can be drawn now, meaning that gold exhibits a safe-haven status while the four cryptocurrencies do not.

5 Conclusions

In this article, we have estimated a system-GARCH-in-mean for gold and four cryptocurrencies and identified significant differences between both. We found that liquidity issues play less of a role in all assets. The negative response to exchange rate changes is more pronounced for cryptocurrencies, i.e. if developing countries are included in the exchange rate. Volatility premia tend to exist for all assets. Most importantly, cryptocurrencies diverge from gold when it comes to global risk premia. While gold is seen as a safe-haven in times of rising stress, thus increasing its value, the reverse is true with respect to all four cryptocurrencies.

The conclusions that can be drawn from our analysis are twofold: First, cryptocurrencies differ but not in all dimensions. While we have shown that there are differences in cryptocurrencies, at least with respect to liquidity, volatility and the exchange rate, they do not differ for global risk. Thus, they do not fulfill one major property of a currency, which is being a store of value. This being said cryptocurrencies have to be seen as speculative assets. So there could be the need to regulate those assets in order to prevent financial crisis resulting from them. But we have also seen, that regulation needs to be coordinated at a global level as the cryptocur-

rencies are not bound to specific countries. This being said, not only developed countries need to find a coordinated approach for regulations but also developing countries need to be incorporated.

Second, while cryptocurrencies do not pursue all properties of a normal currency, they have at least some similarities. We have seen that they react at least qualitatively like other currencies, meaning e.g. in case of a depreciation of the US-dollar also the price of cryptocurrency in US-dollar is rising and vice versa. Therefore, there seems to be some demand for private and digital currency solutions. However, whether the need is driven by privacy (i.e. independence from a central bank as the sole issuer of the currency) or the technology behind cryptocurrencies needs to be seen in the future. Today most central banks in developed economies have started programs to issue a digital currency in the future. Therefore, it will be interesting to see how the public substitute for private cryptocurrencies influences the demand for the latter.

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Table 1: Stationarity test

	Level	Growth rate
Gold price	-0.51	-43.25***
Bitcoin price	-0.78	-42.52***
Ethereum price	-0.71	-17.26***
Bitcoin cash price	-3.47***	-29.31***
Litecoin price	-2.14	-27.09***
Gold bid-ask-spread	-2.27	-14.88***
Bitcoin bid-ask-spread	-10.17***	-43.49***
Ethereum bid-ask-spread	-3.57***	-7.93***
Bitcoin cash bid-ask-spread	-5.49***	-30.15***
Litecoin bid-ask-spread	-6.20***	-13.16***
Broad effective exchange rate	-2.38	-43.91***
Narrow effective exchange rate	-2.53	-43.00***
VIX	-4.83***	-46.35***
US-BBB-government-bond-spread	-3.74***	-9.63***

Notes: Sample period: varying between 7/18/2014 and 7/12/2021; Augmented Dickey-Fuller-Tests are conducted including an intercept, t-statistics of the tests are displayed, */**/*** signal significance at the 10%/5%/1% level.

Table 2: System estimates with VIX

	Broad exchange rate					Narrow exchange rate				
	I	II	III	IV	V	VI	VII	VIII	IX	X
Gold										
Liquidity premium	-0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Exchange rate	-0.47***	-0.44***	-0.51***	-0.45***	-0.47***	-0.47***	-0.55***	-0.57***	-0.55***	-0.56***
	(0.06)	(0.12)	(0.10)	(0.12)	(0.11)	(0.05)	(0.11)	(0.09)	(0.11)	(0.11)
Global risk premium	0.01***	0.00	0.00	0.00	0.00	0.01***	-0.00	-0.00	-0.00	-0.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Volatility	0.03	0.08**	0.07**	0.10**	-0.05	0.03	0.07	0.07*	0.10*	0.09**
	(0.03)	(0.04)	(0.03)	(0.05)	(0.11)	(0.03)	(0.05)	(0.04)	(0.05)	(0.04)
Cross volatility crypto	0.03	-0.03	-0.02	-0.04	0.22*	0.03	-0.01	-0.02	-0.03	-0.05
	(0.03)	(0.03)	(0.03)	(0.04)	(0.12)	(0.03)	(0.04)	(0.03)	(0.04)	(0.04)
Volatility equation										
Constant	0.00***	0.03***	0.01***	0.02***	0.00***	0.00***	0.01***	0.01***	0.02***	0.03***
	(0.00)	(0.01)	(0.00)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.01)	(0.01)
ARCH(-1)	0.17***	0.31***	0.25***	0.29***	0.04**	0.17***	0.22***	0.23***	0.26***	0.29***
	(0.01)	(0.02)	(0.02)	(0.02)	(0.02)	(0.01)	(0.02)	(0.02)	(0.02)	(0.02)
GARCH(-1)	0.98***	0.94***	0.96***	0.95***	1.00***	0.98***	0.97***	0.97***	0.95***	0.94***
	(0.00)	(0.01)	(0.01)	(0.01)	(0.00)	(0.00)	(0.01)	(0.01)	(0.01)	(0.09)
Bitcoin										
Liquidity premium	-0.00				-0.00	-0.00				-0.00
	(0.00)				(0.00)	(0.00)				(0.00)
Exchange rate	-0.55				-0.93	-0.44				-0.56
	(0.34)				(0.58)	(0.29)				(0.57)
Global risk premium	-0.04***				-0.05***	-0.04***				-0.06***
	(0.01)				(0.02)	(0.01)				(0.02)
Volatility	0.01**				0.03	0.01**				0.03
	(0.00)				(0.04)	(0.00)				(0.02)
Cross volatility gold	0.14				0.66	0.14				0.20
	(0.13)				(0.68)	(0.13)				(0.18)
Cross volatility crypto					-0.04					-0.02
					(0.04)					(0.03)
Volatility equation										
Constant	0.87***				1.04***	0.87***				2.52***
	(0.10)				(0.15)	(0.10)				(0.72)
ARCH(-1)	0.36***				0.22***	0.36***				0.31***
	(0.01)				(0.01)	(0.01)				(0.04)
GARCH(-1)	0.92***				0.95***	0.92***				0.89***
	(0.01)				(0.01)	(0.01)				(0.03)
Ethereum										
Liquidity premium		-0.00			-0.00		-0.00			-0.00
		(0.00)			(0.00)		(0.00)			(0.00)
Exchange rate		-1.95**			-1.88**		-1.06			-1.06
		(0.76)			(0.76)		(0.75)			(0.76)
Global risk premium		-0.06**			-0.07***		-0.08***			-0.08***
		(0.03)			(0.03)		(0.03)			(0.03)
Volatility		0.01			-0.02		0.01			0.02
		(0.01)			(0.04)		(0.01)			(0.01)
Cross volatility gold		0.25			1.69**		0.31			0.29
		(0.18)			(0.78)		(0.22)			(0.19)
Cross volatility crypto					-0.01					-0.04
					(0.06)					(0.04)
Volatility equation										
Constant		3.82***			2.26***		3.84***			3.86***
		(1.01)			(0.39)		(1.03)			(1.14)
ARCH(-1)		0.29***			0.22***		0.30***			0.30***
		(0.02)			(0.02)		(0.03)			(0.04)
GARCH(-1)		0.90***			0.95***		0.90***			0.90***
		(0.02)			(0.01)		(0.02)			(0.02)
Bitcoin Cash										
Liquidity premium			-0.00		0.00			-0.00		0.00
			(0.00)		(0.00)			(0.00)		(0.00)
Exchange rate			-1.79**		-2.35**			-1.04		-1.65*
			(0.83)		(0.97)			(0.81)		(0.96)
Global risk premium			-0.08***		-0.10***			-0.09***		-0.11***
			(0.03)		(0.03)			(0.03)		(0.03)
Volatility			-0.00		-0.01			4.07**		0.13
			(0.00)		(0.01)			(0.04)		(0.72)
Cross volatility gold			0.39*		0.88			0.46*		0.54**
			(0.23)		(0.72)			(0.24)		(0.23)
Cross volatility crypto					0.00					0.04
					(0.03)					(0.03)
Volatility equation										
Constant			3.90***		3.21***			4.28***		4.20***
			(0.62)		(0.33)			(0.68)		(0.78)
ARCH(-1)			0.29***		0.37***			0.30***		0.32***
			(0.02)		(0.02)			(0.02)		(0.02)
GARCH(-1)			0.93***		0.92***			0.92***		0.91***
			(0.01)		(0.01)			(0.01)		(0.01)
Litecoin										
Liquidity premium				-0.00**	-0.00**				-0.00*	-0.00**
				(0.00)	(0.00)				(0.00)	(0.00)
Exchange rate				-2.56***	-2.52***				-1.42*	-1.47*
				(0.80)	(0.80)				(0.79)	(0.79)
Global risk premium				-0.06**	-0.06**				-0.08***	-0.08***
				(0.03)	(0.03)				(0.03)	(0.03)
Volatility				0.00	0.02				0.00	0.01
				(0.01)	(0.03)				(0.01)	(0.01)
Cross volatility gold				0.32	0.70				0.32	0.42*
				(0.22)	(0.65)				(0.22)	(0.23)
Cross volatility crypto					-0.01					0.01
					(0.06)					(0.04)
Volatility equation										
Constant				1.54***	1.54***				1.68***	5.18***
				(0.36)	(0.20)				(0.40)	(1.51)
ARCH(-1)				0.22***	0.24***				0.23***	0.28***
				(0.02)	(0.01)				(0.02)	(0.03)
GARCH(-1)				0.96***	0.96***				0.95***	0.89***
				(0.01)	(0.00)				(0.01)	(0.03)
log-likelihood	-7363.11	-3129.69	-4082.02	-3162.20	-8788.39	-7356.84	-3124.04	-4082.50	-3163.49	-9342.59
N	1822	702	890	702	702	1822	702	890	702	702

Notes: All variables in daily percentage changes. Dependent variable is the gold price or the price of cyrptocurrencies. Liquidity premium = bid-ask-spread, exchange rate = broad (narrow) effective exchange rate towards 58 (24) other economies, global risk premium = VIX, volatility = GARCH, cross-volatility = GARCH covariance. Standard errors in parentheses. Significance level of 1%, 5% and 10% is denoted by ***, ** and *.

Table 3: Differences between gold and cryptocurrencies with VIX

	Broad exchange rate					Narrow exchange rate				
	I	II	III	IV	V	VI	VII	VIII	IX	X
Gold versus Bitcoin										
Liquidity premium	0.00				0.50	0.00				0.87
	(0.97)				(0.48)	(0.98)				(0.35)
Exchange rate	0.05				0.63	0.00				0.00
	(0.81)				(0.42)	(0.93)				(0.99)
Global risk premium	15.13***				7.17***	15.74***				7.86***
	(0.00)				(0.01)	(0.00)				(0.01)
Volatility	0.63				0.43	0.56				1.63
	(0.43)				(0.51)	(0.45)				(0.20)
Cross volatility gold	0.73				0.35	0.64				0.78
	(0.39)				(0.56)	(0.42)				(0.38)
Cross volatility crypto					1.13					0.69
					(0.29)					(0.41)
Gold versus Ethereum										
Liquidity premium		0.92			0.54		0.93			0.90
		(0.34)			(0.46)		(0.33)			(0.34)
Exchange rate		3.81*			3.35*		0.47			0.44
		(0.05)			(0.07)		(0.50)			(0.51)
Global risk premium		9.97***			6.98***		8.38***			8.65***
		(0.00)			(0.01)		(0.00)			(0.00)
Volatility		3.35*			0.04		1.92			2.47
		(0.07)			(0.84)		(0.17)			(0.12)
Cross volatility gold		2.12			1.66		2.10			1.58
		(0.15)			(0.20)		(0.15)			(0.21)
Cross volatility crypto					1.25					0.31
					(0.26)					(0.58)
Gold versus Bitcoin Cash										
Liquidity premium			0.20		0.10			0.28		0.07
			(0.66)		(0.75)			(0.60)		(0.79)
Exchange rate			2.32		3.73*			0.33		1.28
			(0.13)		(0.05)			(0.56)		(0.26)
Global risk premium			8.12***		8.69***			10.02***		10.26***
			(0.00)		(0.00)			(0.00)		(0.00)
Volatility			4.07**		0.13			3.41*		1.63
			(0.04)		(0.72)			(0.06)		(0.20)
Cross volatility gold			3.13*		0.13			3.95**		4.60**
			(0.08)		(0.71)			(0.05)		(0.03)
Cross volatility crypto					1.41					3.09*
					(0.23)					(0.08)
Gold versus Litecoin										
Liquidity premium				2.95*	2.70				3.02*	3.10*
				(0.09)	(0.10)				(0.08)	(0.08)
Exchange rate				6.79***	6.38**				1.18	1.30
				(0.01)	(0.01)				(0.28)	(0.25)
Global risk premium				5.19**	5.70**				7.70***	8.11***
				(0.02)	(0.02)				(0.01)	(0.00)
Volatility				3.66*	0.36				3.08*	2.75*
				(0.06)	(0.55)				(0.08)	(0.10)
Cross volatility gold				2.67	0.02				2.47	2.54
				(0.10)	(0.88)				(0.11)	(0.11)
Cross volatility crypto					1.32					1.47
					(0.25)					(0.22)

Notes: Wald-tests for coefficient equality based on the estimates of the previous table. Chi-square test statistic, p-value in parentheses. A significance level of 1%, 5% and 10% is denoted by ***, ** and *.

Table 4: System estimates with BBB-government bond spread

	Broad exchange rate					Narrow exchange rate				
	I	II	III	IV	V	VI	VII	VIII	IX	X
Gold										
Liquidity premium	-0.00	0.00	0.00	0.00	0.00	-0.00	0.00	0.00	0.00	0.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Exchange rate	-0.53***	-0.49***	-0.57***	-0.50***	-0.53***	-0.48***	-0.54***	-0.57***	-0.54***	-0.59***
	(0.06)	(0.13)	(0.10)	(0.13)	(0.13)	(0.05)	(0.12)	(0.09)	(0.12)	(0.12)
Global risk premium	0.08***	0.03	0.04**	0.03	0.03	0.06***	0.02	0.02	0.01	0.02
	(0.01)	(0.02)	(0.02)	(0.02)	(0.02)	(0.00)	(0.02)	(0.02)	(0.02)	(0.02)
Volatility	0.07***	0.12**	0.10***	0.15***	-0.06	0.06**	0.11***	0.10***	0.14***	-0.06
	(0.03)	(0.04)	(0.03)	(0.04)	(0.13)	(0.03)	(0.04)	(0.03)	(0.04)	(0.13)
Cross volatility crypto	-0.05**	-0.08***	-0.08	-0.11***	0.23	-0.03	-0.06**	-0.07***	-0.09**	0.32*
	(0.02)	(0.03)	(0.02)	(0.04)	(0.16)	(0.02)	(0.03)	(0.02)	(0.04)	(0.17)
Volatility equation										
Constant	0.01***	0.02***	0.02***	0.03***	0.00***	0.02***	0.02***	0.01***	0.03***	0.00***
	(0.00)	(0.01)	(0.00)	(0.01)	(0.00)	(0.00)	(0.01)	(0.00)	(0.01)	(0.01)
ARCH(-1)	0.23***	0.30***	0.29***	0.33***	0.02	0.27***	0.28***	0.23***	0.31***	0.02
	(0.01)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
GARCH(-1)	0.97***	0.94***	0.94***	0.93***	1.00***	0.95***	0.95***	0.97***	0.94***	1.00***
	(0.00)	(0.01)	(0.01)	(0.01)	(0.00)	(0.01)	(0.01)	(0.01)	(0.01)	(0.00)
Bitcoin										
Liquidity premium	-0.00				-0.00	-0.00				-0.00
	(0.00)				(0.00)	(0.00)				(0.00)
Exchange rate	-0.37				-0.63	-0.35				-0.20
	(0.36)				(0.62)	(0.30)				(0.58)
Global risk premium	-0.28***				-0.22**	-0.30***				-0.26***
	(0.08)				(0.10)	(0.08)				(0.09)
Volatility	0.01**				0.02	0.01**				0.01
	(0.00)				(0.04)	(0.00)				(0.04)
Cross volatility gold	0.11				0.30	0.13				0.28
	(0.11)				(0.75)	(0.12)				(0.77)
Cross volatility crypto					-0.01					-0.01
					(0.04)					(0.04)
Volatility equation										
Constant	0.91***				1.04***	0.90***				1.01***
	(0.10)				(0.13)	(0.10)				(0.13)
ARCH(-1)	0.36***				0.24***	0.36***				0.24***
	(0.01)				(0.02)	(0.01)				(0.02)
GARCH(-1)	0.92***				0.95***	0.92***				0.95***
	(0.01)				(0.01)	(0.01)				(0.01)
Ethereum										
Liquidity premium		-0.00			-0.00		-0.00			-0.00
		(0.00)			(0.00)		(0.00)			(0.00)
Exchange rate		-1.46*			-1.42*		-0.65			-0.52
		(0.82)			(0.82)		(0.77)			(0.76)
Global risk premium		-0.34***			-0.31**		-0.42***			-0.39***
		(0.013)			(0.13)		(0.12)			(0.12)
Volatility		0.01			-0.04		0.01			-0.04
		(0.01)			(0.04)		(0.01)			(0.04)
Cross volatility gold		0.27			1.34		0.29			1.35
		(0.18)			(0.84)		(0.18)			(0.84)
Cross volatility crypto					0.02					0.02
					(0.06)					(0.06)
Volatility equation										
Constant		4.33***			2.28***		4.38***			2.27***
		(1.17)			(0.38)		(1.16)			(0.36)
ARCH(-1)		0.30***			0.23***		0.28***			0.23***
		(0.02)			(0.02)		(0.02)			(0.02)
GARCH(-1)		0.89***			0.95***		0.89***			0.95***
		(0.02)			(0.01)		(0.02)			(0.00)
Bitcoin Cash										
Liquidity premium			-0.00		-0.00			-0.00		-0.00
			(0.00)		(0.00)			(0.00)		(0.00)
Exchange rate			-1.69**		-2.35**			-0.93		-0.91
			(0.88)		(1.05)			(0.83)		(0.97)
Global risk premium			-0.31**		-0.20			-0.41***		-0.32**
			(0.15)		(0.16)			(0.14)		(0.15)
Volatility			0.00		-0.01			-0.00		-0.01
			(0.00)		(0.01)			(0.00)		(0.01)
Cross volatility gold			0.43**		0.61			0.53***		0.63
			(0.20)		(0.83)			(0.20)		(0.85)
Cross volatility crypto					0.01					0.01
					(0.03)					(0.03)
Volatility equation										
Constant			6.35***		3.47***			6.81***		3.57***
			(0.99)		(0.32)			(1.10)		(0.33)
ARCH(-1)			0.32***		0.36***			0.27***		0.36***
			(0.02)		(0.02)			(0.02)		(0.02)
GARCH(-1)			0.89***		0.95***			0.88***		0.92***
			(0.01)		(0.01)			(0.02)		(0.01)
Litecoin										
Liquidity premium				-0.00*	-0.00**				-0.00*	-0.00**
				(0.00)	(0.00)				(0.00)	(0.00)
Exchange rate				-2.17**	-2.16***				-1.02	-0.89
				(0.87)	(0.87)				(0.81)	(0.81)
Global risk premium				-0.31**	-0.27**				-0.42***	-0.38***
				(0.13)	(0.14)				(0.13)	(0.13)
Volatility				0.00	0.01				0.00	0.01
				(0.01)	(0.03)				(0.01)	(0.03)
Cross volatility gold				0.39*	0.62				0.42**	0.56
				(0.21)	(0.73)				(0.21)	(0.73)
Cross volatility crypto					0.00					0.01
					(0.05)					(0.05)
Volatility equation										
Constant				2.02***	1.59***				2.36***	2.16***
				(0.52)	(0.20)				(0.62)	(0.22)
ARCH(-1)				0.22***	0.25***				0.23***	0.25***
				(0.02)	(0.01)				(0.02)	(0.01)
GARCH(-1)				0.95***	0.96***				0.95***	0.96***
				(0.01)	(0.00)				(0.01)	(0.00)
log-likelihood	-7334.16	-3114.09	-4068.74	-3152.24	-8786.44	-7336.75	-3116.28	-4074.44	-3156.13	-8785.89
N	1822	702	890	702	702	1822	702	890	702	702

Notes: All variables in daily percentage changes. Dependent variable is the gold price or the price of cyrptocurrencies. Liquidity premium = bid-ask-spread, exchange rate = broad (narrow) effective exchange rate towards 58 (24) other economies, global risk premium = BBB government bond spread, volatility = GARCH, cross-volatility = GARCH covariance. Standard errors in parentheses. Significance level of 1%, 5% and 10% is denoted by ***, ** and *.

Table 5: Differences between gold and cryptocurrencies with BBB-government bond spread

	Broad exchange rate					Narrow exchange rate				
	I	II	III	IV	V	VI	VII	VIII	IX	X
Gold versus Bitcoin										
Liquidity premium	0.10				0.42	0.03				0.50
	(0.76)				(0.51)	(0.87)				(0.48)
Exchange rate	0.17				0.02	0.19				0.42
	(0.68)				(0.88)	(0.66)				(0.52)
Global risk premium	18.57***				6.51**	19.29***				8.67***
	(0.00)				(0.01)	(0.00)				(0.00)
Volatility	6.11**				0.29	4.00**				0.26
	(0.01)				(0.59)	(0.05)				(0.61)
Cross volatility gold	2.09				0.10	1.93				0.28
	(0.15)				(0.75)	(0.16)				(0.59)
Cross volatility crypto					0.57					1.00
					(0.45)					(0.32)
Gold versus Ethereum										
Liquidity premium		1.03			0.49		1.10			0.58
		(0.31)			(0.48)		(0.29)			(0.45)
Exchange rate		1.38			1.15		0.02			0.01
		(0.24)			(0.28)		(0.89)			(0.93)
Global risk premium		8.09***			6.96***		12.76***			11.05***
		(0.00)			(0.01)		(0.00)			(0.00)
Volatility		8.40***			0.01		6.08**			0.01
		(0.00)			(0.90)		(0.01)			(0.91)
Cross volatility gold		3.75*			0.55		3.75*			0.29
		(0.05)			(0.46)		(0.05)			(0.59)
Cross volatility crypto					0.67					1.10
					(0.41)					(0.29)
Gold versus Bitcoin Cash										
Liquidity premium			0.15		0.19			0.23		0.24
			(0.70)		(0.66)			(0.63)		(0.62)
Exchange rate			1.59		2.96*			0.19		0.11
			(0.21)		(0.09)			(0.66)		(0.74)
Global risk premium			5.17**		1.91			8.66***		4.68**
			(0.02)		(0.17)			(0.00)		(0.03)
Volatility			10.27***		0.14			8.60***		0.15
			(0.00)		(0.71)			(0.00)		(0.70)
Cross volatility gold			6.85***		0.00			8.71***		0.03
			(0.01)		(0.99)			(0.00)		(0.87)
Cross volatility crypto					0.65					1.07
					(0.42)					(0.30)
Gold versus Litecoin										
Liquidity premium				2.90*	2.44				3.06*	2.58
				(0.09)	(0.12)				(0.08)	(0.11)
Exchange rate				3.65*	3.45*				0.34	0.14
				(0.06)	(0.06)				(0.56)	(0.71)
Global risk premium				6.16**	4.81**				11.73***	9.44***
				(0.01)	(0.03)				(0.00)	(0.00)
Volatility				11.47***	0.27				8.73***	0.27
				(0.00)	(0.60)				(0.00)	(0.61)
Cross volatility gold				5.40**	0.00				5.64**	0.07
				(0.02)	(0.98)				(0.02)	(0.79)
Cross volatility crypto					0.62					1.06
					(0.43)					(0.30)

Notes: Wald-tests for coefficient equality based on the estimates of the previous table. Chi-square test statistic, p-value in parentheses. A significance level of 1%, 5% and 10% is denoted by ***, ** and *.