Finance Research Letters 40 (2021) 101737

Contents lists available at ScienceDirect

Finance Research Letters

journal homepage: www.elsevier.com/locate/frl

Objective and subjective risks of investing into cryptocurrencies[☆]

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ARTICLE INFO

JEL classification:
F31
G10
G11
G41

Keywords:
Cryptocurrencies
Risk
Risk perception
Investment
Systematic literature review

ABSTRACT

New empirical evidence on cryptocurrencies emerges rapidly, and it is thus necessary to consolidate the knowledge gained and identify the gaps therein. We provide a focused, systematic literature analysis of the objective and perceived risks of investing in cryptocurrencies using 50 papers from both the academic and practice-oriented literature. As an additional contribution, we identify three important and promising research avenues, which we contend should be the focus of future research: (i) subjective perception of risks, (ii) adoption of cryptocurrencies implementing innovation research and (iii) non-standard financial risks.

1. Introduction

Cryptocurrencies have received strong attention from ventures, investors, regulators and the media but have also recently become an important topic in academic research. In this light, we face a situation in which, on the one hand, new empirical evidence emerges rapidly due to the popularity of cryptocurrencies among users. However, on the other hand, this goes hand in hand with the need to consolidate the knowledge gained in the cryptocurrency literature and identify the gaps therein. This paper establishes a systematic synthesis of both the academic and practice-oriented literature on the important yet not consolidated topic of the investment risks of cryptocurrencies. Therefore, we go beyond prior work that triaged the sparse but rapidly growing literature on cryptocurrencies (cf. especially Corbet et al., 2019) by investigating not only objective risks but also perceived risks and including high-quality practitioners' opinions.

We identify three strands of research. First, we observe that scholars simultaneously attempt to address common research questions taken from a broad tradition of financial research, such as those based on market efficiency (Urquhart, 2016; Nadarajah and Chu, 2017; Bariviera et al., 2017), price clustering (Urquhart, 2017), and high levels of skewness and kurtosis in returns and associated liquidity constraints (Phillip et al., 2018), to name just a few. According to Corbet et al. (2019, p. 182), such studies are often brief research notes due to the urgency of research problems encountered in this realm and suffer from "utilising similar datasets and employing similar methodologies consequently providing identical evidence". Hence, in-depth or broad studies and underilluminated behavioral aspects or questions on perceived risks that add new insights to the discussion would be desirable.

☆ Financial support by the InnoSuisse Program Project Nr. 35117.1 IP-SBM of the Principality of Liechtenstein is gratefully acknowledged.
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https://doi.org/10.1016/j.frl.2020.101737
Received 1 May 2020; Received in revised form 21 July 2020; Accepted 25 August 2020
Available online 20 September 2020

Second, we argue that the need for comprehensive and systematic meta-analyses, complementary to narrative overviews of the relevant literature (e.g., Vigne et al., 2017) or econometrics on bibliography (e.g., Bahoo, 2020; Zhang et al., 2019), are not only desirable in finance but also strongly indicated by the shortage thereof in the field's publications. "For new research areas such as those based around cryptocurrencies, a systematic [literature] analysis can be the most powerful tool to inform academics, professionals and policy-makers about the current state of knowledge, consensuses and ambiguities in the emerging discipline." (Corbet et al., 2019, p. 183).

Third, our literature review with special emphasis on perceived vs. objective risks is motivated by the problem of paradigmatic unity in finance research highlighted by Lagoarde-Segot (2015). The often-adopted broad traditions of mainly using research approaches based on strongly rational models not only neglect aspects of the academic discipline of behavioral finance but also simply do not capture aspects and issues that are important for practitioners and policy-makers. The crypto environment is unfortunately no exception: a traditional finance stance has been embraced (e.g., as documented by the references given above), while the scope of relevant questions is much broader, i.e., a financial stance. including those that cannot be directly addressed by using quantitative research designs and data mining, e.g., the question of what are the main perceived drivers of risk when investing in cryptocurrencies as an asset class. Therefore, we wish to do justice to such questions, which can be found mainly in the behavioral finance literature. We strongly suggest and advocate not neglecting this source of knowledge and evidence to better understand risk drivers but also to understand behavioral biases in this specific field. Therefore, by means of a systematic and comprehensive literature review, cryptocurrency research can be brought to a higher, more diversified level, enabling more meaningful contributions to knowledge. Generally, risk is paraphrased broadly as the real or realistic possibility of a positive or negative event, the occurrence of which is not certain or expectable but only more or less likely. However, whereas this broad notion of risk retains both positive and negative consequences (in terms of the evaluation of outcomes), we assume henceforth that it is judicious in the context of finance to primarily associate risks with adverse, negative or undesirable events (McNeil et al., 2015, p. 1). However, by doing so, we would need to determine what is undesirable and for whom. An outcome could be positive for some stakeholders and negative for others. For the sake of this investigation on risks in cryptocurrencies, we might thus arrive at a reading of risk whereby consequences are specified as adversely affecting an investor's ability to achieve her objectives and execute her strategies.

The remainder of this paper is organized as follows: In Section 2, we present statistical data from the papers we have analyzed and report the key results in a structured table. In the subsequent Sections 3, 4 and 5, we present potential avenues for future research and argue why it is important to place greater emphasis on them. We conclude the paper in Section 6.

2. Characteristics of the analyzed literature

Opponents of the evolution of cryptocurrencies identify major risks, particularly volatility and liquidity concerns together with cybercriminality and the unknown destabilizing effects on world economies, as the main potential pitfalls of their evolution. In this paper, we set out to illuminate key areas of risk regarding investment cryptocurrencies as assets. To this end, we apply a systematic literature review.[1] In reviewing the relevant management and finance literature from the ISI database and Google Scholar, we included 50 separate research papers in the cryptocurrency analysis at hand, of which 78% are in a more academic style and 22% more practice oriented. As general search terms, we used "cryptocurrency", "asset", and "investment" (as well as their plurals); specific search terms are given by the risk clusters such as subjective vs. objective risks or market and liquidity risk. Along these lines, we principally considered all publications since 2008, but then focused on relevance, i.e., how much and how directly does a paper contribute to addressing our research question and, secondarily, establishedness, i.e., sound research methods, reputable outlet, citations. Only 2 included papers (4%) were available before 2014, with only 1 (2%) and 3 (6%) more being published in 2015 and 2016, respectively. Of the papers included in this literature review, 30% were released in 2018, 38% in 2019, and 4% in 2020. These statistics thus provide evidence of the strong development of cryptocurrency research in recent years. Table 1 presents the results of the systematic literature analysis. We attempt to establish a classification of the literature reviewed for cryptocurrency investment risks by analyzing the main contributions of the papers. We are then able to cluster them and the main topics and research objects therein into 5 main risk areas: (i) market risk, which is subdivided into (a) volatility, (b) tail risks, i.e., the risk of very high losses in positions arising from extreme movements in market prices, and (c) systemic risk; (ii) liquidity risk; (iii) general perceived risk; (iv) operational risk; and (v) cyber risk. Next, we extract three topics that are, in our opinion, important but highly under-researched regarding the risks related to using and adopting cryptocurrencies.

3. Research avenue 1: subjective versus objective risks

There is a major debate among risk professionals about the nature of risks: are risks social or subjective constructions (human ideas about reality, a feature of the agent's informational state) or real-world, objective phenomena (representations of reality, a feature of the world itself). Willett (1901) and Hansson (2018), for example, argue for a strong objective component of risk: "If a person does not know whether or not the grass snake is poisonous, then she is in a state of uncertainty with respect to its ability to poison her. However, since this species has no poison there is no risk to be poisoned by it" (Hansson, 2018). On the other hand, it is obvious to others that risks constitute mental models (Renn and Keil, 2008). They are not veritable phenomena but originate in the human mind. Mainstream

[1] For a good overview of this methodology, see, e.g., Kraus et al. (2020).

Table 1
Systematic literature analysis .

#	Risk field	Risk Drivers	Publication	Key findings
1	Market risk / Volatility	Shocks and crashes in cryptocurrency markets RO: Bitcoin and Ripple	Fry and Cheah (2016) International Review of Financial Analysis	Bitcoin and cryptocurrency markets contain a considerable speculative component and are extremely volatile. 2 In terms of competition between rival cryptocurrencies, evidence of a spillover from Ripple to Bitcoin is found. 3 The extent to which law enforcement and government measures can affect Bitcoin markets appears mixed
2	Market risk / Volatility	Price shocks and structural breaks RO: Bitcoin, Dash, Dogecoin, Litecoin, Maidsafecoin, Monero and Ripple from June 22, 2014, to May 17, 2017	Chu et al. (2017) Journal of Risk and Financial Management	The IGARCH and GJRGARCH models provide the best fits, in terms of modeling volatility in the most popular and largest cryptocurrencies.
3	Market risk	Unique features of cryptocurrencies RO: 224 different Cryptocurrenc ies	Phillip et al. (2018) Economics Letters	41) It is found that cryptocurrencies in general have several unique properties including leverage effects and Student error distributions. 2) Cryptocurrencies show predictable patterns with mostly oscillating persistence. 3) They also display mild leverage effects, varied kurtosis and volatility clustering. 4) With no counterparty credit risk, Ripple shows the weakest leverage effect. 5) Being easier to transact, Ethereum and Dash have a smaller kurtosis than Bitcoin.
4	Market risk	1) time-series cryptocurrency momentum; 2) investor attention; 3) price-to- “dividend” ratios; 4) cost of mining RO: Bitcoin, Ripple, and Ethereum	Liu and Tsyvinski (2018) NBER Working Paper	Cryptocurrencies have no exposure to most common stock market and macroeconomic factors. Instead, cryptocurrency returns can be predicted by factors that are specific to cryptocurrency markets such as time-series cryptocurrency momentum, investor attention or cost of mining.
5	Market risk	n/a RO: Cryptocurrency Index (CRIX) Cryptocurr ency Index (CRIX)	Chuen et al. (2017) The Journal of Alternative Investments	Return correlations between cryptocurrencies and traditional assets are low and adding CRIX returns to a traditional asset portfolio improves risk-return performance.
6	Market risk / volatility	Mass collaboration and imitation, presence of structural breaks and nonlinearities in the data RO: Fixed sample of 14 CCs between 04/2013 -05/ 2018	Bouri et al. (2019a) Finance Research Letters	Herding tends occur as uncertainty increases.
7	Market risk / volatility	Connectedness via return and volatility spillovers RO: Six large cryptocurrenc ies from August 7, 2015, to February 22, 2018	Ji et al. (2019) International Review of Financial Analysis	Litecoin and Bitcoin are at the center of the connected network of returns. This finding implies that return shocks arising from these two cryptocurrencies have the greatest effect on other cryptocurrencies. Further analysis shows that connectedness via negative returns is generally stronger than that via positive returns. Ripple and Ethereum are the top recipients of negative return shocks, whereas Ethereum and Dash exhibit very weak connectedness via positive returns.
8	Market risk / volatility	Herding behavior of non- professional investors RO: 20 largest cryptocurrenc ies	Baur and Dimpfl (2018) Economics Letters	The volatility of the largest cryptocurrencies reacts more strongly to positive price changes (in stark contrast to traditional stock markets) due to the herding of uninformed investors.
9	Market risk / volatility	n/a (rather statistical than causal) RO: 3 crypto currencies and 3 currencies with recognized stores of value using daily and hourly frequency data	Peng et al. (2018) Expert Systems with Applications	Proposal for a novel machine learning model that yields better results for low- and high-frequency volatility on cryptocurrency markets, i.e., those SVR-GARCH models managed to outperform GARCH, EGARCH and GJR-GARCH models with Normal, Student’s t and Skewed Student’s t distributions; for all

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Table 1 (*continued*)

#	Risk field	Risk Drivers	Publication	Key findings
				variables and both time frequencies, the SVR-GARCH model exhibited statistical significance in its superiority over GARCH and its extensions.
10	Market risk	n/a (rather statistical than causal) RO: 500 most capitalized cryptocurrenc ies for the time span 1/1/2015 to 12/31/2017	Brauneis and Mestel (2019) Finance Research Letters	Portfolios feature substantially lower risk than single cryptocurrencies. Markowitz optimal portfolios show higher Sharpe ratios than single cryptocurrencies. The naively diversified 1/N portfolio outperforms all analyzed portfolio strategies.
11	Market risk	n/a (rather statistical than causal) RO: n/a (no access to paper)	Platanakis and Urquhart (2019) Economics Letters	Black-Litterman with VBCs that controls for estimation errors is superior. It provides superior out-of-sample risk-adjusted returns and lower risk. Their results are robust to transaction costs and short selling.
12	Market risk / volatility	Market return shocks and herding behavior among irrational individual (non- professional) investors RO: All coins listed on coinmarketcap between 2015- 01-01 and 2019 -03-25	Kaiser and Stöckl (2019) Finance Research Letters	1) Against existing evidence, significant herding in this dataset is documented. 2) This effect is stronger, when using bitcoin as a "transfer currency". 3) The identified significant herding behavior is attributed to irrational individual (non-professional) investors.
13	Market risk / volatility	Extreme price movements are explained by asset pricing rather than by herding RO: Fixed sample of 65 CCs with data available across the full observation period from 01/2015-2/2017	Vidal-Tomás et al. (2019) Finance Research Letters	1) The cryptocurrency market is characterized by herding during down markets. 2) The smallest cryptocurrencies are herding with the largest ones. 3) The presence of herding is a signal of inefficiency. 4) Traders are not basing their investment decisions solely on the behavior of Bitcoin.
14	Market risk / volatility	Regime changes RO: Bitcoin mid- prices in USD downloaded from Datastream. Aug 18, 2011, to Mar 3, 2018, for a total of 2355 observations	Ardia et al. (2019) Finance Research Letters	1) In-sample fit is best for a two-state asymmetric Student specification. 2) Inverted leverage effect is observed in both high and low unconditional volatility regimes. 3) MSGARCH models clearly outperform single-regime GARCH for value-at-risk forecasting.
15	Market risk / volatility	n/a (rather statistical than causal) RO: Bitcoin, Ethereum, Ripple, Litecoin, Ethereum Classic, Monero, Dash, Augur, MaidSafeCoin, NEM between June 23, 2014, through the end of Sept 2016	Osterrieder et al. (2016) SSRN working paper	Cryptocurrencies exhibit strong non-normal characteristics and large tail dependencies, depending on the particular cryptocurrencies, and heavy tails. Statistical similarities can be observed for cryptocurrencies that share the same underlying technology.
16	Market risk / tail risk	n/a (rather statistical than causal) RO: Bitcoin, Ethereum, Ripple, Bitcoin Cash and Litecoin	Gkillas and Katsiampa (2018) Economics Letters	Bitcoin Cash is the riskiest cryptocurrency. Bitcoin and Litecoin are the least risky cryptocurrencies.
17	Market risk / tail risk	n/a (rather statistical than causal) RO: 7 represen- tative cryptocurrencie s from August 8, 2015 through August 1, 2017	Feng et al. (2018) Journal of Applied Economics	Left-tail correlations are much stronger than right-tail correlations among the cryptocurrencies, and tail correlations increased after August 2016, suggesting high and growing systematic extreme risks. Cryptocurrencies are also both left-tail independent and cross-tail independent with four selected stock indices.
18	Market risk / tail risk	Co-movement in prices between cryptocurrencies RO: Bitcoin, Ether, Ripple and Litecoin	Borri (2019) Journal of Empirical Finance	Cryptocurrencies are highly exposed to tail risk within cryptomarkets. Cryptocurrencies are not exposed to tail risk in other global assets. Portfolios of cryptocurrencies improve risk-adjusted and conditional returns.
19	Market risk/systemic risk	Crashes and contagion RO: n/a	Huynh et al. (2018) Book "Econometrics for Financial Applications"	All pairs have the structural dependence with Kendall-plots and particularly strong left-tail dependence with Chi plots; thus contagion risk among these cryptocurrencies exists. Therefore,

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Table 1 (*continued*)

#	Risk field	Risk Drivers	Publication	Key findings
				investors should carefully pursue portfolio diversification.
20	Market risk/systemic risk	Interdependence among cryptocurrencies RO: 18 major cryptocurrenc ies	Koutmos (2018) Economics Letters	(i) Bitcoin is the dominant contributor of return and volatility spillovers among all the sampled cryptocurrencies; (ii) return and volatility spillovers have risen steadily over time; and (iii) there are “spikes” in spillovers during major news events regarding cryptocurrencies.
21	Market risk/systemic risk	Spillovers on financial and economic stability RO: Crypto-asset phenomenon	Demertzis and Wolff (2018) Policy Contribution, Bruegel Institute	Regulation is the right approach. Global cooperation in the management of the risks of the new technology should be ensured while reaping the opportunities it undoubtedly provides. Agree on the right moment to move supervision of crypto assets from the national level to the EU level.
22	Market risk/systemic risk	Contagion RO: n/a (no access to paper)	Bouri et al. (2019c) Finance Research Letters	1) Show multiple explosivity periods in all cases. 2) Find that explosivity in one cryptocurrency leads to explosivity in another. 3)Show that co-explosivity is not necessarily from larger to smaller.
23	Market risk/systemic risk	Spillovers on the financial system and the economy RO: Crypto-asset phenomenon	Chimienti et al. (2019) ECB Economic Bulletin Articles	Crypto assets warrant continuous monitoring. The challenges in measuring the phenomenon of crypto assets are diverse and relate both to on-chain and off-chain data.
24	Liquidity risk	Low liquidity in local currency Markets RO: Non-public survey data from nearly 150 companies and individuals	Hileman and Rauchs (2017) White paper, Cambridge Centre for Alternative Finance & Visa	The lines between wallets and exchanges are increasingly blurred: 52% of wallets surveyed provide an integrated currency exchange feature, of which 80% offer national-to-cryptocurrency exchange services using one of three existing exchange models.
25	Liquidity risk	n/a (rather statistical than causal) RO: 39 cryptocurrenc ies, obtained from the CRIX cryptocurrenc ies database	Trimborn et al. (2018) Working paper on EconStor	The estimation error on portfolio risk estimation can remain small after liquidity constraints are included. Adding cryptos can improve the risk-return tradeoff of portfolio formation, in both the in-sample and out-of-sample case. Adding liquidity constraints can also improve the out-of-sample performance of the portfolio.
26	Liquidity risk	Under-insurance and uninsurability of crypto companies, resulting in a lack of investor security RO: n/a	Disparte (2018) Forbes Magazine	Despite reports of growing insurer interest in the segment, the majority of crypto assets and crypto companies are either underinsured or uninsurable by today’s standards. There is no deposit insurance “floor” for this asset class, which can help broaden appeal and investor security.
27	Liquidity risk	Crypto-exchange failures, large-scale hoarding of crypto-tokens by a few large investors, and the immaturity of the cryptoexchange market RO: n/a	Greene and McDowall (2018) Long Finance	Cryptocurrency is an extremely illiquid asset class – it is two orders of magnitude more illiquid than equities. It is a classic example of a liquidity black hole. Cryptocurrency will be shunned by money-center banks due to excessive VaR-based economic capital requirements.
28	Liquidity risk	n/a RO: 456 crypto currencies	Wei (2018) Economics Letters	Return predictability diminishes as liquidity increases in cryptocurrencies. Volatility decreases as liquidity increases in cryptocurrencies. There are no signs of an illiquidity premium.
29	Liquidity risk	Assessing the relation between trading volume, market liquidity and volatility RO: 180 cryptocurrency pairs with prices and volume data aggregated from over	Bianchi and Dickerson (2019) SSRN working paper	The interaction between lagged volume and past returns has significant predictive power for future returns. An investment strategy that conditions on past returns and volume generates a

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Table 1 (*continued*)

#	Risk field	Risk Drivers	Publication	Key findings
		250 exchanges from 3 Jul 2017 to 6 Dec 2019		substantial Sharpe ratio with zero correlation with Bitcoin and Ethereum dollar returns.
30	Liquidity risk	Changes in currency liquidity RO: Database of intraday bitcoin data that spans 14 exchanges & includes prices against 13 currencies	Marshall et al. (2019) SSRN working paper	There is both substantial variation in the level of liquidity across different exchanges and currency pairs and a strong systematic aspect to bitcoin liquidity. Moreover, changes in currency liquidity influence bitcoin liquidity. The pricing of bitcoin is relatively inefficient, and liquidity plays an important role. Liquidity declines also contribute to bitcoin crash risk.
31	Liquidity risk	Actual prices for cryptocurrencies can differ greatly, there is no unifying single price mechanism that will reflect the price of a cryptocurrency – such is the power of decentralization RO: n/a	Tan (2019) Altcoin Magazine	Because seasoned traders in cryptocurrency markets are able to detect automated market making bots on cryptocurrency exchanges, “fake” liquidity can often lead to large-scale departures from a cryptocurrency exchange. The greatest danger in financial markets could well be that investors are underpricing liquidity (or rather the lack of liquidity) risk – something that seasoned cryptocurrency traders constantly include in their risk management toolkits.
32	Liquidity risk	Scams, hoarding of crypto- tokens by few RO: CoinMarketCap’s new metric, dubbed Liquidity	Martinez (2019) Cryptocurrency News	Lack of institutional investment. Less than 1% of all cryptos are liquid. Prominent figures in the industry agree that 99% of all cryptos will not prevail.
33	Liquidity risk	Cryptocurrency wealth distribution RO: n/a	Staff Writer Blockchain News	Cryptocurrency wealth distribution is even more skewed than that of traditional wealth, only a few with large stakes in a cryptocurrency, also called bitcoin whales, can hold disproportionate amounts of power over its pricing.
34	General risk of using cryptocurr encies (“perceived risk” is a variable/ construct in the model)	Financial Losses, Legal Risk and Adoption Risk tend to substantially influence Perceived Risk, while Operational Risk has a lower impact RO: Bitcoin	Abramova and Böhme (2016) 37th ICIS Conference	Key determinants and inhibitors of Bitcoin use. Financial losses, legal risk and adoption risk tend to substantially influence perceived risk, while operational risk has a lower impact. Perceived risk in turn has a relatively strong negative influence on the adoption of Bitcoin.
35	General risk of using cryptocurr encies	Risk does barely affect consumer behavior / the intention to use cryptocurrencies RO: A structured and self- administered online survey on the use of cryptocurrencies to sample 402 people between August 1, and September 10, 2018 (older than 20, living in Spain with a university degree)	Arias-Oliva et al. (2019) Frontiers in Psychology	The tested model is able to explain almost 85% of the intention to use cryptocurrencies. Surprisingly, risk was not a significant factor. This could be because most of the respondents considered operating with cryptocurrencies to be risky; the lack of variability in their responses to the questions about perceived risk would explain this lack of explanatory power. However, willingness to manage cryptocurrency risk could be a precondition for adoption. The expected performance of a given cryptocurrency was the most important factor for its success.
36	General risk of using cryptocurr encies	Risk does barely affect consumer behavior / the intention to use cryptocurrencies RO: n/a (no access to paper)	Mendoza-Tello et al. (2019) Information Systems and e-Business Management	Perceived trust, perceived risk, and perceived ease of use are not strong predictors of the intention to use cryptocurrencies, and the strength of their effects on the intention to use is determined by the perceived usefulness of adopting the mentioned disruptive innovation.

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Table 1 (*continued*)

#	Risk field	Risk Drivers	Publication	Key findings
37	Operational risk	The great number of existing markets and the possibility of exchanging easily bitcoins by euros, pounds or dollars is fostering money laundering or illegal traffic of substances RO: Bitcoin	Brezo and Bringas (2012) Proceedings of The Second International Conference on Social Eco- Informatics (SOTICS)	The intrinsic complexity of the protocol and the necessity of having some relatively advanced knowledge on cryptography and computer studies to understand its real behavior make these cryptocurrencies the perfect place for speculation and misinformation. They are the perfect vehicle to perform every kind of transaction related to money laundering or illegal traffic of substances, with all the legal implications associated with the jurisdictional limitation of the criminal acts performed in cyberspace.
38	Operational risk	Vulnerable Bitcoin protocol RO: Bitcoin	Eyal and Sirer (2014) Working paper on arXiv.org	The Bitcoin protocol is not incentive compatible. Presentation of an attack with which colluding miners obtain a revenue larger than their fair share. This attack can have significant consequences for Bitcoin: Rational miners will prefer to join the selfish miners, and the colluding group will increase in size until it becomes a majority. At this point, the Bitcoin system ceases to be a decentralized currency.
39	Operational risk	No intervention of a third party to act as an arbiter of verification RO: Bitcoin	Gao et al. (2016) Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems	Not understanding how Bitcoin works is not a barrier to entry, although non- user participants claim it would be for them and that user participants are in a state of cognitive dissonance concerning the role of governments in the system.
40	Operational risk	"Brain wallets" enable attackers to conduct unlimited offline password guessing RO: Bitcoin. Evaluation of around 300 billion passwords. 884 brain wallets worth $100K in use from September 2011 to August 2015	Vasek et al. (2017) International Conference on Financial Cryptography and Data Security	Large-scale measurement of the use of brain wallets in Bitcoin. All but 21 wallets were drained, usually within 24 hrs but often within minutes. Approximately one dozen "drainers" are competing to liquidate brain wallets as soon as they are funded. No evidence that users of brain wallets loaded with more bitcoin select stronger passwords, but brain wallets with weaker passwords are cracked more quickly.
41	Operational risk	Money laundering and terrorist financing RO: n/a	Secretariat (2018)	To date, the Swiss authorities have not identified a single case of terrorist financing using crypto assets or online crowdfunding and have recorded only a few cases of money laundering using these new technologies.
42	Operational risk	Tokens may be re-qualified retroactively as securities by regulatory agencies RO: n/a	Cloots (2018) Cambridge - McKinsey Risk Prize Paper	The main legal risk is the reclassification of a sizable number of tokens as securities. Any ICO requalified as a security issuance and not compliant with stringent securities regulations can lead to criminal sanctions for the organization and individuals behind the token sale. Further legal risks of cryptocurrency sales and transactions are violations of anti-money laundering laws for financial institutions. Also be aware of the compliance risks regarding the EU's GDPR.
43	Operational risk	Irreversibility of transactions, hacking, scams, password loss RO: n/a	Bodden et al. (2019) Cayman Funds Magazine	If you transfer coins to the wrong account, or "wallet", they are gone – you cannot get them back. If you are running a trading operation and an unscrupulous trader moves coins into his own wallet and not the corporate wallet, there is little you can do to get them back. If an exchange that you are trading on gets hacked or you lose your username/

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Table 1 (*continued*)

#	Risk field	Risk Drivers	Publication	Key findings
				password, your coins are lost; if you are storing your coins on a laptop and a hacker breaks in and steals them, they are gone as well.
44	Operational risk	Know Your Customer ("KYC") as the cornerstone of the AML/CFT due diligence requirements RO: n/a	Poskriakov et al. (2019) Global Legal Insights, Blockchain & Cryptocurrency Regulation	Virtual currency exchange platforms allowing the conversion of virtual currencies into fiat money (and vice versa) are of particular relevance and must be brought within the scope of the respective national anti-money laundering and counter-financing of terrorism ("AML/CFT") frameworks.
45	Operational risk	ICO scams RO: Recent literature on ICOs	Chohan (2019) Book "Cryptofinance and Mechanisms of Exchange"	How the weaknesses of ICOs may be addressed so as to better leverage their strengths in value creation and innovation.
46	Cyber risk	Characteristics of crypto and virtual currencies that may be exploited to launder corruption proceeds RO: 75 FATF and FATF-style regional bodies' mutual evaluation reports	Choo (2015) Handbook of Digital Currency	Characteristics of crypto and virtual currencies that may be exploited to launder corruption proceeds. Proposal of a conceptual intelligence-led AML/CTF strategy.
00000 47	Cyber risk	Crypto-exchange scams RO: Transaction data, Mt. Gox, from 2011/01/01 to 2013/10/08	Glaser et al. (2014) SSRN working paper	Strong indications that especially uninformed users approaching digital currencies are not primarily interested in an alternative transaction system but seek to participate in an alternative investment vehicle.
48	Cyber risk	Money laundering possibilities RO: -	Vandezande (2017) Computer Law & Security Review	Inclusion of virtual currency service providers under anti-money laundering rules appears to be viable; it remains to be seen what the consequences of this evolution are for developments in virtual currencies. Analysis of a regulatory issue currently debated by legislators worldwide.
49	Cyber risk	Consensus mechanism key security, double spending, privacy, smart contracts	Li et al. (2020) Working paper on arXiv.org	A systematic study on the security threats to blockchain and survey of the corresponding real attacks by examining popular blockchain systems. The security enhancement solutions for blockchain are also reviewed, which could be used in the development of various blockchain systems.
50	Cyber risk	Consensus as a fundamental problem of distributed computing RO: Bitcoin and Ethereum consensus algorithms	Gramoli (2020) Future Generation Computer Systems	1) Warning about the dangers of using Bitcoin and Ethereum blockchains without understanding precisely the guarantees their consensus offers. 2) Presentation of a survey of attacks against proof-of-work blockchain systems.

finance emphasizes objective, statistical, distribution-based measures of risk. It deals with historical risk (e.g., beta or standard deviation) and various categories of risk (market risk, credit risk, liquidity risk, etc.) and makes use of long-term data over a specific time period, as well as sophisticated statistical models to assess risk on the macro level for specific financial instruments. By contrast, behavioral finance scholars employ the "behavioral approach" to evaluate risk based on data from laboratory experiments and survey/questionnaire channels. In their view, risk has a subjective (perceived) component: the examination of beliefs, attitudes, and feelings towards risk regarding a specific situation, activity or circumstance. An emphasis lies, thus, on the microfinance perspective given the focus on the judgments of individual decision-makers. Particularly, subjective financial risk can be conceptualized as the perceived negative monetary consequences that can occur when obtaining a financial product (Conchar et al., 2004).

The relevance and importance of considering perceived and non-standard financial risks can be derived, for example, as a key lesson from the global financial crisis of 2007/2008. It has shown that risk has been overly compartmentalized. All the risk categories, from the market risk silo to the liquidity risk silo, interact and possess a subjective component.

Compared to established or well-known financial instruments, it can be hypothesized that investors are likely to perceive greater risk in cryptocurrencies because they typically involve greater monetary risks, e.g., given their high volatility. In this respect, perceived financial risk has been found to positively affect decision-makers' information seeking (Campbell and Goodstein, 2001) and to negatively affect their transformation of purchase/investment intention into actual purchase/investment behavior (e.g., Tan, 2019).

Moreover, it is found that subjective risk attitudes are a better predictor of objective risk attitudes than a set of commonly employed socio-demographic and economic characteristics such as age or income (Oehler et al., 2018). However, these findings relate to consumer research and behavioral finance, not specifically to cryptocurrencies. The relevance of known behavioral factors in the area of crypto investments is clearly underilluminated in the literature, which is why we strongly argue to expand the research scope in future studies. In the following, we will also account for both perceived risks (see the next Section 4) and objective risks (see Section 5 and Table 1).

4. Research avenue 2: adoption of cryptocurrencies implementing innovation research

A risk that is perceived to be high but our literature review indicates has been researched sparsely is the perceived risk of the adoption of a new technology, in this case adopting cryptocurrency for a variety of applications, from cryptocurrency as a peer-to-peer payment solution to cryptocurrency as an asset. Common characteristics of this first group of contributions are as follows:

- They emphasize on the behavioral aspect of general risk by studying what factors empirically influence and determine the adoption or acceptance rate of cryptocurrencies.
- Adoption and acceptance research forms part of innovation research and, thus, is also general in the sense that focuses on the adoption or acceptance of an innovation per se.
- Common theoretical underpinnings are the following: the "unified theory of acceptance and use of technology" (short: UTAUT), according to Venkatesh et al. (2003), combines the findings of the eight most widely used acceptance models at the time. The following theories were merged into this: the "theory of reasoned action" (TRA), the "theory of planned behavior" (TPB), the "theory acceptance model" (TAM), the "motivational model" (MM), the "combined TAM/TPB-model" (C-TAM-TPB), the "model of PC use" (MPCU), the "innovation diffusion theory" (IDT) and "social cognitive theory" (SCT) (Oshlyansky et al., 2007; Venkatesh et al., 2003). In the extended unified theory of acceptance and use of technology (UTAUT2) model, four independent core factors influence the behavioral intention to actually use an innovation (Venkatesh et al., 2003): (i) performance expectancy, (ii) social influence, (iii) effort expectancy, and (iv) facilitating conditions. Moreover, four moderation variables, which influence the four core factors, are taken into account in the model: (i) experience, (ii) voluntariness of application, (iii) gender and (iv) age. The first three independent factors affect behavioral intention and actual use, while the "facilitated conditions" have a direct effect on behavioral use.
- Those models and theories can be adjusted or extended to suit specific investigations. Particularly, "perceived risk" has been added as an independent variable for most FinTech innovations. Following Kalaiarasi and Srividya (2012), a high perceived risk positively affects the reluctance to use an application. The risk factor in the financial services market is presumably very relevant regardless of the object of the study. Lee (2009) shows that perceived risk plays a greater role in banking services than in other service domains, as personal data and financial resources are involved in the financial services sector on the one hand and are very often transmitted online and/or via a mobile device on the other (Kazi and Mannan, 2013). Accordingly, the risk of data misuse is given priority (Arcand et al., 2017). Various studies note that cyber problems and hacker attacks are also perceived as risks in the financial services business (Tai and Ku, 2013). Therefore, it is often reasoned/hypothesized in such studies that perceived risk has a significant negative influence on the behavioral intention to use a FinTech innovation, including cryptocurrencies.

5. Research avenue 3: Non-standard financial risks

One of the most immediate obstacles for cryptocurrencies at large are the sometimes extreme changes in market prices that come with tail and systemic risks. Our literature review shows that although there is recognition of the non-standard financial risks of cryptocurrencies, research on them remains scarce. Of course, market risks and high volatility of cryptocurrencies can easily be gleaned from price data (e.g. by consulting price charts or computing the standard deviation) and, therefore, almost be treated as given. Greater effort is required, however, to explain how such price movements come about, which is why much work in this realm has focused on investigating the risk drivers. For example, Kaiser and Stöckl (2019) point to market return shocks and herding behavior among irrational individual (non-professional) investors, thereby building on the ongoing debate on the existence of herding behavior on the cryptocurrency market. In this context, Bouri et al. (2019a) and Vidal-Tomás et al. (2019) present empirical evidence on the behavioral finance aspect of herding among cryptocurrencies. More broadly, patterns of herding behavior in the cryptomarket can also be related to effects induced from trading volume (Bouri et al., 2019b), price explosivity (Bouri et al., 2019c) and connectedness (Ji et al., 2019). Bouri et al. (2019b) argue for a positive causal relation between trading volume and future returns, based on a quantile regression approach. Moreover, Ji et al. (2019) demonstrate that return shocks to Bitcoin and Litecoin exhibit strong knock-on effects on altcoins, with the effect being stronger for negative shocks. In addition, Baur and Dimpfl (2018) make the case that the volatility of the largest cryptocurrencies reacts more strongly to positive price changes, which stands in stark contrast to traditional stock markets, due to the herding of uninformed investors. The notable exceptions are Bitcoin and (to some extent) Ethereum, which again highlights their special role of being (at least more easily) tradable on fiat exchanges. Fry and Cheah (2016) test for the existence of bubbles using data from 2011 to 2015 and a multivariate methodology. Drawing from statistical physics and mathematics, the authors find evidence of a negative bubble from 2014 onwards in the two largest cryptocurrencies, Bitcoin and Ripple. Evidence also suggests that there is a spillover from Ripple to Bitcoin that exacerbates price decreases in the latter, with Ripple being the more overpriced of the two. In terms of systemic risks, Bouri et al. (2019c) examine the price explosivity of the seven largest cryptocurrencies by market capitalization using daily data from August 7, 2015, to December 31, 2017. The results demonstrate that all cryptocurrencies in the sample (Bitcoin, Ripple, Ethereum, Litecoin, Nem, Dash, and Stellar) exhibited explosive behavior in multiple periods. Furthermore, their study shows a multidirectional co-explosivity behavior, referring to the transmission of these dynamics among alternative cryptocurrencies, while this effect does not necessarily depend on the size of each cryptocurrency. Moreover, Bitcoin is reported to be the least dependent on the explosivity of other cryptocurrencies, whereas altcoins show higher levels of co-explosivity.

6. Conclusion

We provide a focused, systematic literature analysis of the objective and perceived risks of investing in cryptocurrencies. In analyzing the existing literature, we identified three important and promising research avenues, which we argue should be the focus of future research. Recognizing that cryptocurrencies are developed to be used and bought not only by professional investors but also the broad mass of individual investors, we believe that especially in-depth analysis of perceived risks is essential to accomplish a higher level of cryptocurrency adoption and usage.

Author statement

The paper has been produced in close co-working between all authors. All authors have contributed in all areas of the paper as well as during the whole process. We therefore chose to use alphabetical order of authors.

CRediT authorship contribution statement

Martin Angerer: Conceptualization, Project administration, Funding acquisition, Supervision, Writing - review & editing. **Christian Hugo Hoffmann:** Data curation, Formal analysis. **Florian Neitzert:** Validation, Writing - review & editing. **Sascha Kraus:** Writing - review & editing.

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