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Review of Maximal Extractable Value & Blockchain Oracles

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FCA research notes in financial regulation

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1 Notice

This note presents emerging technology research, jointly carried out by the Emerging Technology Research Hub and Wholesale Cryptoasset Policy at the FCA to explore unique behaviours and mechanisms that are present in blockchain ecosystems.

The FCA's approach to regulation takes into consideration the regulatory design principle of "same risk, same regulatory outcome." The FCA is also a technology neutral regulator, meaning the underlying technology of activities does not impact the regulatory perimeter. However, the choice of technology can impact the risk landscape associated with the end application and ultimately affect consumer and market outcomes. As such, the underlying technology may impact how regulations are applied. To do this effectively, it is essential for regulators to understand the ecosystem in which new technology operates and the unique behaviours and mechanisms that can accompany innovation.

This paper is designed to support market participants and regulators to better understand the emerging technology landscape and build the foundation of knowledge needed to assess the potential risks and opportunities created by new technology. The discussions in this paper are not an endorsement of any technology and are not intended to give any particular technology prominence over another.

The FCA has produced this research note to support ongoing efforts to proactively assess where new technology may pose both unique risks and opportunities to consumers and markets. The findings of this research will help to inform the FCA thinking about a regulatory regime for the activities that Treasury has confirmed it plans to bring within the FCA's perimeter, as set out in the Treasury's Feedback Statement on the Future Financial Services Regulatory Regime for Cryptoassets.

Cryptoassets remain a high-risk investment, and consumers should be aware of the risks. Cryptoasset firms marketing to UK consumers will now be required to comply with the UK financial promotions regime. However, consumers that choose to purchase cryptoassets should be prepared to lose all their money and are unlikely to be covered by financial protections such as the Financial Services Compensation Scheme.

Disclaimer

This research note does not reflect policy views or a formal FCA position.

2 Overview

Purpose of the Analysis

Blockchains and distributed ledgers share properties that allow for the recording of information in a way which makes it highly challenging to be changed or altered. The introduction of smart contract technology, self-executing code, has expanded the functionality of blockchains and allowed for new types of cryptoassets and financial activities to take place. Financial activities that make use of decentralised blockchain technology are known as decentralised finance (DeFi) and involve a multi-layered technology stack that automate operations and remove the need for intermediaries that exist in traditional finance (TradFi). As a result, novel technological infrastructure and behavioural mechanisms have emerged to enable DeFi activity and sometimes differ significantly to those observed in TradFi, raising novel questions for regulators.

Through our ongoing in-house horizon scanning activities we have identified various elements at the technical level of blockchain technology that are altering the way in which cryptoasset services and DeFi are provided. This research analyses two novel concepts of blockchain technology, Maximal Extractable Value (MEV) and blockchain oracles. As well as expanding the functionality of decentralised financial applications, these features have been identified as introducing risks and potential sources of vulnerability. This research was undertaken to increase our understanding and build the regulatory expertise into these emerging aspects of blockchain technology.

The insights of this research will be used by stakeholders across the FCA to inform future engagement and discussions. Through analysing the literature and market perspectives of these features, market participants and regulators, both domestically and internationally, will be better placed to evaluate outcomes and make informed decisions in this space.

This paper, and the research within it, is a standalone exploratory deep dive into two emerging technology components of blockchain. This research note serves primarily as a technical knowledge-building exercise in enhancing awareness of developments in blockchain technology and does not serve as part of the policy consultation or development process on cryptoasset regulation. This note will be of interest to market participants and interested stakeholders seeking to expand their knowledge base of blockchain technology, and understand market perspectives on blockchain oracles and ordering strategies associated with maximal extractable value.

Key Findings

We conducted a two-staged qualitative exploration of MEV and blockchain oracles. In stage one we undertook a literature review exploring the two concepts in collaboration with Dr Arthur Gervais from University College London (UCL). In stage two, following a competitive tender process, independent research agency Futuresight Business Intelligence Ltd, conducted a small-scale qualitative study on behalf of the FCA. This involved interviewing a selection of industry experts to gather their views on these issues

and provide anonymous feedback to inform our research. Below provides a brief outline of the concepts and a summary of the key insights:

Maximal extractable value

- Maximal extractable value (MEV) is a metric of value derived from the ordering of transactions into blocks. Transparency on the blockchain enables transaction ordering to occur, incentivising the maximisation of value extraction from block creation.
- The research, both literature review and interviews, indicate there are mixed perspectives over what might be regarded as 'good' and 'bad' strategies to generate MEV.
- Negative perspectives were centred around the transparency and consistency in transaction fees. For example, industry respondents perceive front-running, back-running and sandwich attacks as potentially unethical uses of MEV.[1]
- Respondents acknowledged the positives of MEV such as arbitrage for price discovery, balanced liquidity pools and improved incentive for validators.
- Respondents highlighted that there are incentives in the market to mitigate the negative impacts of MEV such as network congestion, higher costs, and information asymmetries.

Blockchain Oracles

- Blockchain oracles are an important infrastructure component that expand the functionality of smart contracts by providing a mechanism to bring information and data on-chain or across chains.
- Blockchain oracles were regarded by some industry respondents as potential threat vectors that are vulnerable to attacks by bad actors through either directly altering the data flows or using secondary tools such as flash loans to manipulate data flows.[2]
- Design features such as the degree of decentralisation of oracles, number and quality of data sources and data feeder selection process(es) were identified as factors that could impact the vulnerabilities associated with blockchain oracles.
- Respondents from the interviews suggested greater transparency and standards for how oracle reliability should be assessed and verified.
- The concept of 'good practice' in this space is emerging. There were open questions and different perspectives from interview participants regarding the role of regulatory oversight in setting oracle standards.

Regulatory and Market Considerations

As a technology neutral regulator, we acknowledge that the medium of technology can impact the risk profile end users are exposed to. The findings of this qualitative research will help inform and feed into the future pipeline of regulatory thinking regarding cryptoassets and DeFi, and present further considerations for both market participants and regulators.

[1] We provide an outline of these concepts on page 14 in this document. It is important to note that although terminology such as 'front-running' is commonly used to explain specific practices in traditional finance, there is ongoing debate around whether these terms are appropriate for decentralised finance, see Barczentewicz et al. (2023a and 2023b).

[2] See section 3.2 for an overview on how oracle manipulation using flash loans can take place (Qin et al., 2021).

Some key considerations we have identified for regulators and the market include:

- Greater clarity on the different types of MEV. The creation of a taxonomy which identifies factors that could help to distinguish between malicious and benign types of MEV could aide market and regulatory thinking, and understanding in this space.
- The outcomes imposed on different market participants resulting from value extraction and clarity on how these differ depending on the type of value extraction. For example, differentiating between outcomes where the order flow may not be publicly available and there may be considered privileged access to information.
- The interrelationship between blockchain oracles and operational resilience of systems, the potential spillover effect upon the wider ecosystem and responsibility associated with the failure of an oracle.
- The interplay between existing market developments such as smart contract audits, emerging industry standards and regulation to secure desirable outcomes such as enhanced market integrity and consumer protection.
- The future trajectory of novel features in blockchain systems like MEV and oracles, and how they may develop as the ecosystem matures.
- The role of the regulators in monitoring and understanding such developments in technology and the best way to engage with industry to yield the best outcomes for markets and consumers.

Future research activity that seeks to address these areas would be of benefit to the industry and international bodies exploring the implications posed by MEV and blockchain oracles. This research note represents the first small-scale technical study of emerging technology issues by the FCA, and we would like to encourage future research into some of the areas highlighted above to advance thinking in this space and further support regulatory understanding.

Through further engagement on upcoming phases of the cryptoasset regulatory regime with industry, academia, domestic and international regulatory partners, and other market participants, the FCA will continue to evaluate the regulatory considerations raised by MEV and blockchain oracles, along with other questions raised in the consultation process.

3 Research context

On one hand the landscape of innovation in the blockchain space has evolved at pace. On the other, historic volatility events compel a further evaluation of the emerging risks posed by future applications using this technology.[3] Both make imperative the need for continued exploration by market participants and regulators to inform future thinking, discussion, practices, and policymaking.

Key components and features of blockchain technology have gained the attention of regulators around the world, with many exploring the potential implications upon users and markets. Unique features of the blockchain such as MEV, oracles and smart contracts have been called out by regulators in relation to innovation, market abuse and investor protection.[4] Additionally, there remain challenges in addressing cross-border risk, necessitating international cooperation on approaches to DeFi policies that expand beyond the scope of MEV and oracles.[5] As standards and regulation continue to develop and emerge, we believe close collaboration with industry, academia and regulatory bodies around the world will help to advance understanding of unique features of the technology.

In 2023, the UK cryptoasset landscape saw key events such as the introduction of cryptoasset financial promotion rules,[6] and the implementation of Financial Action Task Force (FATF) recommendation 16 to cryptoassets, also known as the Travel Rule.[7] These developments build on top of an existing anti-money laundering regime and set the stage for future phases of regulation. As set out by the Treasury, Phase 1 will see the regulation of fiat-backed stablecoins, and Phase 2 will cover various cryptoasset activities relating to issuance, exchange, investment and risk management, lending, and safeguarding of cryptoassets.[8]

As the regulatory framework for cryptoassets evolves, interest in DeFi is emerging as a topical area of research both in the UK and overseas. DeFi is not formally defined,[9] but generally refers to the use of blockchain technology to deliver financial services such as trading and lending in an open and decentralised way, by reducing the need for intermediaries.[10] The intricate nature of DeFi introduces unique challenges and there is work being undertaken by a number of international organisations to evaluate key risks in the DeFi ecosystem. Outlined below are several key consultations and reports that

[3] For example, major industry events occurred in 2022, such as the de-pegging of the TerraUSD stablecoin in May and the bankruptcy of cryptoasset exchange operator FTX in November (Butts and Qin, 2022).

[4] Crypto, tokens and DeFi: navigating the regulatory landscape (Ocampo et al, 2023); Decentralised" or "disintermediated" finance: what regulatory response? (Fliche et al, 2023); The Financial Stability Risks of Decentralised Finance (Financial Stability Board, 2023); Final Report with Policy Recommendations for Decentralized Finance (International Organisation of Securities Commissions, 2023b).

[5] Assessing Macrofinancial Risks from Crypto Assets (Hacibedel and Perez-Saiz, 2023).

[6] The UK cryptoasset financial promotions regime came into effect on 8 October 2023, applying to cryptoasset firms marketing to UK consumers. See the following FCA webpage for further information.

[7] The Travel Rule came into effect for cryptoasset businesses in the UK on 1 September 2023. For further information, see this statement available on the FCA's website.

[8] DP23/4: Regulating cryptoassets Phase 1: Stablecoins (FCA, 2023); Future financial services regulatory regime for cryptoassets: Response to the consultation and call for evidence (His Majesty's Treasury, 2023b).

[9] IOSCO's final report on DeFi notes that there is no currently accepted definition of DeFi, but also notes that it "commonly refers to financial products, services, activities, and arrangements that use distributed ledger or blockchain technologies (DLT), including self-executing code referred to as smart contracts." (International Organisation of Securities Commissions, 2023b).

[10] Several interesting perspectives on DeFi can be found in the following papers; The Technology of Decentralized Finance (DeFi) (Auer et al. 2023); Decentralised Finance in the EU: Developments and risks (European Securities and Markets Authority, 2023); Policy Recommendations for Decentralized Finance (DeFi) Consultation Report (International Organisation of Securities Commissions, 2023a).

were published over the course of 2023. This points towards a growing exploratory interest in novel features of blockchain technology in domestic and international regulatory research circles.

Publications and Research Reports in 2023

- In February 2023, the Treasury released its consultation on the Future Financial Services Regulatory Regime for Cryptoassets, in which it detailed a phased approach for FCA regulation of cryptoassets in the UK. The Treasury's consultation traced the unique challenges DeFi poses to policymakers, such as the varying levels of decentralised governance and its globalised nature.[11] Chapter 11 of the consultation paper notes the importance of international approaches and called for views from respondents on a variety of regulatory considerations including DeFi. The consultation also outlined the provision of greater powers to the FCA in relation to regulating cryptoasset activities.

- Following the consultation, the Treasury released a feedback statement in October 2023 acknowledging the complexity of DeFi. Emphasising alignment with international efforts, the paper highlighted that the Treasury aims to avoid proposing any DeFi specific regulated activities at present as they may require substantial revisions as global standards for DeFi become more defined. In chapter 9 (paragraph 9.3), the paper mentions the potential for MEV to lead to sub-optimal outcomes for market participants and frontrunning-like behaviour.[12] The Treasury has not currently proposed that running oracles or validators would be categorised as regulated activities.

- The Bank for International Settlements (BIS) produced a research report in May 2023 on the regulatory landscape for crypto, tokens, and DeFi.[13] The BIS's report noted a need for authorities to assess current regulatory perimeters or develop new legal frameworks to address risks posed by features of DeFi. The paper in its fourth section made brief mention that a legal framework for operating oracles would allow for the liabilities of oracles to be defined, enabling the integration into DeFi of some of the safeguards seen in TradFi.

- Organisations from the European Union have published a number of papers exploring unique features of blockchain. The European Systemic Risk Board released a paper on cryptoassets and decentralised finance in May 2023 which considered systemic implications and policy options.[14] The report flagged that when reliant on external information sources like oracles, smart contracts "are susceptible to both corruption and malicious manipulation." In October 2023, the European Securities and Markets Authority (ESMA) published a risk analysis of DeFi in the EU, flagging MEV as a technique in the decentralised space raising

[11] For more information on the regulatory challenges posed by DeFi, see chapter 11 ('Call for Evidence: Decentralised Finance (DeFi)') from the Treasury's consultation document (His Majesty's Treasury, 2023a).

[12] Future financial services regulatory regime for cryptoassets: Response to the consultation and call for evidence (His Majesty's Treasury, 2023b).

[13] Crypto, tokens and DeFi: navigating the regulatory landscape (Ocampo et al, 2023).

[14] Crypto-assets and decentralised finance (European Systemic Risk Board, 2023).

market manipulation concerns.[15] ESMA's paper also mentions how tools such as flash loans can be used to facilitate the manipulation of an oracle.

- A joint paper was published by the International Monetary Fund (IMF) and the Financial Stability Board (FSB) in September 2023 following the G20 summit hosted in India.[16] Section 2.3.3 of the paper highlights the prevalence of examples of manipulation in cryptoasset markets, adding that some MEV practices could lead to profits for validators and losses to other market participants, and that this phenomenon stems from the ability of validators to order transactions. The paper further highlighted that forms of MEV are resultant from practices that would be considered in traditional finance as illegal in some jurisdictions.

- The International Organization of Securities Commissions (IOSCO) released a Final Report in December 2023, presenting nine policy recommendations for DeFi, relating to challenges surrounding market integrity and investor protection.[17] The paper reinforces the need for regulators to gain a holistic understanding of the structural components of DeFi. The consultation and final report discuss how analysis at a technical level, including settlement layer operations such as maximal extractable value and technology components such as oracles, can help to understand DeFi activity and the resulting products and services. In addition, similarly to the IMF-FSB joint paper, IOSCO's paper mention that certain MEV practices, such as the ordering of transactions, would be considered manipulative or unlawful by some if done in traditional financial markets. The paper recognised that DeFi products often rely on oracles to provide off-chain information like pricing data, but also noted that oracles present operational risks like manipulation and mispricing.

Research in this space can help provide a nuanced understanding of where differences in the underlying infrastructure may lead to certain behaviours, opportunities, and risks. As such, research that supports regulators to grasp the intricacies of the technology's context helps to make informed decisions. In this research note, we investigate MEV and blockchain oracles in order to understand potential channels of risk, emerging market perceptions and add to the growing body of research in this space. Through the Emerging Tech Research Hub, the FCA will continue to proactively engage industry and academia on novel technology features like MEV and blockchain oracles to the extent that they pertain to upcoming phases of the future regulatory regime for cryptoassets, where relevant. In addressing the currently fragmented and borderless nature of blockchain technology, the FCA will also continue to contribute to the global discussion on DeFi through working groups of global standards setting bodies such as the Fintech Task Force of IOSCO.

At a fundamental level, the FCA is guided by its primary strategic, to ensure financial services markets function well, and operational objectives: an appropriate degree of consumer protection, the protection and enhancement of the UK financial system, and the promotion of effective competition in the interests of consumers. The FCA also

[15] Decentralised Finance in the EU: Developments and risks (Chone et al. 2023).

[16] IMF-FSB Synthesis Paper: Policies for Crypto-Assets (International Monetary Fund and Financial Stability Board, 2023).

[17] IOSCO published a consultation report in September to seek feedback on the proposed policy recommendations (International Organisation of Securities Commissions, 2023a) which was followed by the Final Report outlining the finalised recommendations in-line with feedback from the consultation and wider research (International Organisation of Securities Commissions, 2023b).

considers its secondary international competitiveness and growth objective (SICGO) alongside the primary objectives. The way in which MEV and blockchain oracles cohere with upcoming phases of the future regulatory framework for cryptoassets, the contemporary state of the industry, and the FCA's primary and secondary objectives continues to be under consideration.

4 Methodology

This research programme began in early 2023 and used a twofold approach to evaluate the theoretical and practical opportunities and challenges presented by MEV and oracles. Stage one of the research involved conducting an internal literature review with academic oversight. In stage two, an external market research agency, Futuresight Business Intelligence Ltd conducted 22 qualitative interviews with industry experts to gather market perspectives and share anonymously with the FCA. The following section provides more detail on each of these stages.

Stage 1 - FCA Literature Review

The literature review constituted the foundational stage of the research. This stage was carried out with the support and collaboration of relevant experts across the FCA and with the support of Dr Arthur Gervais from UCL. This research note does not contain the full literature review carried out in stage one and instead uses the insights where necessary to supplement the key findings from stage two.

The primary objectives of the internal literature review were:

1. **Concept Exploration:** The initial step involved a technical exploration of MEV and blockchain oracles. This encompassed analysing existing definitions, core principles and the underlying theories relating to both, MEV and oracles. This step was essential to establish a solid conceptual framework for the research.
2. **Identification of Risks and Opportunities:** Through the literature review we identified potential risk channels associated with blockchain oracles and importance of the mechanism within the infrastructure to enable functionality and ecosystem interoperability. The risks of MEV were analysed in relation to how value is extracted in the blockchain (potential strategies) and the possible impact on the wider ecosystem. This entailed a systematic analysis of existing literature to gain insights into both the challenges and opportunities these features pose.
3. **Market Mapping:** Creating a map of the market ecosystem was an important step in the research to understand the dynamics at play. This included identifying core ecosystem players, their roles, and interconnections within the system. Where possible, we provided quantitative analysis including market concentration of providers and sector breakdown associated with the implementation of blockchain oracles.
4. **Key Regulatory Questions:** From the steps above, we identified high-level considerations for market participants and regulators. The internal literature review helped to identify and formulate future research questions that could help guide future thinking in this space.

Stage 2 - External Market Research by Futuresight Business Intelligence Ltd

For stage two, we ran a competitive tender process to select an independent research agency to conduct a small number of the qualitative interviews to gain anonymous and unfiltered perspectives on MEV and oracles.

The fieldwork took place from April – May 2023 and was led by Futuresight Business Intelligence Ltd. The qualitative assessment involved 22 individual in-depth interviews with subject matter experts and industry stakeholders. Participants spanned across UK,

EU, USA, Switzerland, Australia, Singapore and the United Arab Emirates. The final sample comprised of experts across different roles including software developers, infrastructure and service providers, traditional financial experts, academia, and regulated entities.

Stage two gathered real-time insights and opinions and provided a valuable perspective from individuals with first-hand experience in this area.

This approach supplements the literature review by enabling:

1. **Access to independent experts:** interview participants were carefully selected by Futuresight Business Intelligence Ltd to ensure diversity of attitudes and representation across the ecosystem.
2. **Unfiltered input and feedback:** independent research increases the likelihood of gaining open and honest feedback from participants that is not influenced by our role as the regulator.
3. **Assessment of market incentives:** first-hand insights into the motivation, interests, and expectations of industry stakeholders.

Limitations of the Research

The literature review references research published from sources such as blogs, whitepapers, web pages, and peer-reviewed papers. This breadth of sources is essential because the most current information in this rapidly evolving field cannot always be found in peer-reviewed journals due to publishing time lags. The qualitative sources in stage two are not assumed to reflect the entire market as some participants, such as traders and arbitrage developers, were not necessarily included. It is important to note that the exclusion of these participants might introduce a limitation in the scope of perspectives, however, the insights obtained in stage two offer a valuable representation of certain market views, shedding light on significant aspects within the studied context. The highly emergent and rapidly changing nature of MEV and blockchain oracles means the information documented in this research note is a snapshot in time, which is likely to change as the ecosystem evolves.

Participants involved in stage two of the research were made aware of the FCA's role in procuring the research. Whilst this transparency could foster participation, it also poses a risk of influencing the dialogue of the external interviews. To mitigate this risk, a thorough pre-screening of interviews was conducted, ensuring anonymity and confidentiality of responses during the interview process. These limitations, along with the potential for biased responses and a limited sample size, were taken into account when evaluating the results. Comparisons with findings from other sources were employed to cross-examine the prevalence of views gathered during stage two.

5 Key Insights

The following section summarises the key findings combined from stage one, the literature review, and stage two of the research, the qualitative interviews. The aim of this section is to provide a technical overview and market perspectives of the concepts.

The information below reflects the perspectives of academic researchers and industry stakeholders and should not be interpreted as FCA views.

Maximal Extractable Value

MEV is a metric of value derived from a phenomenon specific to blockchains where transactions can be ordered in such a way as to maximise the value extracted from block creation.[18] This can involve including additional transactions, excluding transactions by pushing them out of a block or altering the order of transactions in the block production process. The high degree of visibility associated with transactions that take place on the blockchain has created opportunities for market participants to explore new strategies to maximise the economic gain from each block.[19]

This behaviour can be viewed as helping to optimise blockchain networks and maximise profit for those responsible for ordering the transactions, but it also raises concerns over the externalities it imposes on the wider network and users. These could include increased network congestion, higher costs for users, information asymmetries and in some cases, user exploitation and potential manipulation.[20]

In the interviews, there was strong agreement by respondents that MEV is a multifaceted and evolving concept.[21] MEV was highlighted as a core foundational behaviour in the blockchain ecosystem that is fundamental to how the blockchain operates. Interviewees underscored the intricate nature of MEV and highlighted the need for a nuanced understanding of this concept. Despite being a core component of how blocks are ordered, there was widespread agreement that some of the activities considered as MEV may act as a pain point for the scaling of blockchains if they are not mitigated. Technological developments such as proposer-builder separation (PBS), outsources the block building to third-party builders which can help to remove congestion from the network and improve scalability. However, PBS is a more complicated approach to transaction execution and can centralise the information propagation among privileged entities involved in the block building process.[22]

[18] There are a variety of terms used in the blockchain community to describe the concept of the value derived from transaction ordering, these include miner extractable value, maximal extractable value, blockchain extractable value (BEV) and realised extractable value (REV). Unless otherwise specified, we use the term 'maximal extractable value' to describe the theoretical value a user can extract given a set of transactions and is not specified to a particular consensus mechanism (mainly proof-of-stake or proof-of-work).

[19] The concept of maximising value from transaction ordering is not unique to blockchains and is observed across many sectors. MEV is unique due to the transparency associated with pending transactions in blockchain systems. Different websites categorise the 'types' of MEV in different ways, see Barragan (2022), Ethereum (2023), Chainlink (2023a).

[20] See "Miners as intermediaries: extractable value and market manipulation in crypto and DeFi" (Auer et al. 2022).

[21] When discussing MEV, it is important to consider how the perspectives and incentives of market participants involved in MEV differ. In this paper, we mainly consider MEV from the perspective of those carrying out ordering strategies detailed in the table below. Alternatively, MEV can also be considered from the perspective of validators looking to maximise block space where incentives are more likely to be driven by efficiency.

[22] A discussion on how PBS can lead to scalability and the current implications on the centralisation of block building visit https://ethereum.org/nl/roadmap/pbs/#pbs-and-mev. To visualise PBS and the flow across relayers, builders and validators, showing the split across the market participants visit https://mevboost.pics/ (Wahrstätter, 2023).

How does transaction ordering work?

Many users of DeFi protocols may be unaware of MEV and yet have most likely contributed to MEV in some way. For example, when a user places an order on a decentralised exchange, there may be slippage, in DeFi this is the difference between the expected price of an asset and the actual price at which the trade is executed.[23] This price differential is a source of value. Depending on the underlying blockchain features, such as the type of consensus mechanism the blockchain employs, this may influence how value is extracted and who is involved.

For example, on Ethereum, PBS is a system that dominates block creation. It relies on economic incentives to strategically order transactions and aims to reduce the power of block producers by distributing power across searchers, builders and relayers.[24] The roles within the PBS system are distributed across these and the proposers (validator nodes), although, two or more of these roles may be operated by the same entity which might diminish the realised degree of decentralisation.[25] The flow chart below provides a high-level illustration of how MEV works under PBS.

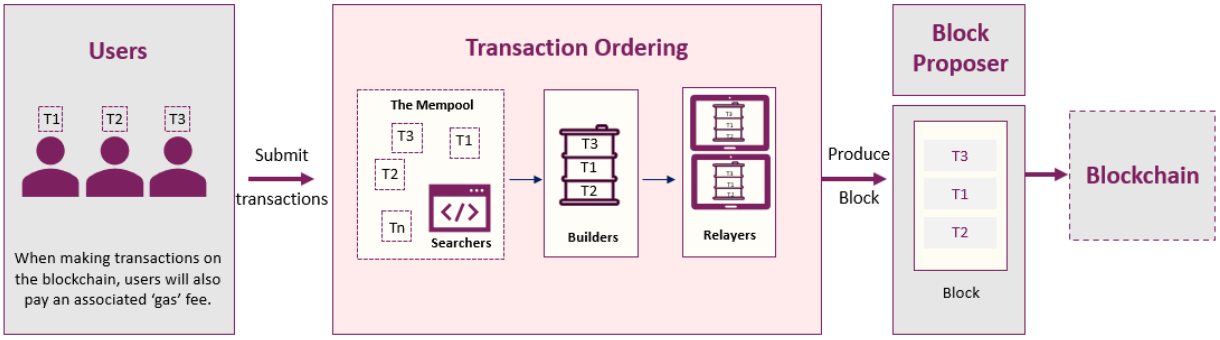

Figure 1: The chart is a high-level illustration of the flow of information during block creation using PBS. The way in which transactions can be ordered can vary in-line with factors such as application design and wallet software employed by the user. It is important to note, the entities themselves (searchers, builders, relayers) are not always distinct. Proposer-builder separation (PBS) splits the block producing across searchers, builders and relayers, instead of the block producer building their own blocks. Source: adapted from Chainlink by the authors.

The ability to set the order of transactions before they are confirmed within a block introduces different types of profit seeking behaviours and strategies that are often referred to as MEV. The continuously changing landscape of MEV has resulted in a lack of consensus or agreed-upon taxonomy within industry and academia on how to categorise different types of MEV. There is also some debate over whether it is correct to categorise 'types' of MEV, or, whether MEV should instead be considered a tool, enabling certain activities to take place.[26]

[23] Similarly to traditional markets, transactions that take place on a decentralised exchange are executed within the price boundaries set by the user or exchange. The difference in the expect price and the executed price in decentralised markets is called slippage. In this context, the expected price refers to a price that is executed within the slippage limit but above the traders hope for a better price. Users agree to accept any price within the limits of the trade, however, narrow limits may cause a trade to fail.

[24] For a comprehensive summary of block construction markets, see "Time to Bribe: Measuring Block Construction markets" by Wahrstätter et al. (2023a).

[25] It is important to note that the roles and terminologies used in blockchain systems vary across protocols, consensus mechanisms and platforms. The functionality and specific actions of searchers, builders, and relayers differ depending on the design and requirements of blockchain systems and the protocol being referenced. Visit https://mevboost.pics/ for more info.

[26] The IOSCO (2023a) policy recommendations for decentralised finance (DeFi) report introduces MEV strategies as a tool that can be used to order transactions in a way that is consistent with 'efficient market dynamics' (arbitrage), but can also be used to exploit mempool data through strategies such as front-running, back-running and sandwich attacks.

Some common approaches to categorise types of MEV include arbitrage, liquidation, front-running, back-running and sandwiching. The terminology in this space is very similar to terms used to refer to existing abusive practises in traditional finance and, as a result, has attracted the attention of regulators and policymakers internationally.[27] These strategies are explained briefly below.

Arbitrage	Liquidation	Front-running/ back-running	Sandwiching
Taking advantage of price differentials between platforms or markets.	Triggering profit from the forced sale of cryptoassets (including stablecoins) locked up as collateral.	Profit is derived from inserting a transaction ahead (behind) of a known transaction, observed in the mempool. Includes copying strategies.	Altering the order of transactions in a block by inserting transactions both before and after a target transaction to profit from the impact of the inserted transactions.

Figure 2: Overview of strategies that may be used to extract value when ordering transactions. These strategies have been referenced in the literature and interviews as common ways to extract value through the visibility of pending transactions. They are not an exhaustive list and there is not consensus on what should be classed as MEV.

Market perceptions of MEV

There is a broad spectrum of perspectives in industry and academia on whether MEV, in some cases, raises market manipulation concerns. Some believe the strategic ordering of transactions can distort market conditions, affect price discovery, and potentially harm market participants.[28] Reviews by Barczentewicz et al. (2023a and 2023b) analysed MEV behaviours on the Ethereum blockchain from a legal perspective.[29] They discussed sandwiching and oracle manipulation, suggesting that in some circumstances they may be illegal (for example, when non-public information is used). They also raised concerns over the use of sophisticated transaction-copying 'bots', especially when they replicate attempts to hack DeFi applications.[30] Alternative perspectives are centred around the idea that MEV is a natural market outcome of the dynamics inherent within blockchain systems due to the transparency of transactions ordering.

A fundamental understanding of the context, behaviours, incentives, and outcomes associated with MEV could help decision makers to consider the implications of MEV and any potential malicious types that could amount to market abuse.[31] The UK Market Abuse Regulation (MAR) contains prohibitions on insider dealing, unlawful disclosure of inside information, and market manipulation.[32] Determining whether an action constitutes a market abuse offence in traditional finance often entails further evaluation. In addition, because information in the mempool is transparent, but also because there are ways to

[27] The terms used in DeFi, so called front-running and arbitrage, do not necessarily refer to the same phenomena as in traditional finance and is a perceived market abusive behaviour that is being challenged by the process of building and executing transaction on a blockchain. See Barczentewicz et al. (2023a).

[28] Crypto-assets and decentralised finance (European Systemic Risk Board, 2023); Miners as intermediaries: extractable value and market manipulation in crypto and DeFi (Auer et al, 2022).

[29] Barczentewicz et al. analyse MEV against U.S. securities and commodities law.

[30] Barczentewicz et al. (2023a and 2023b).

[31] MEV, and the nature of related practices, is an area for further consideration for market participants and regulators. Through this paper we have explored a non-exhaustive list of the regulatory and market consideration aspects of MEV and Oracles. These should not be interpreted as policy statements.

[32] For further information on UK MAR, please refer to the FCA's webpage here.

introduce information asymmetries, an assessment of whether certain MEV behaviours parallel unfair market practices requires more nuance.[33] Thus, ascertaining whether some forms of MEV have parallels to certain TradFi abusive market behaviours continues to be subject to discussion.

Through both the literature review and market interviews, there were mixed attitudes over how MEV is perceived from an ethical perspective. The majority of interview respondents viewed MEV as a behaviour that has both positive and negative impacts on the wider ecosystem. However, some respondents strongly regarded MEV as a net-positive behaviour, whilst some viewed it as entirely negative, and in some cases, criminal.

'MEV isn't inherently bad or evil – mainly it just allows many kinds of good things already happening in a healthy DeFi ecosystem. Liquidity pools stay balanced. And liquidations can become faster – and it keeps those systems more robust. That is what we consider "good MEV", but of course there is a dark side too – which can have a really negative influence...' [Blockchain developer, MEV expert][34]

MEV was referred to positively in relation to circumstances where it led to more efficient market operations, including allowing arbitrageurs to operate and identify more profitable transactions, and contribute to more efficient practises. The activities associated with MEV were seen to help contribute to a well-functioning DeFi ecosystem through supporting efficient liquidations and arbitrage opportunities. It is important to note that many respondents did not perceive MEV as inherently bad in nature, but as a tool which can also lead to negative outcomes. Most respondents viewed activities such as front-running, back-running and sandwiching as negative forms of MEV.

The variety of attitudes surrounding MEV appear to be largely determined by individual beliefs around what is considered morally acceptable. One respondent suggested the optimal outcome is to ensure the incentives of the block proposers are aligned with the wider community, which could be achieved through technological design solutions.

*'The guys that are doing MEV attacks are not doing anything illegal. They're also not hacking. They are just exploring the options that are there – in the blockchain. It's not a hacking attack, it's just a vulnerability. In blockchain design, blockchain designers never thought that somebody might reorder the transactions.'" [*Co-Founder*, Blockchain Services Provider].*

Through this research, a common theme has emerged around the need to consider MEV in the context of the broader behaviours present in DeFi. For example, as the DeFi ecosystem evolves, there may be new dynamics that change the welfare impact of potential value extracting strategies such as sandwiching. An emerging risk acknowledged by a few participants were the possibility of multi-block MEV, where builders use consecutive blocks to generate profit opportunities.[35] Respondents acknowledged the importance of considering how alternative factors such as the centralisation of validators and the ability to exploit design choices, for example, the time delay of oracles that provide time-weighted average prices (TWAP), might impact the

[33] As mentioned in the Research Context section above the question, on whether certain MEV behaviours have parallels to unfair market practices in traditional finance has been briefly discussed by international bodies (see IMF and FSB, 2023; IOSCO, 2023).

[34] Italic text (here and throughout section 5) reflect views provided by respondents in the research carried out by Futuresight Business Intelligence Ltd.

[35] Babel et al, (2021); Flashbots (2022); Jensen et al, (2023).

risks associated with multi-block MEV.[36] Several respondents highlighted that advancements in design can help to mitigate the risks and impact posed by harmful MEV and suggested improvements were already underway.[37]

Blockchain Oracles

Blockchain oracles are data feed services that allow information to enter a blockchain system or to be transferred between blockchain networks and consumed by external systems. They are important infrastructure components that are responsible for facilitating the transfer of data that is required for the operation of decentralised applications such as decentralised lending platforms.[38]

Functionality and importance of Oracles

Oracles play a critical role in extending the functionality of smart contracts and the interoperability of multiple blockchain networks through the transfer of information between data stores that are on-chain and off-chain. Decentralised financial applications therefore rely on information from oracle networks to feed important data points such as reflecting asset prices into smart contract operations. The 'oracle problem' is commonly cited in the literature as the challenge that developer teams face in ensuring the data passed through an oracle is reliable and that execution is based on accurate and verifiable information. [39] The immutability function of blockchains (meaning once a transaction has been verified into a block it cannot be changed or removed) introduces a critical risk vector, particularly concerning oracles, as any inaccuracies in the information that oracles provide can instantly impact downstream applications that rely on the oracle. The oracle problem also concerns other issues such as the dilemma of balancing the degree of decentralisation of a blockchain system with centralised intervention or a point of failure that can arise in oracles.[40]

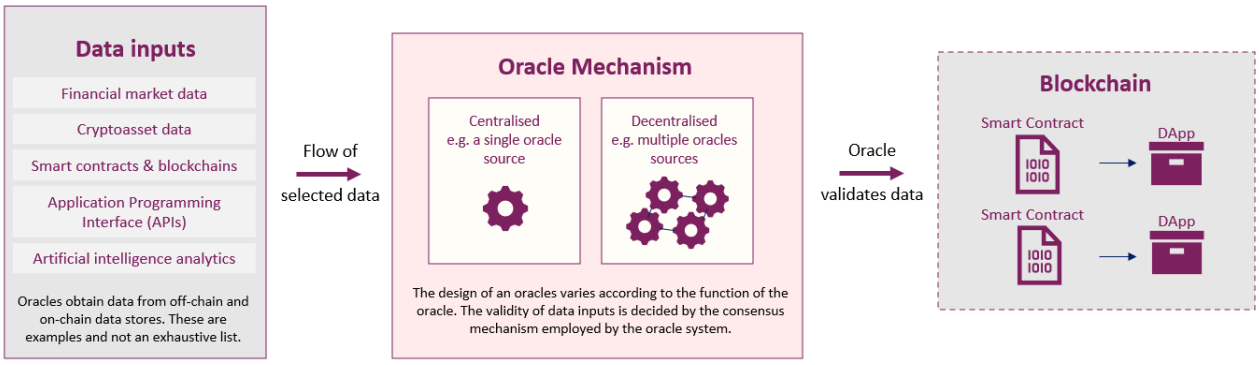

Figure 3: High level flow chart showing the flow of information associated with blockchain oracles. Source: authors illustration.

[36] Time weighted average prices (TWAP) is metric that measures the average price of an asset over time. More information on how TWAP can be calculated and a discussion on the safety of decentralised oracle designs and adjustment parameters can be found here (Aspembitova and Bentley, 2022).

[37] Drake (2023).

[38] See Chainlink (2023b).

[39] See Calderelli (2020) for a comprehensive literature review of the 'oracle problem' and the relationship to trust of the system.

[40] To note, there is some debate among ecosystem players in defining 'decentralised' oracles. For more information on the 'oracle problem' and the trade-offs associated with increasing the degree of decentralisation of oracles with blockchain efficiency see Duley et al. (2023).

In stage two of this research, respondents emphasised the current importance of blockchain oracles in expanding the functionality of smart contracts. Common use cases for oracles were highlighted as transferring price, financial, sports, and weather data, identity verification data, and random number generation. There was speculation over how the future functionality of oracles and their role in the ecosystem will evolve, with suggestions that in the future oracles could have broader applications such as streamlined processes for asset management.

Oracle system fragilities

Whilst necessary to enable functionality and interoperability, oracles can be a source of vulnerability used by bad actors looking for economic gain.[41] Sub-optimal oracle implementation coupled with the interconnected nature of oracle systems can lead to operational failure and theft of capital across decentralised ecosystems. Within the interviewed sample, some agreed with the literature, that oracles pose a specific challenge for the DeFi ecosystem as they introduce a new dimension of risk that, if exploited, could have downstream impact. In some cases, oracles were seen to represent a 'single point of failure' meaning bad actors can more easily identify where smart contracts are relying on vulnerable oracles, and then exploit the vulnerability for high financial gains.

'Oracles and bridges are two of the most significant vulnerabilities that exist in the DeFi world today. Because if you can hack the oracle, you can change the outcome of actions driven by a smart contract. And that can be both at a pure transactional level, or it could be at a whole blockchain level.' [*Security expert]*

The design of an oracle was identified as one of the key features influencing the risk associated with the oracle. Respondents in stage two highlighted the variation in design structures, coupled with poor understanding and implementation into blockchain systems as a mechanism increasing the risk of exploitation. For example, exploiting the governance process used to select the data, 'Sybil attacks', were identified as a key risk and channel for decentralised oracle manipulation.[42]

However, the research also indicated several additional channels through which oracle failure or vulnerabilities can arise. These include elements such as the quality of data sources, dynamic changes in volume and price, weak selection of data feeders, node quality and reliability and sub-optimal aggregation methods.[43] Several industry stakeholders suggested the threat vectors of oracles could be differentiated between two channels. The first channel relates to direct data misrepresentation where inaccurate data is provided through faults or weaknesses in the oracle design or incentive structures. The second channel refers to exploitation through secondary or ancillary tools. This refers to market participants using techniques such as deploying flash loans to impact market prices and alter the price feed through the oracle for financial gain.

[41] On-chain oracle manipulation is a key risk vector in the protocol layer accounting for 15% of incidents (Zhou et al. 2022).

[42] Sybil attacks are where bad actors are able to influence the outcome of a vote using fake identities to skew the decision.

[43] Eskandari et al. (2021) analyses the design options for oracles and categorise the key modules of a oracle into 6 work flows including: ground truth, data sources, data feeders, selection of data feeders, aggregation techniques and the mechanise for reviewing data correctness known as the dispute phase. The paper explores the potential fragilities that exist in each stage and potential mitigation strategies.

Incentives to mitigate risk

Respondents were asked to discuss potential solutions to the risks raised during the interviews. The collective research indicates there are incentives in the market to mitigate the potential risks posed by oracles and to overcome the 'oracle problem'.

A series of improvements and innovations in general blockchain oracle security and emerging good practice in the design space were mentioned. It was suggested that real-time data feeds and implementing, where appropriate, TWAP, and volume-weighted average prices (VWAP) could mitigate against some of the risks posed by price manipulation.[44] However, it was noted that using such adjustments should not be considered a silver bullet and can also be vulnerable to attacks. Risks posed by the centralisation of data sources can be mitigated to some extent by using decentralised oracle networks and a variety of data sources that reduce the risk of a single point of failure. It is important to note that the true degree of decentralisation is often subject to debate depending on factors such as the distribution of nodes in the networks and centralisation and quality of off-chain data stores.[45]

Also, in terms of design, oracle systems can encourage honest behaviours through incentive structures that reward the provision of correct information through reputation building and penalise the provision of incorrect information. The survey highlighted the utility of using third-party audits to review oracle accuracy and reliability. Additionally, layered oracle networks, where each layer checks the veracity of the data provided, can help to identify erroneous data inputs. The majority of respondents in the sample support the idea of some form of regulatory oversight. One suggested solution to the design risks outlined above from the interviews, was to create a certification programme for oracles undertaking certain tasks, such as price oracles. Interventions such as setting minimum standards for oracles that could be enforced by a third party or certifier were also suggested by respondents in stage two of the research. It was suggested that this could be coupled with a 'proof of deployment' verification that certifies when specific standards were met. Participants in the interviews did not specify whom should be responsible for the potential certification of oracles.

A recurring theme in the research was the underlying notion of immaturity in the oracle sector. This is emphasised by the variation in security models and frequency of exploits in this space. There was also some indication that the current challenges faced in oracle implementation at the protocol level and design are improving. Advancements in the field of smart contract security and the broad agreement of the current criticality of oracle systems indicate there are incentives in the blockchain community to improve oracle reliability and trust.

[44] Volume-weighted average prices (VWAP) is a metric used in the blockchain system to assess the average price of a cryptoasset over a specified period of time. VWAP calculates average prices by taking account of the average price and trading volume of an asset weighted by the amount of liquidity in the asset market. More information on how VWAP is calculated on Chainlink can be found here.

[45] Broader than oracles, there is an ongoing debate among researchers on the true degree of decentralisation in DeFi more generally. Aramonte et al. (2021) explore the 'decentralisation illusion' with a particular lens on the centralisation created in specific governance structures and structural elements of blockchain systems.

Regulatory and Market Considerations

The considerations outlined below capture reflections that have been developed throughout the research journey. The technical nature of the note, a specific deep dive into two emerging technological elements, are separate from the policy development process and will be used to inform regulatory expertise.

Maximal Extractable Value

Due to the fundamental role of transaction ordering in blockchain ecosystems, MEV requires careful consideration, research, and collaboration with participants in the broader decentralised ecosystem. In areas where other research reports have drawn parallels to abusive behaviours in traditional financial markets, or where concerns about best execution have been raised, further discussion among market participants, industry, and other stakeholders could help explore the risks associated with MEV. A joined-up approach is needed to ensure the risks in the system are adequately mitigated against.

MEV raises several potential questions which may or may not have market abuse and best execution of transactions considerations, such as:

- What factors should be considered when assessing whether a particular MEV-related action is malicious or not, should it be solely outcome based? Would the creation of a MEV taxonomy, differentiating between malicious and benign MEV, prove beneficial to market participants?
- How does the ecosystem best engage to assess and remedy the risks presented by MEV?
- How will the landscape for MEV evolve in the future? What are the consequences of other types of innovations that interact with the fundamental execution and consensus layer (for example, staking delivery channels and re-staking)?
- Does MEV impact what execution factors are most relevant to the best execution of cryptoasset orders (such as price, costs, speed, likelihood of execution and settlement, size, nature, or any other relevant considerations)?

Blockchain Oracles

Similarly, blockchain oracles also present considerations given their integral role to DeFi, potential susceptibility to manipulation and potential future applications of blockchain technology in traditional finance, such as tokenisation or trade lifecycle management. If and how blockchain oracles should be treated by any future regulatory framework, remains a question for further discussion.

Some considerations include:

- What are best practices that will reduce the risks presented by blockchain oracles, given their role in smart contract functionality and interoperability between multiple blockchain networks?
- How, or through what methods, can blockchain oracles be designed and deployed to mitigate against the risks they present?
- What are the potential roles of blockchain oracles in the future, and how will they develop alongside the wider ecosystem, including new innovations?

Novel features like MEV and blockchain oracles present unique considerations for further evaluation, some of which may change as the DeFi ecosystem and associated technology evolves.

The findings of this research note, the regulatory and market considerations, and any future developments in these areas could help inform engagement with market participants on upcoming stages of UK and global cryptoasset regulation.

6 Conclusions

MEV and blockchain oracles have garnered increasing attention. Among other emerging technologies identified through FCA horizon scanning activities carried out in 2023, we identified MEV and blockchain oracles as starting points for further research. Various intergovernmental organisations have conducted their own research calling for further analysis of unique features of blockchain, such as MEV and oracles. This highlights the growing interest into how technology features are changing the nature of financial activity and posing unique questions for regulators.

The aim of this research note is to provide foundational knowledge and exploratory analysis of the regulatory considerations posed by MEV and blockchain oracles. These key features incentivise certain behaviours from market participants, enable the operation of integral blockchain systems, and engender various risk profiles that differ to those seen in comparable activities in traditional financial systems.

From our qualitative exploration of MEV and oracles there were several key findings. Regarding MEV, our research indicated a mix of views on what may constitute 'good' or 'bad' MEV. Respondents found that MEV presented some benefits for market participants, such as arbitrage, balanced liquidity pools, and improved incentives for validators. But there were also concerns around front-running and sandwich attacks, and the resulting externalities upon users and wider ecosystem. The wide range of attitudes is likely attributable to varying individual beliefs on what is morally acceptable. When discussing blockchain oracles, respondents noted the importance of oracles to blockchain systems, especially to achieve greater interoperability and expand the functionality of DeFi applications. The research indicates that oracles are potential threat vectors vulnerable to attacks by bad actors which can pose immediate downstream effects. The fragilities inherent in oracles systems are impacted by the design choices of oracles, such as the number and quality of data sources and the data feeder selection processes. Whilst oracle standards and certification upon deployment were suggested by the small-scale market research as potential solutions, there are mixed views on who should be responsible for this the market, or regulators.

Several qualitative findings and pertinent market considerations were identified through this research that could be explored further. Given the rapid pace of change in this space and time lag associated with the publication of this research, any future research in this space should account for new technological or behavioural developments that might take place in the market.

By understanding the fundamental basis, opportunities, and challenges posed by MEV and oracles, international regulators are better placed as policymakers to make informed judgements which aim to mitigate potential risks. The rapidly evolving landscape surrounding blockchain based financial activity demands agility in the face of innovation and high engagement with external experts pioneering developments in this space. Additionally, collaborative engagement with other stakeholders and market participants is fundamental to building a framework that safeguards consumers and market integrity, regardless of the technology that is used.

As the UK's regulatory regime for cryptoassets continues to progress through upcoming phases of regulation, the key insights on MEV and blockchain oracles derived from this paper could provide useful context, where relevant, to inform engagement with key stakeholders and market participants.

Emerging Technology Research Hub

To further inform regulatory thinking, the FCA continues to explore emerging technology matters through the Emerging Tech Research Hub. If you would like to engage with us on this subject matter, please contact us at emergingtech@fca.org.uk.

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