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The Bisq decentralised exchange: on the privacy cost of participation☆

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ABSTRACT

The Bisq Trade Protocol and the Bisq DAO (decentralised autonomous organisation) are core components of Bisq, a decentralised cryptocurrency exchange. The Bisq Trade Protocol systematises the peer-to-peer trading of Bitcoin for other currencies and the Bisq DAO decentralises the governance and finance functions of the entire exchange. However, by following the Bisq Trade Protocol and interacting with the Bisq DAO, participants necessarily publish data to the Bitcoin blockchain and broadcast additional data to the Bisq peer-to-peer network. We examine the privacy cost to participants in sharing this data. Specifically, we use novel address clustering heuristics to construct the one-to-many mappings from participants to addresses on the Bitcoin blockchain and augment the address clusters with data stored within the Bisq peer-to-peer network. We describe address clustering heuristics for both the Bisq Trade Protocol and the Bisq DAO. We show that the heuristics aggregate activity performed by each participant: trading, voting, transfers, etc. We identify instances where participants are operating under multiple aliases, some of which are real-world names. We identify the dominant transactors and their role in a two-sided market. We conclude with suggestions to better protect the privacy of participants in the future.

1. Introduction

Bitcoin and its altcoin brethren, with the notable exception of 'privacy coins', seek decentralisation first and privacy second [1]. The synergistic pairing of blockchain analysis service providers with regulated cryptocurrency exchanges has exploited this. The former performs blockchain-wide analyses for high coverage but low individual identification. The latter enforces identity checkpoints for high individual identification but low coverage. Their pairing, combining aggregation with identification, is an example of a well-known privacy-risk [2].

Bisq is a decentralised cryptocurrency exchange that does not enforce identity checkpoints but relies on the Bitcoin blockchain and its own peer-to-peer network to operate; thereby falling under the purview of blockchain analysis service providers. In this article, we analyse the Bisq Trade Protocol, the component of Bisq responsible for systematising the peer-to-peer trading of Bitcoin for other currencies, and the Bisq DAO (decentralised autonomous organisation), the component of Bisq responsible for decentralising the governance and finance functions of the entire exchange, from a privacy perspective. We show that there is a significant privacy cost to participating in Bisq trades and the Bisq DAO.

Specifically, our analysis applies address clustering with Bisq-specific heuristics. Address clustering is a cornerstone of blockchain analysis. It employs heuristics to partition the set of addresses observed on a blockchain into *address clusters* that are likely controlled by the same participant. When combined with *address tagging*, or associating real-world identities with addresses, and graph analysis, it is an effective means of analysing blockchain activity at both the micro- and macro-levels, see, e.g., Refs. [3–5]. The Bisq Trade Protocol creates Bitcoin transactions with a distinctive structure and is subject to this form of analysis. Additionally, the Bisq DAO relies on a coloured-coin issued on the Bitcoin blockchain known as the BSQ token and is also subject to this form of analysis. We utilise the structure of the Bisq Trade Protocol transactions and the structure of the BSQ token transactions to create Bisq-specific address clustering heuristics.

At the time of our analysis on 10th February 2021, or Bitcoin block height 670 026, traders had completed approximately 90 000 trades

☆ This is an extended version of a paper that appeared in the proceedings of the 1st Workshop on Blockchain Theory and Applications (BRAIN'20) at the 25th IEEE Symposium on Computers and Communications (ISCC'20). The original paper focused solely on the Bisq DAO; this paper deals with both the Bisq Trade Protocol and the Bisq DAO. It includes updated analysis and discussion.

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using Bisq and the market capitalisation of the BSQ token was approximately USD 13 million. Both numbers are small when compared with the equivalent numbers for centralised exchanges such as Coinbase and decentralised exchanges that deal only with digital tokens such as Uniswap (see Section 2). However, Bisq is noteworthy and deserving of attention from a privacy perspective for two reasons. Firstly, Bisq provides an on-ramp to the world of cryptocurrencies without enforcing any identity checkpoints. This could attract the scrutiny of regulators and blockchain analysis service providers. It is currently a blind-spot in their coverage. Indeed, recent guidance from the Financial Action Task Force (FATF) regarding Virtual Asset Service Providers (VASPs) states that "the decentralisation of any individual element of operations does not eliminate VASP coverage if the elements of any part of the VASP definition remain in place" [6]. If the FATF considers Bisq to be a VASP, then the obligation to enforce identity checkpoints may fall upon those who operate Bisq, even if the operation is decentralised. The ability to identify the contributors will be central. Secondly, Bisq is novel in its construction amongst exchanges, in that it is decentralised and it supports both cryptocurrencies and fiat currencies. It enables traders to exchange, say, euros in a bank account for bitcoins, without having to trust a counterparty or facilitator. Although Bisq is the first of its kind, it has spawned forks and competitors. For example, Haveno [7] is a fork of Bisq based on Monero instead of Bitcoin that cites our earlier work [8] as a motivating factor[1]. An analysis of privacy within Bisq can inform both blockchain analysts and those seeking to hinder blockchain analysis.

This article is organised as follows. In Section 2 we review related work, including address clustering, decentralised exchanges, and decentralised governance. In Section 3 we introduce Bisq, the Bisq Trade Protocol, the Bisq DAO, and our Bisq-specific address clustering heuristics. We detail our analysis and results in Section 4 and countermeasures in Section 5. Finally, we conclude in Section 6.

2. Related work

We categorise related work into five areas: address clustering, token analysis, transaction analysis, decentralised exchanges, and decentralised governance.

Address clustering is a fundamental building block upon which many high-level blockchain analyses can be performed, see, e.g., Refs. [3–5, 9–13]. Experimental analysis has shown that a single heuristic for address clustering, the multi-input heuristic, can identify more than 69% of the addresses in the wallets stored by lightweight clients [14]. This heuristic assumes that the addresses referenced in transaction outputs spent in a single multi-input transaction are controlled by the same entity [15]. Although vulnerable to techniques such as CoinJoin [16] and its kin, it is a useful heuristic in practice [17]. Recently, specialised approaches for sharing address tags [18], standardising the scalable extraction and examination of blockchain data [19], crowd-sourcing the classification of transactions [20], parsing and representing the flow of bitcoins between addresses [21], and developing address clustering heuristics for the Ethereum blockchain [22] have extended this line of research.

We use address clustering to track trade amounts, security deposits, and the BSQ token, a coloured-coin [23] issued on the Bitcoin blockchain by the Bisq project. Tokens are a form of 'digital voucher' that provide access to a service or asset while providing revenue or funding to token-based business models [24]. Voshmgir [25] posits the token as the primary building block of Web3 applications. She surveys a variety of token economies including those based on stable tokens, privacy tokens, trading tokens, lending tokens, asset tokens, social tokens, attention tokens, and token curated registries. She discusses the technical, legal, economic, and ethical aspects of token engineering. There exist several network analyses of ERC-20 tokens on the Ethereum blockchain that quantify their age, economic value, activity volume, etc. [26,27].

Additionally, specialised heuristics have proved successful in tracing transactions in 'privacy coin' blockchains. For example, heuristics have been used to link public addresses on either side of Zcash shielded transactions [28] and to identify the true transaction inputs in Monero Ring Confidential Transactions [29].

Decentralised exchanges enable traders to exchange cryptocurrencies and/or fiat currencies without having to trust a centralised entity to act as an intermediary for the exchange or as a custodian for the currencies. However, decentralised exchanges vary widely in terms of technology, trustlessness, and security [30]. Bisq is an example of a decentralised exchange. It goes to great lengths to decentralise all aspects of its operation. The terms decentralised autonomous corporation (DAC) and decentralised autonomous organisation (DAO) [31–33] have a tainted past due to the infamous failure of 'The DAO' on the Ethereum blockchain [34]. However, progress continues unabated [35]. Decentralised exchanges are a focus of DeFi (Decentralised Finance). DeFi includes several projects that extend the decentralised nature of cryptocurrencies to other areas of modern finance. They are generally non-custodial, permissionless, openly auditable, and composable [36]. DeFi projects typically take the form of DApps (Decentralised Apps), that operate using smart contracts. There are several decentralised exchange DApps, such as Uniswap[2], SushiSwap[3], 0×[4], and many others[5]. These decentralised exchange DApps facilitate the exchange of ERC-20 tokens using methods such as community powered liquidity pools or order book-based protocols.

Fully decentralised systems require decentralised governance [37]. distinguish between on-chain and off-chain governance. On-chain governance is a form of decentralised governance that defers control to an underlying blockchain. Off-chain governance refers to all other rules and decision-making processes that might affect the system. The rules can originate within the community that build and maintain the system or they can be imposed by external sources, e.g., financial regulators. There are tensions between both forms of governance [38,39]. Decentralised exchanges use decentralised governance, in particular on-chain governance, in a bid to circumvent rules imposed by external sources. For example, they do not impose identity checkpoints or comply with embargoes or watchlists. It is unclear if fully decentralised exchanges fall into the same regulatory perimeter as centralised ones, and, if they do, how regulations are to be enforced [40,41].

We use common terminology from graph theory through-out the article. Please refer to Ref. [42] or a similar reference for definitions.

3. Bisq and address clustering

The following is a description of Bisq, the Bisq Trade Protocol, and the Bisq DAO; see Refs. [43,44] for a more thorough treatment. We are particularly interested in the transactions that are published by Bisq to the Bitcoin blockchain. We omit details regarding peer-to-peer messaging, the data stored locally by Bisq nodes, the Bisq developer ecosystem, etc.

Bisq, formerly known as Bitsquare, is a decentralised exchange that enables traders to exchange bitcoins for altcoins (e.g., Ethereum, Litecoin, Monero, etc.) and bitcoins for fiat currencies (e.g., USD, EUR, GBP, etc.). One side of each Bisq trade must involve bitcoins. Bisq nodes connect to a peer-to-peer network over Tor to create an order book, coordinate trades, and resolve disputes. Trades require security deposits that are held using Bitcoin multi-signature transactions.

A central tenet of Bisq, like Bitcoin, is the importance of decentralisation. Bisq has two goals: the first is to enable traders to trade bitcoins

[1] https://github.com/haveno-dex/haveno/wiki/FAQ.

[2] https://uniswap.org.

[3] https://www.sushi.com.

[4] https://0x.org.

[5] https://distribuyed.github.io/index.

for altcoins and fiat currency; the second is to free traders from having to defer control to any central entity. In isolation, the first goal is easy to achieve. Centralised exchanges are a good example. They are efficient and efficacious. The caveat is that centralised exchanges are subject to failures and regulatory requirements. Bisq achieves both goals but with some added costs. For example, the user experience is arguably more complex than with a centralised exchange and the system publishes transactions to the Bitcoin blockchain incurring transaction fees and a privacy cost.

In the following, we consider the privacy cost incurred by participants. Bisq is a double-edged sword for financial privacy. It allows anyone to trade with anyone else in the world without having to divulge identifying information to a central entity. However, it requires participants to broadcast transactions on the Bitcoin blockchain. The contents of the transactions and their relationship with other transactions can unintentionally disclose information about the transactors to interested third parties.

3.1. The Bisq Trade Protocol

Bisq enables the non-custodial peer-to-peer exchange of bitcoins for other currencies. The Bisq Trade Protocol describes the sequence of steps performed by traders when engaging in a trade. The Bisq software implements and executes the protocol on their behalf. For every successful trade, the Bisq software publishes four transactions to the Bitcoin blockchain: a **maker** fee transaction, a **taker** fee transaction, a **deposit** transaction, and a **payout** transaction (see Fig. 1). In the maker fee transaction, the maker, or the trader adding liquidity to the order book, pays a trade fee, a mining fee, a security deposit, and, if they are selling bitcoins, the trade amount. In the taker fee transaction, the taker, or the trader removing liquidity from the order book, also pays a trade fee, a mining fee, a security deposit, and, if they are selling bitcoins, the trade amount. Both traders interact to create the deposit transaction: it combines the mining fees, the security deposits and the trade amount from the maker fee and taker fee transactions and locks the bitcoins in a multi-signature transaction output. The trader buying the bitcoins, or the buyer, makes a payment to the seller using an altcoin or fiat currency. The traders interact to create the payout transaction: it refunds the security deposits and sends the trade amount to the buyer. There are mechanisms in place to handle disputes, including mediation, arbitration, and time-locked transactions.

We can identify the four transactions in the Bitcoin blockchain for successful Bisq trades. The maker fee, taker fee, deposit and payout transactions have a distinctive structure: every deposit transaction has two transaction outputs, a transaction output whose redeem script is a 2-of-2 or 2-of-3 multi-signature script, and a transaction output with an `OP_RETURN` containing the hash of the Bisq trade contract. The hash cannot be used to identify Bisq trades. However, the trade fee transaction outputs in the maker fee and taker fee transactions are either sent directly to known Bisq addresses that collect trade fees, or are coloured using the BSQ token (see Section 3.2.1 below). We used the structure of deposit

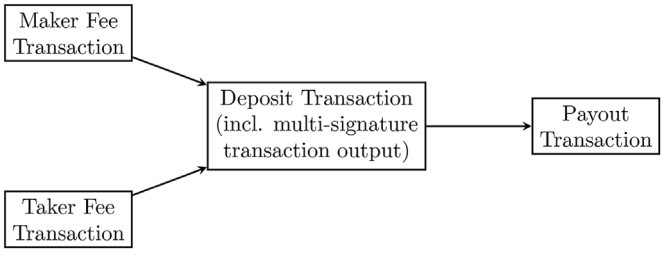

Fig. 1. A successful Bisq trade publishes four transactions to the Bitcoin blockchain. The maker fee and taker fee transactions create transaction outputs that are redeemed by the deposit transaction. The deposit transaction creates a multi-signature transaction output that is redeemed by the payout transaction.

Table 1
Trade statistics compared the deposit transactions identified by Bisq with the deposit transactions identified by us.

Item		Identified By Bisq in Trade Statistics	
		Deposit	Non Deposit
Identified By Us	Deposit	68 048	541
Trade Statistics	Non Deposit	18	>300 million

transactions to identify 87 326 Bisq trades[6] as of Bitcoin block height 670 026.

Bisq publishes and locally stores statistics relating to trades, and, until recently, this included the complete list of deposit transaction hashes[7]. We cross-checked our list of deposit transaction hashes with the 68 517 trades stored by Bisq[8].

We compared the two methods for the time-period between the first and last deposit transactions that were identified and stored by Bisq as part of its trade statistics. Table 1 shows that both methods produced similar results. They agreed on 68 048 deposit transactions; we identified 541 deposit transactions that were not identified by Bisq; and Bisq identified 18 deposit transactions that were not identified by us. The differences were small and, on inspection, were due in part to inaccuracies in the data stored by Bisq. This is an important finding since it shows that we can continue to identify deposit transactions, and Bisq trades, even though Bisq has stopped publishing and storing the deposit transaction hashes as part of the trade statistics.

This leads to our Bisq Trade Protocol address clustering heuristic: for each maker fee, taker fee, deposit, and payout transaction corresponding to a successful Bisq trade, the addresses referenced by all of the transaction inputs of the fee transaction that does not contain the trade amount, i.e., the fee transaction created by the trader buying bitcoins, and the address referenced by the transaction output of the payout transaction containing the trade amount, belong to the same trader. The same applies in reverse to the trader selling bitcoins. Additionally, the addresses referenced by all of the transaction inputs of the maker fee transaction and the address referenced by the transaction output of the payout transaction containing the maker's security deposit, belong to the maker, and similarly for the taker fee transaction and the taker's security deposit. In other words, we can follow the trade amount and security deposits through the four transactions. The trade amount is exchanged between the traders whereas the security deposits are returned to the traders. This allows the addresses referenced by the transaction inputs of the maker fee and taker fee transactions to be clustered with corresponding addresses referenced by the transaction outputs of the payout transaction. We can also add the addresses referenced by the second and third output of the maker and taker fee transactions to these clusters, the second output being an address used to construct the deposit transaction controlled by the transaction's creator, and the third output being an optional change output. We exclude the first output of the maker and taker fee transaction as this output contains the Bisq trade fee itself. Appendix A provides pseudo-code for the heuristic and we have released a C#/.NET implementation[9].

This heuristic shows that participating in a Bisq trade does not obfuscate the flow of bitcoins between a seller and a buyer in any way, and identifies the activity as a Bisq trade. Of course, this heuristic can be

[6] https://github.com/Liam-Hickey-Ire/BisqTradeProtocolAnalysisSource/blob/master/Data/670026/our-deposit-tx-hashes.csv: Each line contains the hash of a deposit transaction that we identified.

[7] As of Bisq 1.4.0, deposit transaction hashes are no longer published and stored as part of the trade statistics.

[8] https://github.com/Liam-Hickey-Ire/BisqTradeProtocolAnalysisSource/blob/master/Data/670026/bisq-deposit-tx-hashes.csv: Each line contains the hash of a deposit transaction that Bisq identified as part of the trade statistics.

[9] https://github.com/Liam-Hickey-Ire/BisqTradeProtocolAnalysisSource.

combined with the heuristics for clustering addresses on the Bitcoin blockchain referenced in Section 2. We will not expand upon this analysis in the remainder of this article since its impact on privacy is evident. Instead, we turn our attention to the Bisq DAO and a novel address clustering heuristic based on its operation.

3.2. The Bisq DAO

There are two types of participants in the Bisq ecosystem: those who use Bisq solely as a decentralised trading platform and those who take part in the development, operation, and governance of Bisq. The Bisq DAO is the vehicle through which the latter group manages the governance and finance functions of Bisq in a decentralised fashion [43]. Participants in the Bisq DAO can make and vote upon proposals relating to Bisq using a stake-based voting system. They propose and vote on measures such as rewarding contributors, approving support agents, modifying trade fees, etc. Voting occurs in approximately monthly cycles known as DAO cycles. The DAO cycle times are determined by block heights on the Bitcoin blockchain. As of Bitcoin block height 670 026, there have been twenty-one DAO cycles. Each cycle includes a proposal phase, a blind vote phase, a vote reveal phase, and a vote result phase. The former group may also participate in the Bisq DAO to a lesser extent by acquiring and burning BSQ tokens in lieu of paying trading fees denominated in bitcoins.

3.2.1. The BSQ coloured-coin

The Bisq DAO operates by tracking the actions of a token or coloured-coin, BSQ, issued on the Bitcoin blockchain. BSQ tokens are simply transaction outputs that are coloured and tracked by the Bisq software. BSQ transactions are Bitcoin transactions, recognised as valid transactions by Bitcoin nodes, and recognised as valid transactions by the Bisq software. Participants of the Bisq DAO must first hold some BSQ in order to make and vote upon proposals. There is a two-sided market for BSQ. On the supply side, BSQ can be acquired in several ways. BSQ was minted and distributed in a genesis transaction on 15th April 2019. Additionally, new BSQ is minted and distributed after each DAO cycle to contributors using the proposal and stake-based voting system. BSQ can also be transacted between parties using transfer transactions. On the demand side, traders using Bisq can opt to pay trade fees at a reduced rate by acquiring and burning BSQ, thereby creating a demand for BSQ and rewarding contributors indirectly. In this way, BSQ is used to financially reward contributors as well as manage the operations of the Bisq DAO itself.

Every action on the Bisq DAO, such as a proposal or vote, takes the form of a BSQ transaction. There are twelve transaction types:

1. **Trade fee** transactions pay Bisq trade fees at a reduced rate using BSQ. The reduced rate incentivises users trading on Bisq to pay using BSQ rather than bitcoin, thereby creating a demand for BSQ.
2. **Transfer** transactions transfer BSQ between addresses in much the same way as Bitcoin transactions transfer bitcoin.
3. **Compensation request** transactions request BSQ compensation for contributions to the Bisq project. Users supply non-coloured Bitcoin that will be coloured as BSQ should the request be accepted by vote. The details of the request are stored in an off-chain document, e.g., GitHub issues. The transaction includes an `OP_RETURN` containing the hash of the off-chain document.
4. **Reimbursement request** transactions are functionally similar to compensation requests. They reimburse users for out-of-pocket expenses relating to Bisq or compensate users for failed trades.
5. **Proposal** transactions make proposals that are neither compensation nor reimbursement requests. These include approving support agents, modifying trade fees, etc.
6. **Blind vote** transactions vote on open requests and proposals during the blind vote stage of a DAO cycle.
7. **Vote reveal** transactions publish unblinded votes during the vote reveal stage of a DAO cycle.
8. **Lockup** transactions lock BSQ for a specified duration. They are often used as a bond for a specified role in Bisq such as a trade mediator or arbitrator.
9. **Unlock** transactions unlock previously locked BSQ.
10. **Asset listing fee** transactions list new tradable assets on Bisq, such as a new altcoin. Assets are initially listed for a trial period. If they do not reach a minimum trade volume, they are removed.
11. **Proof of burn** transactions destroy BSQ. They do not have a specific use case but can be used as a form of reputation by proving that an individual burned BSQ.
12. The **genesis** transaction was the initial transaction that minted and distributed the initial quantity of BSQ.

3.3. The self-transfer issue

Due to the Bisq DAO's reliance on the BSQ token, a significant amount of DAO related activity is published to the Bitcoin blockchain. For example, if a participant makes a compensation request, their Bisq node generates a BSQ transaction on the Bitcoin blockchain that is a compensation request transaction. Furthermore, by inspecting the specification of the compensation request transaction[10], we can see that the transaction inputs and the transaction outputs always belong to the same participant. In other words, the participant is making a self-transfer with special data included in an `OP_RETURN` to signal to the Bisq DAO that this is a compensation request. We can inspect the specifications of the remaining transactions types, and identify the transactions that are self-transfers. In fact, the majority of the transactions are self-transfers. In the list of twelve transaction types above, all but the transfer transactions and the genesis transaction are self-transfers.

This points to our Bisq DAO address clustering heuristic: for each self-transfer BSQ transaction, the addresses referenced by all of its transaction inputs and all of its transaction outputs belong to the same participant; for each BSQ transfer transaction, the addresses referenced by all of its transaction inputs and all but the first of its transaction outputs belong to the same participant. Only the address referenced by the first transaction output in a BSQ transfer transaction belongs to the recipient rather than the sender. The self-transfer issue allows the addresses referenced at either side of these transactions to be clustered. Only the BSQ genesis transaction and transfer transactions are not necessarily self-transfers. This information can be derived directly from the specifications of the BSQ transaction types. Appendix B provides pseudo-code for the heuristic and we have released a C#/.NET implementation[11].

We have specified a heuristic by which the addresses associated with BSQ transactions can be clustered. This is a 'heuristic' because it is possible for a participant to manually construct a BSQ transaction that violates these assumptions. This could cause our heuristic to generate misleading information. It could identify two or more addresses as belonging to a single entity, when in fact they were controlled by separate entities. Or, it could identify two addresses as belonging to separate entities, when in fact they were controlled by the same entity. This is a perennial problem with address clustering heuristics. The assumptions underlying the multi-input heuristic (see Section 2) can be violated by CoinJoin transactions. This is the analogous situation for our heuristic. However, the ability to construct such transactions is not supported by the Bisq software, i.e., the only way to transfer BSQ is to create a BSQ transfer transaction, and we are not aware of any additional tools to support this. We will discuss the impact of false positives and false negatives in Section 4.1 and Section 5.

In this article, we analyse all 56 775 BSQ transactions as of Bitcoin block height 670 026 after the completion of Bisq DAO Cycle 21 on 10th

[10] https://docs.bisq.network/dao-technical-overview.html.
[11] https://github.com/Liam-Hickey-Ire/BisqDAOAnalysisSource.

Table 2
The twelve valid BSQ transaction types, their counts and whether or not they are self-transfers.

Type	Count	Self-Transfer?
Trade Fee	51 785	✓
Transfer	3489	×
Compensation Request	482	✓
Blind Vote	368	✓
Vote Reveal	365	✓
Proposal	118	✓
Lockup	48	✓
Proof of Burn	37	✓
Reimbursement Request	36	✓
Asset Listing Fee	26	✓
Unlock	17	✓
Genesis	1	×

February 2021[12]. Table 2 shows the distribution of the BSQ transaction types, excluding three irregular transactions. We note that 91% of the transactions burn BSQ for trade fees and 94% are self-transfers: participants burn BSQ and/or signal an action to the Bisq DAO (submitting proposals, voting, locking BSQ, etc.), but the remaining BSQ and the underlying bitcoin are returned to the same participant.

4. Analysis and results

The transaction inputs and outputs of the 56 775 BSQ transactions reference 163 430 distinct addresses[13]. The address clustering heuristic produces 1532 address clusters[14]. That is, it partitions the 163 430 addresses into 1532 subsets such that all addresses in the same subset are likely controlled by the same participant. The median number of addresses per address cluster is 25 (mean=107, standard deviation=274). This is due to the Bisq software creating new addresses for each BSQ transaction. Although this is good from a privacy perspective, it is often negated by address clustering [17].

Generally, it is difficult to assess the validity of an address clustering due to the unavailability of a ground truth [14]. However, the Bisq DAO offers the following partial solution. We can assign a role to each address cluster:

1. If an address cluster contains at least one address referenced by a transaction output of a BSQ proposal transaction, we assign it the proposer role.
2. If an address cluster is not a proposer but it contains at least one address referenced by a transaction output of the BSQ genesis transaction, we assign it the generator role.
3. If an address cluster is neither a proposer nor a generator, we assign it the user role.

Then, we can make use of address tagging to assess the validity of our address clustering.

4.1. Address tagging

There are 1244 users, 175 generators, and 113 proposers. The roles are significant because we can assign tags, or links to pseudonyms and real-world identities, to all of the proposers using data stored by the Bisq DAO for the BSQ compensation, reimbursement, and proposal transactions. Furthermore, we can assign tags to many of the generators using GitHub account usernames associated with transaction outputs of the BSQ genesis transaction.

Prior to the launch of the Bisq DAO and the BSQ coloured-coin, the Bisq community performed the operations of the Bisq DAO and managed the issuance and circulation of prototypical BSQ coloured-coins manually and centrally. During this bootstrapping phase, the Bisq community tracked voting and staking using a spreadsheet[15]. Additionally, contributors creating compensation requests at this time stated the BSQ address to which compensation should be directed in the request's associated GitHub issue. Using the addresses found in both the spreadsheet and within the issues found on GitHub, we created a pre-launch BSQ tag database.

The Bisq DAO was launched on the 15th April 2019. BSQ holders were given the opportunity to specify the address they wished to use in the BSQ genesis transaction. They could take one of three actions: retain their pre-launch address; publicly announce a new address or change their address privately by notifying the individual(s) who constructed the genesis transaction. For each of these cases, we can create a mapping from pre-launch addresses to post-launch addresses, thus creating a post-launch tag database for addresses referenced by the BSQ genesis transaction. Creating a mapping for the first two cases is trivial as addresses are publicly stated on GitHub[16]. However, we were also able to ascertain post-launch addresses for those who chose to change their addresses privately. We found that the ordering of the transaction outputs of the BSQ genesis transaction matched the ordering of the entries in the spreadsheet.

Together, we can assign tags to 134 distinct address clusters[17]. We stress that assigning tags to individual addresses is trivial; the information is publicly available and released by the proposers and generators. However, we are assigning tags to entire address clusters generated using our Bisq DAO addressing clustering heuristic and all of their constituent activity, e.g., trading, voting, transfers, etc.

Returning to the question of validity, we inspected the tags assigned to each address cluster. Out of the 134 tagged address clusters, we identified nine with conflicting tags: nine address clusters were assigned multiple tags that, ignoring obvious capitalisation and spelling errors, were not the same. This could be an indication of false positives generated by our address clustering heuristic. However, on further inspection, we observe that at least one case contains three different pseudonyms who submitted three different BSQ compensation proposal transactions for overlapping translation contributions. In many of the other cases, we observe real-world names combined with pseudonyms. We don't believe these are false positives but evidence of participants operating under multiple aliases. The privacy risk is stark.

Additionally, there are shared tags: several address clusters were assigned tags that were identical to tags assigned to other address clusters. These are false negatives generated by our address clustering heuristic. They may be due to participants managing multiple Bisq nodes with distinct BSQ wallets or migrating between BSQ wallets using BSQ transfer transactions. We use the shared tags to reduce the number of

[12] https://github.com/Liam-Hickey-Ire/BisqDAOAnalysisSource/blob/master/Data/670026/dao-txes.csv: Each line contains the hash of a Bisq DAO transaction.

[13] Our number differs from that shown on the BSQ Block Explorer (https://explorer.bisq.network) since our number includes addresses not carrying BSQ-coloured bitcoins.

[14] https://github.com/Liam-Hickey-Ire/BisqDAOAnalysisSource/blob/master/Data/670026/addr-clusters.csv: Each line contains the addresses in an address cluster.

[15] https://long.af/kcaift.

[16] https://github.com/bisq-network/compensation/issues/260 and https://github.com/bisq-network/compensation/issues/263.

[17] https://github.com/Liam-Hickey-Ire/BisqDAOAnalysisSource/blob/master/Data/670026/cluster-tags.csv: Each line contains the tags assigned to an address cluster.

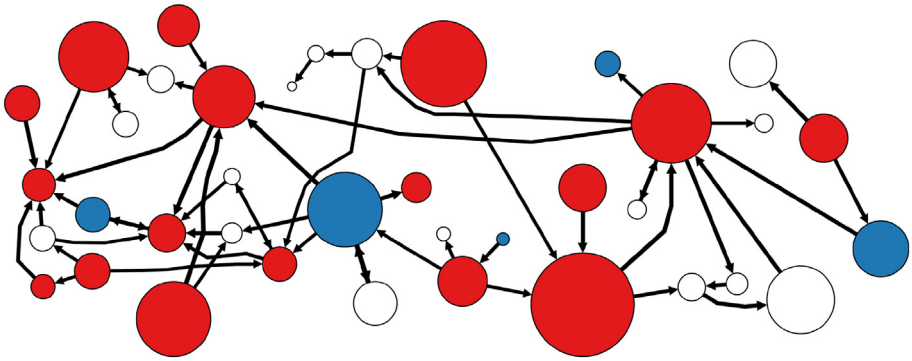

Fig. 2. A graphical summary of the significant flows of BSQ between address clusters (Bisq DAO participants). Vertex colour indicates role (red for proposers, blue for generators, and white for users) while vertex size indicates transaction volume.

address clusters to 1504[18] and the number of tagged clusters to 106[19]. In the context of address clustering, a false negative is less serious than a false positive: assuming that two address clusters may be controlled by two separate participants when in fact they are controlled by one is a lack of information, whereas assuming that one address cluster is controlled by one participant when in fact it is controlled by more than one is incorrect information.

4.2. The address cluster graph

Once we have generated the address clusters, we can perform higher-level analyses of activity within the Bisq DAO. We can construct an address cluster graph where each vertex corresponds to an address cluster or Bisq DAO participant and each edge corresponds to a set of BSQ transfer transactions where the source and target vertices represent the sender and recipient of the transactions, respectively. Fig. 2 is a visualisation of the largest connected component of the address cluster graph where the total value of the transactions associated with each edge exceeds 10 000 BSQ. This is an arbitrary value chosen to produce a graph whose size is suitable for this article; an interactive graph visualisation system is required to navigate the entire graph.

The colour of each vertex represents the role of the corresponding address cluster: red vertices are proposers; blue vertices are generators and white vertices are users. The size of each vertex is proportional to the total amount of BSQ sent to the addresses in the corresponding address cluster. We note that all of the red vertices can be linked with pseudonyms, GitHub account names, and/or real-world names.

The address cluster graph represents a financial network where the vertices represent Bisq DAO participants, some of whom are identifiable, and the edges represent financial relationships. Fig. 2 is a small subgraph of the address cluster graph. However, it points to the type of tools that can be built to investigate Bisq activity. For example, suppose a particular proposer (red vertex) is the subject of an investigation but they have carefully separated their real-world identity from their Bisq activity. They will appear in the address cluster graph without immediately identifying information. But it is a simple matter to identify nearby vertices who have financially interacted with the proposer in the past, and may possess identifying information about the proposer. Blockchain analysis service providers offer similar functionality to identify Bitcoin users: they automatically point to centralised services that may possess Personal Identifiable Information (PII) for users or their close contacts [45]. This is a privacy risk since it implies the applicability of a multitude of financial network analysis techniques.

4.3. The two-sided BSQ market

All BSQ originates with contributors to the Bisq project in either the transaction outputs of the BSQ genesis transaction or the issuance transaction outputs of the accepted BSQ compensation and reimbursement request transactions. Once minted, BSQ can be transferred between any number of participants until it is eventually burnt, primarily by traders for trading fees. We can use the address cluster graph to classify the BSQ transfer transactions based on the roles of the sender (the source address cluster) and the recipient (the target address cluster). The breakdown for the 3489 BSQ transfer transactions is shown in Table 3. For example, there are 860 transfers from users to users, 20 transfers from users to generators, etc. Although there are far fewer proposers (113) and generators (175) than users (1244), the proposers and generators are involved in 75% of all BSQ transfer transactions.

A similar situation presents itself in Bitcoin: large centralised services such as exchanges, mining pools, gambling services, and darknet markets generate ‘super-clusters’ in the address clustering of the Bitcoin blockchain [17]. Even though they are few in number when compared with the total number of Bitcoin users, they have a high degree of centrality in the corresponding address cluster graph and are involved in a significant number of Bitcoin transactions [13]. Because of this, they are a focus of regulators and blockchain analysis service providers. Within Bisq, the proposers and generators could attract a similar focus: they are involved in a significant number of BSQ transfer transactions, they play a central role in the network and, in many cases, they are easily identifiable.

4.4. The dominant BSQ transactors

At the time of our analysis, the Bisq DAO had minted 5823351.09 BSQ, the participants had burnt 1323984.99 BSQ, primarily for trade fees, and 4499366.10 BSQ remained in circulation. It is an easy task to identify the address clusters that have transacted the most BSQ. Out of the top ten BSQ transactors, five can be linked with GitHub account

Table 3
The breakdown for the 3489 BSQ transfer transactions[a]

Item	User	Generator	Proposer
User	860	20	154
Generator	126	15	35
Proposer	1091	25	242

[a] The rows indicate the role of the sender, the columns indicate the role of the receiver.

[18] https://github.com/Liam-Hickey-Ire/BisqDAOAnalysisSource/blob/master/Data/670026/addr-clusters-2.csv: Each line contains the addresses in an improved address cluster.

[19] https://github.com/Liam-Hickey-Ire/BisqDAOAnalysisSource/blob/master/Data/670026/cluster-tags-2.csv: Each line contains the tags assigned to an improved address cluster.

names and real-world names. The individuals are providing their names when submitting BSQ compensation and reimbursement proposal transactions. Our address clustering heuristic is linking this information with the entirety of their Bisq DAO activity, including their transaction volume and balances.

Decentralisation can result in governments placing increased regulatory burdens on individuals. For example, at the turn of the century, Newman [46] made the following observation in relation to out-of-state sales taxes in the USA:

> The irony of the movement toward local control and decentralising government is that the increased dependence on local taxes and revenue in an increasingly global retail market is pushing governments towards policies of more burdensome regulation on business and more intrusive government on the individual in order to collect those out-of-state sales taxes. As local regions become increasingly artificial boundaries for government jurisdictions, even more jerry-rigged regulations are attempted to salvage regional financial health.

Decentralised exchanges, and those who participate in them, may suffer a similar fate. If the dominant BSQ transactors can be identified and linked with the entirety of their Bisq DAO activity, including their transaction volume and balances, then they may become a target for increased regulation.

4.5. Impact within the bitcoin blockchain

We have assessed the Bisq DAO and BSQ token in isolation. However, all BSQ transaction data is published on the Bitcoin blockchain. The set of BSQ transactions is, by definition, a subset of the set of Bitcoin transactions. We can assess the impact of the Bisq DAO on address clusterings of the entire Bitcoin blockchain. We can also combine the Bisq Trade Protocol address clustering heuristic (Section 3.1), the Bisq DAO address clustering heuristic (Section 3.2), and the heuristics referenced in Section 2. The address clusters generated by our heuristic are equally valid when viewed through the lens of the larger Bitcoin blockchain. In fact, BSQ addresses are simply Bitcoin addresses with a leading `B` character. By extension, the observations stemming from the use of this heuristic are equally applicable.

5. Countermeasures

There is no silver bullet to addressing the privacy leaks presented in the previous sections. Both the Bisq Trade Protocol heuristic (Section 3.1) and the Bisq DAO heuristic (Section 3.2) extend the multi-input heuristic that is an effective means of aggregating user activity on the Bitcoin blockchain [17]. A coloured coin system, such as Bisq, that builds on top of Bitcoin will be subject to this type of analysis. Furthermore, the most obvious countermeasures involve obfuscation through additional transactions, which incur transaction fees. This is undesirable since transaction fees on the Bitcoin blockchain are expensive and expected to rise.

The Bisq Trade Protocol heuristic relies on the structure of the maker fee, taker fee, deposit, and payout transactions (see Fig. 1). We can follow the trade amount and the security deposits through the four transactions. The Bisq software could obfuscate the flow of the security deposits by keeping the security deposit belonging to the buyer of bitcoins separate from the trade amount and randomising the order of the transaction outputs containing the security deposits in the payout transaction. However, this would also necessitate careful coin-control by the buyer in future transactions [47,48].

A number of approaches can be taken to defeat the Bisq DAO heuristic. The heuristic relies on BSQ self-transfer transactions. The Bisq software could trigger false positives or false negatives in this heuristic by introducing ambiguity into the distinction between self-transfers and non-self-transfers. Other than the BSQ genesis transaction, transfer transactions are the only BSQ transactions that are not entirely self-transfers. As a result, transfer transactions have the effect of separating clusters generated by our heuristic. Disguising transfer transactions so that they cannot be distinguished from self-transfer transactions would trigger false positives in the heuristic, invalidating generated clusters. For example, a participant could create a BSQ trade fee transaction to transfer BSQ where the ‘change’ was directed to the recipient and a small amount of BSQ was burnt to satisfy the requirement of a BSQ trade fee transaction. While this solution defeats the heuristic as it stands, there are other ways in which BSQ transaction types can be deduced. Every trade fee transaction can be linked to the four transactions (maker fee, taker fee, deposit, and payout) of a Bisq trade. Consequently, any trade fee transaction that is not linked to a Bisq trade could be identified as a disguised transfer transaction and treated as such.

Additionally, transfer transactions can be used to trigger false negatives in our heuristic, thereby diminishing the heuristic's effectiveness. Triggering a false negative requires the use of ‘dummy’ transfer transactions after each self-transfer transaction. This transfer transaction sends BSQ from the change address used in the last self-transfer to a new address owned by the same user. This gives the appearance of BSQ being sent between parties, thus reducing the size of the address clusters generated by our heuristic. While dummy transfer transactions reduce the effectiveness of the heuristic, they also create transactions that are not otherwise needed, increasing the cost for users. Of course, functionality to create dummy transactions and a best-practices guide could be included in the Bisq software and documentation and only used to improve privacy as required.

The Bisq Trade Protocol heuristic and the Bisq DAO heuristic rely on the ordering of transaction inputs and transaction outputs of particular transactions created by the Bisq software, see Appendix A and Appendix B. In the case of the Bisq Trade Protocol, the orderings of the transaction inputs and transaction outputs of the four transactions (maker, taker, deposit, and payout) could be randomised if both peers agreed on the orderings as part of each Bisq trade contract. However, the orderings could still be deduced by following the trade amount from the seller to the buyer. Similarly, the Bisq DAO could randomise the ordering of the transaction outputs of a BSQ transfer transaction that carries BSQ. The first transaction output carrying BSQ is for the recipient of the transfer. The second transaction output carrying BSQ, if it exists, is a change for the sender. However, even if their ordering was randomised on a per-transfer basis, we could still use a change heuristic to tell them apart, see, e.g., Ref. [4].

Haveno [7] is a fork of Bisq based on Monero [49] instead of Bitcoin with improved privacy. It uses a one-time ring signature to weaken traceability: when signing a transaction, the signer can search for other entries in the Unspent Transaction Output Set (UTXO) and create a one-time ring signature that could have been created by the owners of any of those transaction outputs. This renders the Bisq Trade Protocol heuristic ineffective. Haveno has also removed the Bisq DAO completely. Traders must pay for trade fees using Monero's native currency. However, the Bisq DAO and the BSQ token facilitate the transfer of value from the traders using Bisq to the contributors maintaining it, without requiring a centralised treasury. It is unclear how the Haveno treasury will be managed and whether it will foster community participation.

6. Conclusion

We demonstrated the privacy cost in participating in Bisq trades and the Bisq DAO. Firstly, we showed that Bisq trades on the Bitcoin blockchain can be easily identified. The trade amount in bitcoins and the security deposits can be linked with their respective owners before and after a trade. This points to a Bisq Trade Protocol address clustering heuristic. Secondly, participants of the Bisq DAO disclose significant information about themselves, especially when submitting BSQ compensation and reimbursement proposal transactions. Even though Bisq

generates new address(es) for every BSQ transaction, 94% of these transactions are self-transfers, i.e., all of the transaction inputs and outputs belong to the same participant. This points to a Bisq DAO address clustering heuristic. We implemented this heuristic and applied it to all BSQ transactions to date. The heuristic proves effective in aggregating all activities performed by each participant, such as trades, votes, proposals, etc. We can attach pseudonyms, GitHub account names, and real-world names to many of the central participants. This has important implications for user privacy. Although not examined in this article, it has further implications for the Bisq DAO voting system and address clustering in the broader Bitcoin blockchain.

The Bisq Trade Protocol and the Bisq DAO are innovative approaches to peer-to-peer trading of bitcoins for other currencies and to decentralise the governance and finance functions of a decentralised exchange. However, when viewed through the prism of blockchain analysis and address clustering, they appear vulnerable. Traders and participants of the Bisq DAO will expect certain limits on what is known about them and on what others can find out. Blockchain analysis could unsettle this expectation and have a 'chilling effect' on adoption.

Declaration of comepting interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendices.

A. *The Bisq Trade Protocol Address Clustering Heuristic*

We identify all Bisq Trade Protocol transactions on the Bitcoin blockchain using their distinctive structure (see Section 3.1 and Fig. 1). Once we have identified the trades, we iterate through each one and cluster the associated addresses. ClusterBisqTrade clusters the addresses associated with a single Bisq trade (see Algorithm 1). The inputs are the maker fee transaction (M), the taker fee transaction (T) and the payout transaction (P). P always has exactly two transaction outputs: the first contains the security deposit for the seller; the second contains the security deposit and the trade amount for the buyer. The relevant addresses are the addresses belonging to the transaction inputs of M (Line 2), the addresses belonging to the transaction outputs of M (Line 3), the addresses belonging to the transaction inputs of T (Line 4), the addresses belonging to the transaction outputs of T (Line 5), and the addresses belonging to the transaction outputs of P (Line 6). The output is a partition of the addresses into subsets such that all addresses in the same subset are controlled by the same entity.

IsSeller? distinguishes between two cases: either M is the seller or T is the seller (Line 7). M and T always have at least two transaction outputs where the second transaction output contains either a security deposit or a security deposit combined with the trade amount. In addition, the second transaction output of the seller is spent by the second transaction input of D. The ordering of the transaction inputs and transaction outputs can be deduced from the Bisq source code[20]. Therefore, by inspecting M and D, we can deduce if the maker is the seller or the taker is the seller. If the maker is the seller, then we cluster the addresses belonging to the transaction inputs and outputs of M with the address belonging to the first transaction output of P, and we cluster the addresses belonging to the transaction inputs and outputs of T with the address belonging to the second transaction output of P (Line 8). Alternatively, if the taker is the seller, we cluster the addresses belonging to the transaction inputs and outputs of M with the address belonging to the second transaction output of P, and we cluster the addresses belonging to the transaction inputs and outputs of T with the address belonging to the first transaction output of P (Line 10). In both cases, we are simply following the flow of bitcoins from a seller to a buyer.

We note that the addresses belonging to the first transaction outputs of both M and T, and the addresses belonging to the transaction input of P, are not clustered. The input of P is only used by the Bisq Trade Protocol itself and is never reused, while the first output of both M and T contain Bisq trade fees.

Algorithm 1. The Bisq Trade Protocol Address Clustering Heuristic

Algorithm 1 The Bisq Trade Protocol Address Clustering Heuristic

```
1:  function ClusterBisqTrade(M, T, D, P)
2:      {a_0, a_1, ..., a_p} ← TxInAddrs(M)
3:      {b_0, b_1, b_2} ← TxOutAddrs(M)
4:      {c_0, c_1, ..., c_q} ← TxInAddrs(T)
5:      {d_0, d_1, d_2} ← TxOutAddrs(T)
6:      {e_0, e_1} ← TxOutAddrs(P)
7:      if IsSeller?(M, D) then
8:          return {{a_0, a_1, ..., a_p, b_1, b_2, e_0}, {c_0, c_1, ..., c_q, d_1, d_2, e_1}}
9:      else
10:         return {{a_0, a_1, ..., a_p, b_1, b_2, e_1}, {c_0, c_1, ..., c_q, d_1, d_2, e_0}}
11:     end if
12: end function
```

[20] https://github.com/bisq-network/bisq/blob/7233979d94abde020eadaab7dae33b0efb0e2e7e/core/src/main/java/bisq/core/btc/wallet/TradeWalletService.java: Line 304.

B. The Bisq DAO Address Clustering Heuristic

We identify and categorise all BSQ transactions on the Bitcoin blockchain (see Section 3.2 and Table 2). Once we have identified the transactions, we iterate through each one and cluster the associated addresses. ClusterBisqDAOTransaction clusters the addresses associated with a single Bisq DAO, or BSQ transaction (see Algorithm 2). The only input is a BSQ transaction (T). The relevant addresses are the addresses belonging to the transaction inputs of T (Line 2) and the addresses belonging to the transaction outputs of T (Line 3). The output is a partition of the addresses into subsets such that all addresses in the same subset are controlled by the same entity.

IsGenesisTx? and IsTransferTx? distinguish between three cases: either T is the BSQ genesis transaction, T is a BSQ transfer transaction, or T is some other type of BSQ transaction (see Table 2). In the first case, we cluster the addresses belonging to the transaction inputs of T (Line 5) only. Those addresses are controlled by the creator of the BSQ genesis transaction. This information can be derived directly from the specification of the genesis transaction. In the second case, we cluster the addresses belonging to the transaction inputs of T and the addresses belonging to all but the first transaction output of T. Those addresses are controlled by the creator of the BSQ transfer transaction. This information can also be derived directly from the specification of a transfer transaction. The address belonging to the first transaction output of T is the address of the recipient. The ordering of the transaction outputs can be deduced from the Bisq source code[21]. In the third case, we cluster the addresses belonging to the transaction inputs of T and the addresses belonging to the transaction outputs of T. Those addresses are controlled by the creator of the BSQ transaction. Again, information can be derived directly from the specification of the remaining transaction types.

Algorithm 2. The Bisq DAO Address Clustering Heuristic

Algorithm 2 The Bisq DAO Address Clustering Heuristic

1: **function** ClusterBisqDAOTransaction(T)
2: $\{a_0, a_1, \ldots, a_p\} \leftarrow$ TxInAddrs(T)
3: $\{b_0, b_1, \ldots, b_q\} \leftarrow$ TxOutAddrs(T)
4: **if** IsGenesisTx?(T) **then**
5: **return** $\{\{a_0, a_1, \ldots, a_p\}, \{b_0\}, \{b_1\}, \ldots, \{b_q\}\}$
6: **else if** IsTransferTx?(T) **then**
7: **return** $\{\{a_0, a_1, \ldots, a_p, b_1, \ldots, b_q\}, \{b_0\}\}$
8: **else**
9: **return** $\{\{a_0, a_1, \ldots, a_p, b_0, b_1, \ldots, b_q\}\}$
10: **end if**
11: **end function**

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