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Bitcoin under the microscope[☆]

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ABSTRACT

This paper explores and describes historical on-chain transaction data recorded on the Bitcoin blockchain, constructs a panel of all individual Bitcoin users, and computes their balances in the cross-section and over time. We run clustering algorithms to combine addresses that belong to the same user into wallets and we find that using wallets over addresses as the unit of analysis allows for more economically meaningful interpretations of user behavior. We identify and divide wallets into user categories – miners, exchanges, services, retail wallets and receiving-only addresses – and observe varying activity levels and balances in the cross-section and over time, corresponding to their intended role in the Bitcoin network. Our findings also suggest heterogeneity in financial performance across user categories with miners exhibiting higher realized returns relative to exchanges and retail users.

1. Introduction

Since Bitcoin was proposed in late 2008, there has been a growing literature studying its blockchain both theoretically and empirically (for instance Basu et al., 2023; Easley et al., 2019; Pagnotta, 2022; Cong et al., 2021). However, only a few studies take advantage of public blockchains (such as Foley et al., 2019; Griffin & Shams, 2020; Makarov & Schoar, 2022) and employ granular on-chain Bitcoin data to identify and track behavior of specific user categories over time.[1] In this paper, we create a panel of *all* Bitcoin users and compute their balances in the cross-section and over time. We provide a complete classification of different user-types, their wealth and transaction behavior within the Bitcoin blockchain network. We highlight pitfalls and peculiarities in the calculation of simple network characteristics such as accurate time series of user balances, and thereby provide clean snapshots of the network at different points in time, with focus on accuracy and aggregating balances and other metrics in a detailed and economically meaningful way.

We study the Bitcoin blockchain from the genesis block on January 3, 2009 to April 30, 2022 and sort user wallets by different types: miners, exchanges, services, retail wallets and receiving-only addresses. We explore their transaction activities and balances in

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[1] On Ethereum blockchain, Momtaz et al. (2022) study the behavior and evolution of individual wallets.

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the cross-section and time-series. With the granularity and accuracy of our database, we are able to match each user transaction with a respective USD price to create a measure of wallet-level profitability on the Bitcoin blockchain. To the best of our knowledge, we provide one of the first empirical analyses of the Bitcoin blockchain through the lens of individual user wallets using a comprehensive, user-level on-chain data. We do this by holding Bitcoin on-chain data under the microscope and taking advantage of the Cardiff University B*i*tcoin Database (CUB*i*D), which provides a structured, transaction-level database of all transactions on the Bitcoin blockchain.[2]

To start with, we provide an overview of the network by considering transaction activity and number of addresses on the Bitcoin blockchain. We then examine the estimated supply of bitcoins at any given point in time. There are many articles in the media speculating on the amount of bitcoins still in circulation versus lost bitcoins. For instance, the blockchain analysis firm Chainalysis estimates that 23% of bitcoins may be lost, which is estimated as bitcoins that have not moved between addresses in more than five years.[3] We show that the percentage of bitcoins considered as not in circulation, depending on the cutoff date to define inactivity, increases steadily over time, with a steeper growth in bitcoins not in circulation following the 2017 bull market. We also highlight user errors recorded on the blockchain such as bitcoins being sent to 'invalid' addresses or some bitcoins being lost due to miners' fault in claiming their rewards and transaction fees.

Moreover, we study the ownership concentration of bitcoins across users and over time. To identify individual users, we follow Foley et al. (2019) and employ the Union-Find Algorithm to cluster individual addresses together into wallets and show that most addresses and wallets in the Bitcoin network do not carry any balance while most wallets are comprised of multiple addresses and better represent economic agents active in the network. This is because users on the network often change their addresses and move their bitcoins to new addresses to ensure the security and privacy of their bitcoins. We also observe that the vast majority of addresses and wallets hold very small amounts of bitcoins, indicating that the distribution of wealth is broad across the bitcoin blockchain. However we do show that some specific users possess significant amounts of bitcoins.

As a next step, we classify wallets by their intended usage. We utilize a set of wallets and entities identified by walletexplorer.com, whale-alert.io, and bitinfocharts.com to uncover the identity of user addresses and wallets. We are able to determine the addresses of exchanges and other services that accept Bitcoin for payments.[4] Unsurprisingly, we show that exchanges hold some of the largest balances. With respect to miners, we classify addresses (wallets) as Level 1 (L1) miners if they receive the newly created bitcoin reward in the block they mined and Level 2 (L2) miners as those addresses (wallets) that receive their Bitcoin from L1 miners shortly after the block was mined. We show that miners hold a proportion of their bitcoins for long time-periods and that their transaction frequency (both L1 and L2 miners) is low. For example, the median miner is involved in two blocks and two transactions. Overall, we find that using wallets over addresses as the unit of analysis allows for more economically meaningful interpretation of user behavior. Bitcoin balances, as a measure of wealth, does not take into account the dollar cost of entering the network and the returns each user experiences when disposing of their bitcoin. We match each on-chain transaction with the latest price at the creation of the block and calculate users' realized returns. We observe a wide range of realized returns among Bitcoin blockchain users, with miners having the highest average percentage returns per bitcoin transacted.

Our paper contributes to the wide-ranging literature on Bitcoin but specifically, we contribute to the literature on granular analyses of the Bitcoin blockchain. Recently, Makarov and Schoar (2022) also analyze Bitcoin blocks and transaction details, with a focus on geographic distribution of miners and wealth. We examine the number of lost bitcoins on the blockchain, estimate real transaction volumes, and illustrate the distribution of bitcoins across *all* addresses and wallets in great detail. We provide estimates of the distribution of realized financial returns (in percentage and dollar values) across different wallet holders, where we categorize users into exchanges, miners, services and retail users. Therefore, our paper also adds to the growing literature attempting to understand the dynamics of bitcoins as a new asset class, by providing a detailed analysis of realized financial returns at the user level, rather than studying market returns in aggregate (see, e.g., Hu et al., 2019; Borri, 2019; Zhang et al., 2021; Liu & Tsyvinski, 2021; Liu et al., 2022).

2. Data & overview of the bitcoin network

In this section, we provide a detailed analysis of on-chain transactions recorded on the Bitcoin ledger and explain how to transform them into economically meaningful metrics that describe user dynamics on the Bitcoin blockchain. First, we estimate the economic magnitude of potential errors made when not adjusting the total supply of bitcoins for various definitions of address inactivity. Second, we provide descriptive statistics on transactions, addresses, and blocks recorded on the ledger over time. Third, we compare the structure of the Bitcoin blockchain viewed through the lens of addresses versus wallets as a proxy for individual users' activity. We classify user wallets by different entity types that describe their role in the ecosystem and study the heterogeneity in their behavior over time.

2.1. Data sources

By construction, Bitcoin blockchain data is publicly available and can be obtained by running a network node that stores and validates a full copy of the ledger or by accessing information from blockchain web explorers such as blockchain.com. We utilize the

[2] https://cubid.cardiff.ac.uk and https://www.cardiff.ac.uk/cubid.
[3] See, e.g., https://www.newsbtc.com/news/bitcoin/chainalysis-up-to/.
[4] *Services* includes firms or entities that refer to activities such as gambling, Virtual Private Network providers, dark web applications, and more. See the Appendix for more details on services.

structured and already processed Bitcoin blockchain database provided by Cardiff University B*i*tcoin Database (CUB*i*D) which spans between January 3rd, 2009 and April 30th, 2022. CUB*i*D contains two data layers, the raw Bitcoin blockchain data and a post-processed data layer. Layer 1 contains all the information that any copy of the Bitcoin ledger would store such as the block header and details on each individual transactions. Thus, we have detailed network information and statistics on the total number of blocks, number of addresses, or transaction sizes, and fees. Layer 2 contains post-processed, in-depth information on all addresses and wallets and their transaction activities and balances over time.[5]

One particular advantage of CUB*i*D is that it provides information on both the individual address level but, more importantly, combines information on addresses that belong to the same wallet (i.e., the same user) via the Union-Find Algorithm (UFA). For each wallet, we know its bitcoin balance over time, details on its transactions sent and received as well as, in some cases, additional information that lets us determine what type of user corresponds to a particular wallet. For example, any wallet that proposes and signs new blocks is recognized as a (L1) miner; other wallets have been identified to belong to certain type of user categories in the ecosystem such as exchanges or other marketplaces and services where bitcoins are used for transacting.[6]

To estimate and assign U.S. dollar values to each transaction recorded on the Bitcoin blockchain, we face the issue that Bitcoin trading occurs on different exchanges with different transaction volumes. Therefore, we obtain all the historical bitcoin trade prices against U.S. dollar on available exchanges from BitcoinCharts.com and calculate the most representative trade price across all exchanges as the volume-weighted-average price (VWAP) of all exchanges at each minute and then consider the last VWAP before or at the block mining time as the Bitcoin:USD exchange rate. Considering the first Bitcoin trade on BitcoinCharts.com is recorded on 2010/04/25 at 16:37:04 UTC (before mining of block 53,005), at the price of $0.003 per Bitcoin with a volume of 1000 Bitcoin, we assume a price of zero dollars before block 53,005.

2.2. *Overview of the Bitcoin network*

Table 1 shows the number of blocks, transactions, and new addresses created on the Bitcoin blockchain each year. The Bitcoin protocol aims to have an expected block arrival time of 10 min, which would result in 52,560 expected blocks being added to the blockchain per year (365 days). This target has been exceeded almost every year except for 2009, where only 32,490 blocks have been mined. As we will see later, the number of miners participating in the consensus process has been increasing over the years and more mining power deployed for updating the ledger results in blocks being added at a faster rate than every 10 min, until the mining difficulty is adjusted every two weeks to match the (increased) supply of hash power in the network. The number of transactions and number of new addresses created every year steadily increases until 2017, which coincides with the 2017 bull market, and is slightly lower in 2018 following the price crash. However, respective transaction and address counts are even higher in 2019 and 2020 compared to their previous peak in 2017. Overall, there have been over 729 million transactions involving more than 970 million addresses on the Bitcoin blockchain as of April 30th, 2022.

2.3. *Estimated Bitcoin supply*

The Bitcoin protocol states that the maximum supply will be 21 million Bitcoin. New bitcoins can only be created as a reward for mining, where miners receive the block reward for proposing the next block. Initially, miners received 50 bitcoins as reward but mining rewards halve every 210,000 blocks so that in 2022, miners receive 6.25 bitcoins for every block they mine. Once new bitcoins are created, they are recorded on the ledger as transactions with no input, also known as *coinbase* transactions.

However, these hypothetical numbers are not necessarily achieved in practice. There is ample anecdotal evidence of cases where users have lost access to their private keys and thus, their address or wallet and respective bitcoin balances. Consequently, although their bitcoin balance is recorded and observable on the ledger, such users are unable to access their bitcoin holdings and thus, transact on the network. Empirically, it is almost impossible to distinguish between aforementioned addresses that have lost access versus those that simply choose not to transact for a long time period (i.e., they choose to hold their bitcoins for a long period). Nevertheless, it is possible to estimate the amount of bitcoins not in circulation ('inactive') based on simplifying assumptions. For example, *Chainalysis* estimate that over 23% of bitcoins may be lost due to inactivity of addresses for at least five years, which would significantly shrink the market capitalization of tradeable bitcoins.[7] We are agnostic in our definition of 'inactive' bitcoin balances with respect to the length of any inactivity period. Instead, we deem bitcoins as 'not in circulation up to a given point in time' if they have not been moved by an address since a given block (timestamp), with end of April 2022 as our reference point. Specifically, if a bitcoin has not been moved from one address to another on the blockchain up to a certain point, we denote it as inactive. We do this for each block and are thereby able to compute a measure of active bitcoins on the blockchain for each point in time.

Fig. 1 presents the total and percentage of bitcoins not in circulation, defined as bitcoins that have been not moved since that block (point in time).[8] Given our definition, the number and percentage of bitcoins not in circulation, as shown in Fig. 1, will increase over

[5] For a full description of post-processed data items provided in CUB*i*D we refer to its user manual.

[6] We cross-check publicly identified addresses and respective wallets using walletexplorer.com and whale-alert.io.

[7] See https://www.newsbtc.com/news/bitcoin/chainalysis-up-to/.

[8] Although the reference point for the Fig. 1 is end of April 2022, the figure is drawn up to the end of December 2021 for visualization purposes. Defining inactivity as having less than a few months since the last transaction would classify the large majority of users as inactive and is therefore not fit for purpose.

Table 1
Overview of the Bitcoin blockchain.
This table reports key statistics of the Bitcoin blockchain by year: the number of new blocks, transactions and new addresses and new wallets.

Year	#Blocks	#Transactions	#New Addresses	#New Wallets
2009	32,490	32,709	32,611	631
2010	67,920	185,305	143,715	67,052
2011	59,627	1,901,765	2,592,169	1,408,686
2012	54,526	8,453,050	5,938,883	2,567,324
2013	63,433	19,643,241	16,099,271	6,679,171
2014	58,865	25,263,720	34,059,607	11,348,873
2015	54,321	45,674,023	56,111,964	20,383,662
2016	54,851	82,626,623	94,416,994	43,200,392
2017	55,928	104,063,229	143,736,041	66,541,120
2018	54,498	81,395,636	111,413,920	51,428,932
2019	54,232	119,783,647	130,764,496	61,401,255
2020	53,222	112,553,498	163,665,274	68,700,518
2021	52,686	97,796,453	162,976,346	56,225,405
2022	17,716	30,542,583	49,000,056	15,449,913
Σ	734,315	729,915,482	970,951,349	405,402,934

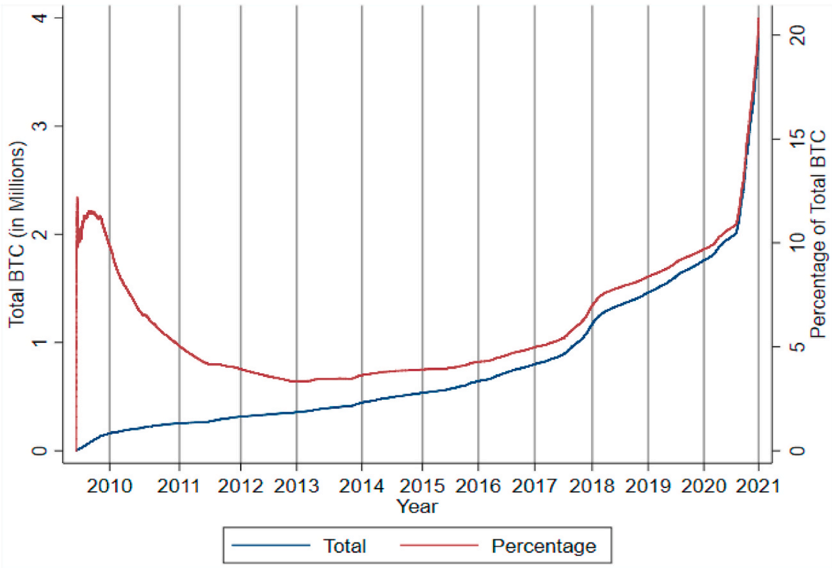


Fig. 1. Bitcoins not in circulation (Inactive).
This figure shows the total amount and percentage of the total bitcoin supply not in circulation as of April 2022. At each point in time (*x*-axis), we compute bitcoins not in circulation as those that have not been used for transactions up to that given point in time (*x* coordinate). The blue line, using the primary *y*-axis, illustrates the total number (in millions) of bitcoins not in circulation at each point in time, *x*, while the red line shows the percentage of bitcoins not in circulation using the secondary *y*-axis. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

time, as even recently transacted bitcoins could be deemed as not in circulation if a very short time period is chosen. Intuitively, bitcoins that have not been moved since 2010 are more likely to be lost than those that have not moved since 2015, as marketplaces and exchanges did not exist. Further, bitcoins that haven't moved for a period of time may be held for long-term investments. In line with that intuition, we can see that the total number of bitcoins not in circulation increases steadily over time, with a steeper growth in bitcoins not in circulation following the 2017 bull market. If we assume that even long-term investors would transact their bitcoins at least once every five years, i.e., we would fix an inactivity period of bitcoins of more than 5 years as a definition for bitcoins not in circulation, Fig. 1 shows that around 5% of all bitcoins could be considered as not in circulation as they have not been moved since the beginning of 2017.

Apart from bitcoins that can be considered as not in circulation anymore, there are some minor errors or deviations from the intended bitcoin supply schedule that are present in the Bitcoin blockchain. These errors have resulted in some of the native assets being lost over time. For example, when miners propose the next block, they claim the reward and fees included with the transactions included in the block. However, there are some instances where miners made errors, likely by accident, so that some bitcoin are essentially sent but never received or have not claimed correctly and are therefore not in circulation anymore. Therefore they are out of circulation and can be considered as "burnt".[9] Between the first and the second halving, all bitcoins rewarded were claimed by the miners, creating a cumulative amount of 5,250,000 bitcoins. However, between the second and third halving, in block #501,726, the output address entered by the miner was a non-standard bitcoin address and the 12.5 bitcoin block reward was burnt. Also, between the second and third halving in block #526,591, the miner claimed for a reward of 6.25 bitcoin rather than the 12.5 bitcoin they were entitled to and thereby 6.25 bitcoin were burnt. While these deviations do happen, only a total of 8.75 bitcoins have been lost due to such mining errors. A second reason for lost bitcoins is when miners do not claim all of the transaction fees that are included in a block. In total, we find that 1,020,502,903 satoshis (10.2 bitcoins) are lost by miners not claiming the full transaction fee entitled to them. Thus, we estimate that a total of 18.95 Bitcoin have been lost due to unclaimed rewards and fees. Although the total of 18.95 bitcoin does not seem economically that large, it shows us two important points. First, the maximum supply for bitcoin is not 21 million but 20,999,981,05 and it may reduce further in the future. The actual maximum supply may be much lower with lost bitcoin and other issues. Second, and related to the previous point, these lost bitcoins are due to mistakes by miners, who through their role in the block validation process, enable to the Bitcoin blockchain to function. Therefore they should be some of the most diligent and proficient users on the blockchain. For miners to make a number of mistakes that lead to bitcoins being lost is quite surprising and shows that even some of the most knowledgeable users on the blockchain are prone to errors.

2.4. Estimated transaction volume on the Bitcoin Blockchain

It is difficult to measure *real* on-chain transaction volume on the Bitcoin blockchain. Easley et al. (2019) use total reported volume on the blockchain (i.e., transaction output given as transaction input minus the transaction fee) while we Estimate Transaction Volume (ETV) as the total volume of a transaction that does not belong to any address of the sender's wallets (i.e., minus the change that is returned to the sender in each transaction).[10]

Consider the transaction ba92ef4aa8c059ef85c67b91b9fa735ad8b2042de79136ff5df697fa4471bf72, submitted by the *Coinbase* exchange, where 13.2744 bitcoins are returned to the same input address (*19KHfhPNu5dB271471pfDyVuaqXzecrBd5*) and the remainder goes to an external address (wallet). Thus, ETV is 4.7255848 bitcoins rather than the full 17.9999848 bitcoins as transaction output. There are also cases where none of the output addresses match the sender's input address, but one or more of the output addresses still belong to the sender's wallet.[11] We are still able to compute the ETV through identification of each wallets' addresses using the UFA.[12] Note that we do not consider transactions from Bitcoin's *coinbase* as part of the input.

In Fig. 2, we illustrate the transaction output compared to our ETV over time in totals (Panel A) and as shares (Panel B). In the early years of the Bitcoin network, estimated transaction volume is comparable to total transaction output and makes up over 80% of the total transaction volume recorded. However, there is a clear downward trend of that ratio where estimated transaction volume is now only a fraction of total volume. Fig. 2 Panel B shows that for instance in 2021, only around 20% of the transactions' total volume is real volume, i.e., using total volume as measure of transaction volume would be an overestimation by fivefold. This is likely the result of a maturing network where existing users exchange some of their bitcoins with other existing users rather than emptying their wallets entirely by sending the bitcoin balance elsewhere (which would result in ETV being equal to total volume).

2.5. Segregated Witness (SegWit)

The Bitcoin blockchain has undergone several changes in its technical specifications and one the biggest changes has been the introduction of Segregated Witness (SegWit), which refers to a change in the transaction format. Its stated purpose as a protocol upgrade was to protect against transaction malleability and decrease transaction times by increasing block capacity. Specifically, it enables transactions to be broadcast to the network that carry a much smaller weight than previously, therefore enabling miners to fit more transactions into blocks. It does this by dividing the transaction into two segments where the unlocking signature (the "witness" data) is removed from the original portion, but it remains a part of the blockchain as a separate structure at the end. The original portion holds the sender and receiver data, while the separate structure at the end (the "witness" structure) contains scripts and signatures. As a result of this segregation of data, more space is created, and more transactions can be added to the blockchain. Therefore many blocks sizes are now over 1 MB. More recently, native SegWit – also known as *bech32* – is the latest development in the address formats. It is even more weight-efficient than its predecessor which means having an even faster transaction speed versus SegWit transactions, better scalability and lower fees per transaction.

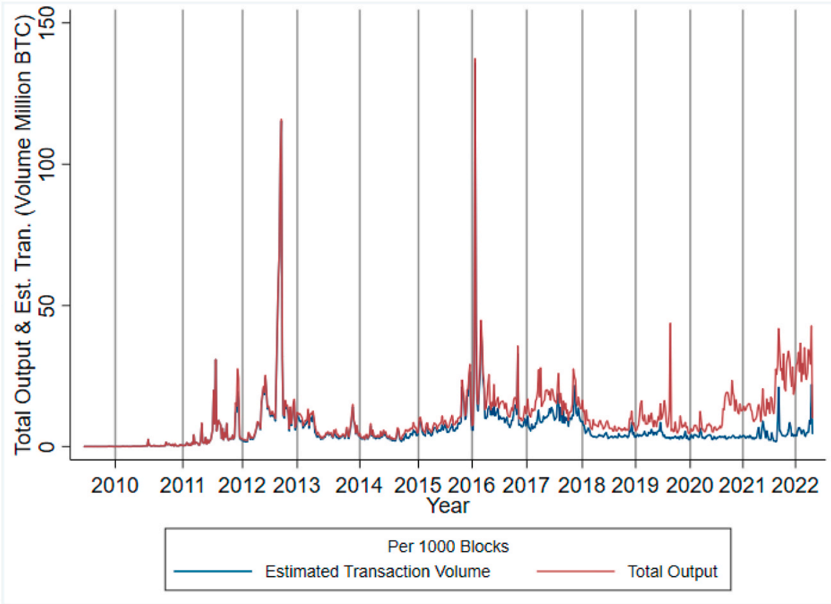
To see the impact of these new types of addresses, Fig. 3 shows the percentage of blocks created that are larger than 1 MB on the

[9] For example, the miner of block #124,724 should have claimed a reward of 50 bitcoin but instead claimed 49.9999999 bitcoin, leaving 1 satoshi unclaimed.

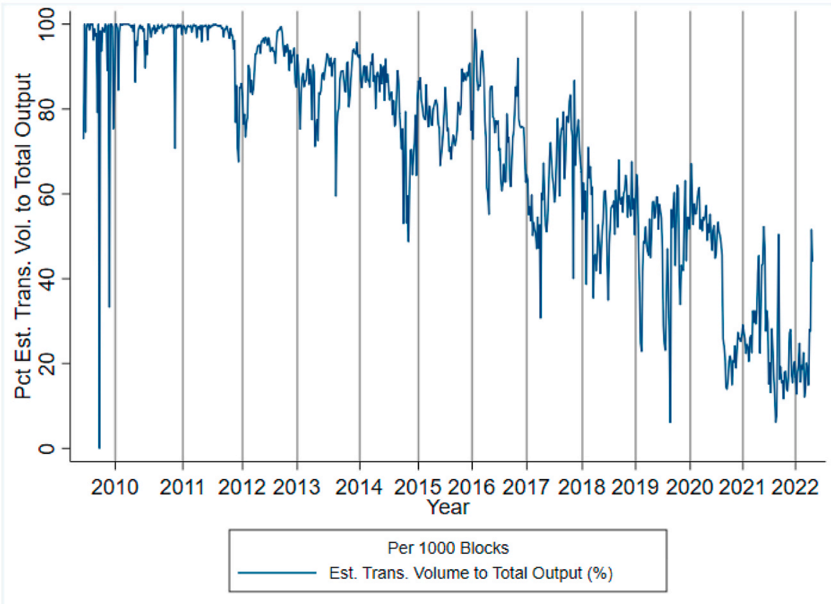
[10] Makarov and Schoar (2022) further split total volume into three components: bitcoins that go back to the sender's cluster (internal), bitcoins that go to other clusters (real), and pass-through volume (real output transactions with additional conditions). Including pass-through volume in total volume calculations can be misleading on the actual volume being traded on the blockchain. Pass-though transactions can be miners allocating rewards to the mining pool so it can be argued it is not actual volume on the blockchain but a miner rewarding their team. Therefore inclusion of these sorts of transactions in any volume calculation can be misleading.

[11] Cf. transaction hash: 0164565ab6c07171fbe458930ebf5c2b2673535ff09271af25a144005034daaf.

[12] For instance, in this transaction, one of the output addresses (*1MNWdde7hrHYjFK4QZ2RrbAfhrij2Cn8Mv*) and the input address belong to the same wallet (part of the Coinbase Global, Inc. exchange wallet) alongside 33,202,571 other addresses.



(a) The total volume of blocks and the estimated transaction volume per 1,000 blocks throughout our sample period.



(b) The percentage of transaction volume from total volume per 1,000 blocks throughout our sample period.

Fig. 2. Bitcoin transaction output and estimated transaction volume.
Panel A of this figure plots the total volume of each block, per 1000 blocks, and the estimated transaction volume, while Panel B reports the estimated transaction volume as a percentage of total volume over time, per 1000 blocks (~ one week) (a) The total volume of blocks and the estimated transaction volume per 1000 blocks throughout our sample period.
(b) The percentage of transaction volume from total volume per 1000 blocks throughout our sample period.

blockchain, noting that before the introduction of SegWit, there was no possible way to create blocks larger than 1 MB. We can see that the percentage of blocks larger than 1 MB has grown substantially over time, reaching over 90% between 2019 and 2021, indicating that Bitcoin users are using SegWit addresses and miners are choosing SegWit transactions to add to their blocks. Fig. 4 delves deeper and shows the percentage of different types of addresses being used on the blockchain. Specifically, we separate out legacy addresses, native SegWit and SegWit addresses. We can see that initially, legacy addresses have dominated but over time, we observe an increase first in SegWit addresses and second an increase in the use of native SegWit addresses. By 2022, both types of SegWit addresses are

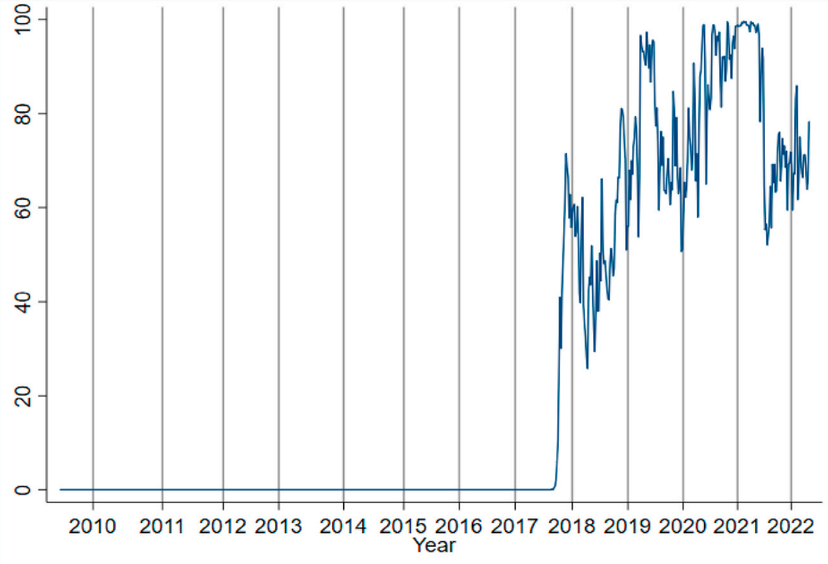


Fig. 3. Percentage of blocks larger than 1MB.
This figure shows the percentage of blocks with the size of more than 1 Megabyte (MB) throughout the years. While the Bitcoin blockchain reports block size in bytes, we calculate 1 MB as 1024 Kilobytes (KB) where each KB is 1024 bytes.

more popular with users than the traditional legacy addresses. Nevertheless, Bitcoin blockchain users still employ all three types of addresses and about 20% of new transactions are initiated by legacy addresses.[13]

3. Addresses, wallets, and wealth by entity type

Each Bitcoin transaction is initiated by one individual user, but each user can have multiple addresses, combined in one or more wallets, that are used as input addresses for the submitted transactions. Bitcoin transactions can have multiple sets of output addresses belonging to several, disjoint users in addition to addresses belonging to the sender.

In our sample, we divide addresses and wallets into different categories of users to gain a better understanding of the underlying behavior and wealth distribution across different users of the Bitcoin network in the cross-section and over time. We follow Foley et al. (2019) and Makarov and Schoar (2022) and employ walletexplorer.com and the Bitcoin rich list from bitinfocharts.com and whale-alert.io to identify addresses and their wallets and classify them by user-types, such as cryptocurrency exchanges or gambling websites and other services that accept bitcoins for payments.

First, we highlight those entities whose addresses and wallets are identified as 'Exchanges'. As is highlighted in Table 2, which shows the ten largest wallets in our sample (in terms of bitcoin balances at the end of April 2022), some of these exchanges are the largest holders of bitcoins in one single wallet although they may posses multiple wallets for different purposes. The largest wallet only consists of 35 addresses and is associated with the Binance exchange, which also controls the 7th largest wallet as of April 2022 (i.e., Binance as a company controls multiple wallets, but these wallets may not have been used in the same transactions as inputs/outputs and thus, are not classified as one wallet using the UFA). Bitfinex, Gemini, and OKEX are three of the other identified major exchanges in the Bitcoin ecosystem.

Second, we distinguish 'Services', which consist of all entities listed on walletexplorer.com under 'Services/Other' (e.g., 'Marketplaces', 'Gambling' and 'Old/Historic').[14]

[13] As we have shown, it is possible for wallets to contain many addresses but it is also possible for wallets to contain many different types of addresses in those wallets. An example of a wallet containing all types of legacy and SegWit addresses is the wallet that includes addresses such as 3G4FDxt25MjN3GJZ3xJH2cFNVMHWLiHAkQ, bc1q377fd8nf8zn0m40khqwyxuunm7kzg2x9zu5p7n, and 17RTTUAiiPqUTKtEggJPec8RxLMi2-n9EZ9, with all these addresses being active at the same time indicating that users manage these different types of addresses concurrently.

[14] Although Walletexplorer.com categorizes some of the identified wallets as "Old/Historic", we categorize these wallets more accurately, i.e., allocating them to *Exchange* or *Gambling* categories by researching their past activity. For example, the *Services* user category includes websites such as bitclix.io, which matches advertisers paying bitcoins to potential online customers when they view ('click') respective advertisements. Services also include soft- or hardware providers related to cryptocurrency wallets such as Coinkite.com, which accept bitcoins as payment for the goods and services they offer and thus, possess addresses and wallets with bitcoin balances. In the Appendix, we provide a full list of *Exchanges* and wallets assigned to the *Services* category along with relevant information on the number of addresses and transaction activity starting dates. We do not highlight each specific sub-category of *Services* wallets in our tables and figures below as their combined bitcoin balances are not sufficiently high and instead combine all the different usage purposes in the *Services* category.

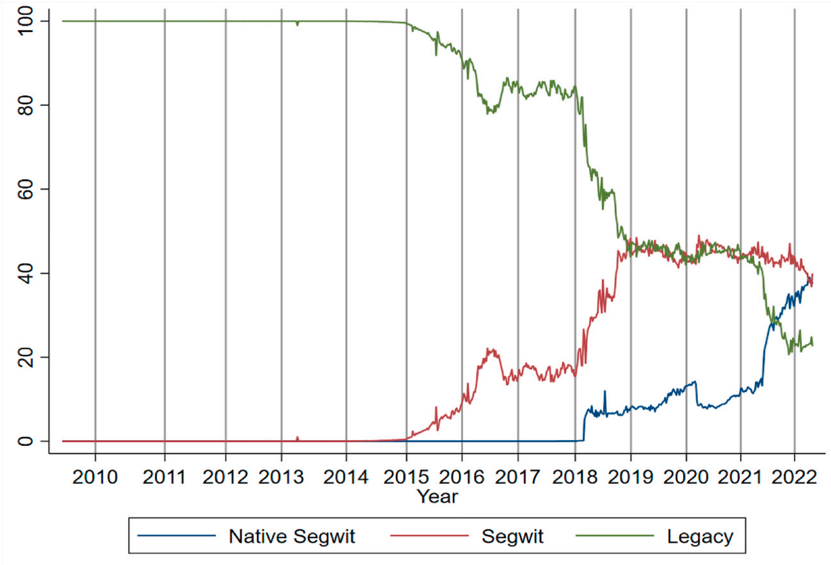


Fig. 4. Evolution of legacy, native Segwit, and Segwit address usage.
This figure shows the percentage of each type of address (Legacy, Native Segwit, and Segwit) used either as input or output address of transactions. For each block, usage percentage is calculated as the number of addresses of a certain type (Legacy, Native Segwit, Segwit) involved in either input or output of a transaction. The percentage is reported every 1000 blocks.

Table 2
Top 10 largest wallets by Bitcoin balances.
This table shows a snapshot of then largest wallets in terms of bitcoin balance at the end of April 2022.

Name	#Addresses	#Transactions	Balance (in Bitcoin)
Binance	35	904	252,597.2329
Bitfinex	1	92	168,009.9857
Gemini	1176	10,832	166,903.9144
$Unknown_1$	1	725	124,052.5388
$Unknown_2$	2	138	94,505.34212
OKEX	1	276	84,067.02086
Binance	40	297	68,730.00006
$Unknown_3$	120	428	52,900.0062
$Unknown_4$	15	634	51,764.9081
$Unknown_5$	218	3080	49,182.292

To identify our next entity type, ‘L1 Miners’, we consider those addresses that are the recipient of a block reward in each *coinbase* transaction and match them to their corresponding wallet(s). We also consider a second layer of mining wallets or addresses that are derived from the first layer of block proposing addresses. The reason for considering second layer of miner is that in many cases, miners send their block rewards to other addresses, either to store their balance separately or to distribute mining revenue across members of mining pools (Cong et al., 2021). Whenever a *Miner Layer 1 (L1)* address sends a transaction to another address, we classify that new address as a ‘second layer miner’ (*Miner* L*2*).

Next, the category ‘Received only’ (Rec_Only) is comprised of single-address users that have only received but never sent any transaction and therefore cannot be linked to any wallet (i.e., there is not enough information for the UFA to allocate them to another set of addresses). Any address that has received a *coinbase* reward but has never sent a transaction, is classified as Rec_Only (i.e., not as L1 miner). All other wallets that do not fall under any of the above categories are combined together as ‘Retail’ wallets.

That is, we split our full sample of wallets into six categories (Miner (L1), Miner (L2), Exchange, Service, and Retail wallets and Rec_Only addresses). A wallet could be assigned to multiple categories, e.g., an exchange wallet also contains addresses that are associated with mining. In such cases, we assign wallets to only one category based on what is the main role of that user wallet. For example, *Exchanges* wallets that also mine blocks mainly exist for the purpose of providing exchange services and thus, we categorize them as exchanges. In the same way, L1 miners may receive transactions from other L1 miners over time and therefore could also be classified as L2 miners. In such cases, we assign them to be L1 miners as they have successfully mined blocks themselves (i.e., received *coinbase* rewards).

To identify trends in the types of users active on the Bitcoin blockchain, Table 3 shows the estimated number of newly created wallets per year that belong to one of the six user categories. The total number of unique wallets controlled by L1 miners is 115,563 and that of L2 miners is 396,089 (as of end of April 2022), respectively. Most of these miner wallets are created from 2010 to 2014 and less than 10% of all miners started proposing blocks after that, i.e., block production is highly concentrated to few L1 miners. This shows that L1 miners tend to be established stakeholders of the Bitcoin blockchain. The total number of new L2 miners wallets is nearly four times as many as L1 miner wallets, i.e., on average, L1 miners will distribute some of their block reward to about four other wallets. There are 201 wallets identified as *Exchanges* and 215 as *Services*, of which most are created in the year 2014. The vast majority of wallets on the Bitcoin blockchain are *Retail* (99.87%) types.[15]

Table 4 provides descriptive statistics for the total set of addresses and compares it to those in wallets as identified in CUB*i*D using the UFA to link addresses together. Panel A of Table 4 reports statistics on the number of addresses that are combined within a wallet for the full sample and by entity type. On average, considering the full sample of addresses and wallets, each wallet contains 2.28 addresses, but even the 75th percentile indicates that most wallets only hold one single address rather than multiple, indicating that the average number is biased upwards due to few wallets with many addresses. For example, the most extreme case is where one wallet, from the *Exchange* category, combines 33,202,572 different addresses.[16]

When studying the distribution of balances among addresses, we find that a large proportion (89.74%, unreported) of addresses have a zero balance. When restricting the sample to addresses with non-zero balances in Fig. 4 Panel B, we find that the average holding is 0.4571 bitcoin indicating that individual addresses do not hold large amounts of bitcoin in each single address. However, the distribution of bitcoin balances is heavily skewed, e.g., with one address holding 252,579.23 Bitcoin. This address belongs to a wallet controlled the Binance exchange (see Table 2). Across entity types, addresses belonging to *L1 Miners* have the highest average bitcoin balance, followed by *Exchanges*. Given the very low figures for median and the 75th percentile of balances, we can assume that these numbers are skewed upwards to the very high outliers for few addresses belonging to these two user categories.

Table 4 Panel C reports statistics the wealth distribution (in April 2022) in terms of bitcoin holdings at the wallet level (for non-zero balance wallets). When considering the full sample of users, the average balance in a wallet is 0.881 bitcoin, but the 75th percentile is only 0.0052 Bitcoin, i.e., the majority of wallets do not have significant bitcoin holdings. Overall, there are stark differences between the distribution of bitcoin holdings in non-empty (non-zero) addresses versus wallets. When combining bitcoin balances of addresses to the wallet level, we observe an increase in average holdings controlled by single entities. For example, the average *Exchange* wallet holds 6177.5738 bitcoins in April 2022, versus 1.5585 bitcoins for the average *Exchange* address, which is the result of combining small balances from many addresses associated with one Exchange wallet. Similarly, the difference between bitcoin balances of the average address of a L2 miner versus the combined balances in a wallet is almost tenfold. On the one hand, this shows that combining addresses' balances to the wallet level matters most for entities such as *Exchanges*, *Services* or *Miners*, where each user controls many addresses in one wallet. On the other hand, we also see that combining retail addresses to wallets, with an average of only 1.73 addresses per *Retail* user wallet, is less relevant. Overall, given the obvious differences in balances of addresses versus wallets, any economically meaningful analysis of bitcoins transactions should therefore be conducted at the wallet level as unit of analysis rather than the address level, as wallets better represent economic agents active in the network.

Table 4 provides only a snapshot of such distribution and does not allow us to study the evolution of wealth concentration over time. To illustrate the evolution of the on-chain bitcoin wealth distribution, Fig. 5 shows the sum of balances aggregated by wallet type every 10,000 blocks and reveals that there is heterogeneity in the wealth distribution both in the cross-section and over time. In particular, we observe that the 201 wallets belonging to exchanges only hold a small fraction of all bitcoins created, although they possess the single largest wallets as shown in Table 2. However, their share has been increasing especially in 2019 and 2020, respectively, and all exchanges combined hold over 1,013,068 bitcoins overall at the end of the sample period. Wallets in the *Services* category only hold negligible amount of bitcoin at any point in time. L1 and L2 miners combined used to hold a major proportion of all bitcoins on the blockchain, especially between 2010 and 2011, but that proportion and total amount has since then shrunk to almost 472,000 bitcoins in combined holdings. The share of bitcoins held in receive only (Rec_Only) addresses, by construction, is increasing over time and they hold close to 15,000,000 bitcoin. These are addresses that have not yet initiated a transaction and thus, cannot be linked to any existing user wallet because the Union Find Algorithm would not be able to associate that address with existing wallets yet, suggesting that a large proportion of users prefers the pseudonymity that comes with storing Bitcoin in receive only addresses with a lack of transaction history. Alliteratively, it can be argued that the increase in receive only addresses is a reflection of new participants joining the ecosystem. The largest share of all bitcoins on the blockchain for most of the sample period (after 2012) belong to *Retail* wallets which have sent at least one transaction. As of April 2022, they hold over 2.58 million bitcoins out of the roughly 19 million bitcoins created overall.

In Table 4, we have shown that the average balance of most of the over four million wallets with positive balance is less than one bitcoin, but from Fig. 5 we see that the sum of all *Retail* wallets make up a large proportion of the wealth on the Bitcoin blockchain. Miners on the other hand have always captured a relatively stable share of Bitcoin created, while exchanges are only starting to emerge as major bitcoin holders.

4. User transaction activity and realized financial returns

The Bitcoin blockchain is occupied by users of different types, with varying degrees of wealth and different ways of using the blockchain to transact value. In this section, we portrait different entity types' performance by studying their financial returns from

[15] Makarov and Schoar (2022) categorize online wallets as exchanges as well and identifies 393 exchanges while we separate these two entities.

[16] This wallet belong to the Coinbase Global, Inc. exchange.

Table 3
Number of new wallets and receiving only addresses by entity type and year.
This table reports the number of new L1 and L2 miners' wallets, exchanges, services, retail, and receiving only addresses in each year from January 2009 to April 2022.

Year	Miners L1	Miners L2	Exchanges	Services	Retail	Rec Only
2009	604	18	0	0	9	21,521
2010	14,349	2560	0	1	50,142	17,449
2011	40,898	28,224	12	12	1,339,540	390,375
2012	24,420	27,441	10	10	2,515,443	125,309
2013	15,704	90,904	28	54	6,572,481	534,149
2014	11,126	92,200	76	68	11,245,403	587,690
2015	2611	44,061	18	28	20,336,944	1,186,871
2016	3344	13,661	10	27	43,183,350	2,133,451
2017	1496	24,023	11	11	66,515,579	3,864,355
2018	873	28,571	12	1	51,399,475	3,299,257
2019	64	21,048	8	1	61,380,134	3,074,895
2020	31	11,298	9	1	68,689,179	3,829,105
2021	33	9875	7	1	56,215,489	9,253,089
2022	10	2205	0	0	15,447,698	6,350,667
Total	115,563	396,089	201	215	404,890,866	34,668,183

Table 4
Addresses versus wallets by entity type.
This table provides descriptive statistics (minimum, maximum, mean and various percentiles) on bitcoin balances at the address and wallet level, respectively. Each panel reports summary statistics for the full sample of addresses as well as for subsamples of addresses belonging to one of six entity types: *Exchanges*, *Services*, *Miners (L1 & L2)*, *Retails* and *Receive Only* addresses. Panel B reports statistics on the number of addresses per user wallet identified via the Union Find Algorithm, for the full sample of wallets as well as by the six entity types. Panel C reports the same statistics as in Panel B at the wallet level.

Panel A. # Addresses per Wallet

Entity Type	N	P10	P25	Median	Mean	P75	P99	Max
Exchanges	201	2	382	5576	276,947.65	78,119	1,670,953	33,202,572
Services	215	131	999	5966	107,662.24	26,302	1,542,063	9,655,220
Miners L1	115,563	1	1	1	216.23	2	134	2,704,229
Miners L2	396,089	1	1	2	303.59	4	366	6,074,860
Retails	404,890,866	1	1	1	1.73	1	9	599,414
Full Sample	405,402,934	1	1	2.28	1	9	33,202,572	

Panel B. Address Final Balance Non Zero (in bitcoins)

Entity Type	N	P10	P25	Median	Mean	P75	P99	Max
Exchanges	650,119	$546 \cdot 10^{-8}$	10^{-5}	0.0002	1.5585	0.0020	0.9699	252,597.2325
Services	95,751	$547 \cdot 10^{-8}$	10^{-5}	10^{-5}	0.2688	0.0008	1.0001	17,568.9904
Miners L1	259,121	$100 \cdot 10^{-8}$	0.0001	0.0013	7.1831	0.0244	50.0000	31,643.3822
Miners L2	926,657	$547 \cdot 10^{-8}$	0.0001	0.0006	0.6145	0.0049	1.4995	29,415.0012
Retails	5,090,223	$546 \cdot 10^{-8}$	$3 \cdot 10^{-8}$	0.0004	0.5020	0.0050	1.7249	124,052.5388
Rec Only	34,572,949	$1699 \cdot 10^{-8}$	0.0001	0.0010	0.3756	0.0010	2.0000	116,601.1366
Full Sample	41,594,820	$546 \cdot 10^{-8}$	0.0001	0.0009	0.4571	0.0093	2.0698	252,597.2325

Panel C. Wallet Final Balance Non Zero (in bitcoins)

Entity Type	N	P10	P25	Median	Mean	P75	P99	Max
Exchanges	164	0.0003	0.0271	0.4454	6177.5738	105.2535	167,313.1608	252,597.2329
Services	182	0.0001	0.0014	0.0544	141.4334	1.2716	1661.7052	17,753.3245
Miners L1	15,017	$546 \cdot 10^{-8}$	0.0002	0.0045	8.3891	0.0789	40.8347	31,643.3822
Miners L2	68,595	$1000 \cdot 10^{-8}$	0.0002	0.0051	5.2497	0.0726	25.8384	51,764.9081
Retails	4,549,499	$547 \cdot 10^{-8}$	0.0001	0.0005	0.5621	0.0050	1.9780	124,052.5388
Full Sample	4,633,457	$547 \cdot 10^{-8}$	0.0001	0.0005	0.8810	0.0052	2.1022	252,597.2329

participating in the Bitcoin ecosystem. The advantage of using granular, transaction-level data is that we can characterize the activity profile of each single wallet and highlight the differences across and within groups of users.

4.1. Transaction activity by entity type

Before computing and interpreting realized returns of different users, we consider the transaction activity profile of each entity type. In Table 5, we report descriptive statistics of each wallet type's activity level, such as the number of transactions they send and receive and the number of blocks in which they have been active by submitting or receiving a transaction. There is stark heterogeneity

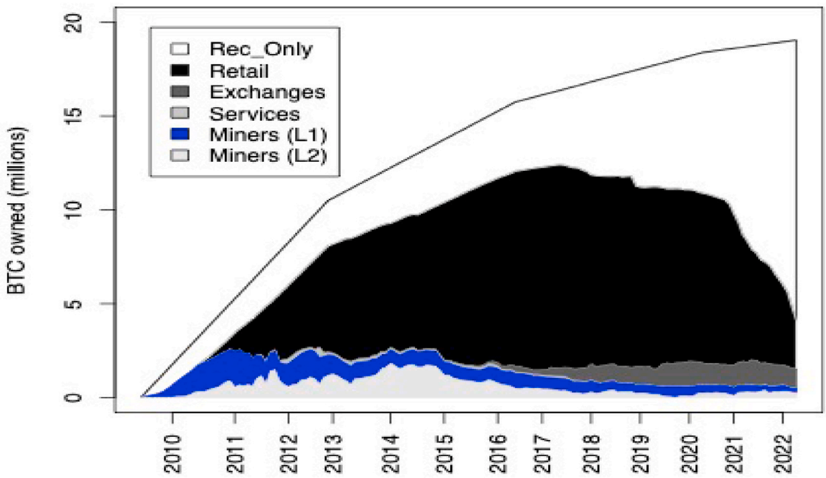


Fig. 5. Evolution of Bitcoin balances by entity type.
This figure illustrates the share of the total bitcoin supply controlled by user category, including miners (L1 and L2), exchanges, services, and retail wallets. Rec_Only are those addresses (wallets) that have only received but never sent a transaction and therefore cannot be allocated to other existing wallets.

in the number of transactions a particular type of user engages in, which is in line with the intuition that the wallet types we identify transact on the Bitcoin blockchain with different purposes.[17]

From Table 4 we know that *Exchange* wallets contain many individual addresses (median of 5576; mean of 276,948), but only few of them contain non-zero balances (at the end of April 2022). The reason that exchange wallets are comprised of many addresses is that every customer of the exchange is assigned an address ('deposit address') that is controlled by the exchange. In practice, customers will have a public key (address) so that they can send additional assets to their exchange account, but they are not in control of the private key, which is held by the exchange. Exchanges also have other types of wallets, e.g., for withdrawal of assets from the pool of funds or a 'hot wallet' to be used internally by the exchange. That is, whenever users interact with an exchange wallet, i.e., deposit funds before or withdraw them after trading on the exchange, the exchange wallet will initiate a transaction that is recorded upon the Bitcoin blockchain and thus, is recorded in our data sample. Thus, the activity profile of an exchange can better be interpreted as the agglomeration of all transactions of users who wish to exchange bitcoins with other assets. Consequently, exchange wallets are active in many blocks over the sample period, indicating that they tend to be involved in on-chain interactions frequently and continuously. Table 5 reveals that, on average, exchange wallets tend to receive almost five times more transactions than they sent, which can be viewed as deposits occurring more often than withdrawals from an exchange user's account. Overall, wallets of exchanges send the highest number of transactions as compared to other wallet user types.

Services wallets comprise a variety of merchants, marketplaces, and applications that accept and use bitcoins for payments or facilitate services such as gambling or coin mixing (privacy tools to make transactions more anonymous and harder to trace on the Bitcoin blockchain). This heterogeneity is reflected in their high standard deviation of the number of transactions across the subsample of *Services* wallets. What is also noteworthy is their high transaction activity with a mean and median of over 300,000 and 13,000 transactions, respectively.

The average L*1 Miner* is only involved almost 180 blocks, but the transaction frequency is low for most miners. However, the median *L1 Miner* wallet is only active in two blocks and two transactions, i.e., it only receives and sends one transaction, respectively e.g., when the respective miner receives and disposes of a block reward. That is, a large proportion of *L1 Miner* wallets are only used for mining one block. However, the average number of transactions by *L1 Miner* wallets is high at almost 700 transactions, indicating that there are few outliers that account for the majority of transactions initiated or received by L1 miners. This is in line with few large (L1) miners (or mining pool providers, cf. Cong et al., 2021) dominating the block validation process upon the Bitcoin blockchain, as they are the ones receiving many block rewards and sending some of the rewards to either another wallet they control or to share the reward with sub-contractors in a mining pool setup, i.e., sending it to L2 miners.[18]

[17] Note that we do not report statistics on the Rec_Only wallets as they do not, by definition, have any transactions sent.

[18] Note that we do not consider additional layers of miners, e.g., L3 or L4 miners. Makarov and Schoar (2022) document that there are practices of miners to distribute awards using a "peeling chains" approach where L1 miners may send reward to "one-off addresses" they control to then further distribute the rewards to others. In our analysis, we classify that address as belonging to a L2 miner wallet if it cannot be linked to the original L1 miner address (sender) based on future transactions. If the new address/wallet is controlled by the original L1 miner, i.e., the L2 miner wallet is part of a peeling chain to distribute rewards to L3 or L4 wallets (and further), we would not classify them specifically as L3 or L4 miners. This is because we cannot distinguish with an appropriate level of certainty whether such peeling chain approach is happening or not. That is, if peeling chains are occurring, we would nevertheless classify those additional layers as part of our *Retail* wallet subsample.

Table 5
Summary statistics on user activity by entity type.
This table reports user activity by wallet entity type (exchanges, services, L1 miners, L2 miners and retail). We present descriptive statistics on the number of blocks in which a wallet has been active, the number of transactions (total, sent, received) from January 2009 to April 2022.

User activity by type	Mean	Min	Max	SD	P1	P25	Median	P75	P99
Exchanges (N=201)									
#Blocks active	62,895	2	493,856	95,322	67	4014	19,943	89,217	403,521
#Transactions	788,211	2	44,208,522	3,511,679	81	4566	34,910	321,237	10,623,857
#Transactions sent	167,405	1	8,957,407	848,786	21	1018	6444	52,514	4,016,121
#Transactions received	749,875	1	39,435,630	3,216,662	66	4566	33,004	306,377	10,609,032
Services (N=215)									
#Blocks active	34,485	74	379,346	64,893	310	1882	6632	31,610	324,367
#Transactions	309,597	107	11,730,230	1,261,894	340	5403	13,659	106,935	7,105,436
#Transactions sent	89,042	4	6,407,548	505,817	21	496	2492	21,854	2,002,652
#Transactions received	289,207	46	11,724,700	1,240,904	315	4989	13,595	93,630	6,970,524
L1 Miners (N=115,563)									
#Blocks active	178	2	359,570	4034	2	2	2	15	1294
#Transactions	695	2	7,970,485	34,806	2	2	2	16	1521
#Transactions sent	95	1	1,468,654	5810	1	1	1	2	237
#Transactions received	662	1	7,713,934	33,488	1	1	1	13	1457
L2 Miners (N=396,089)									
#Blocks active	211	1	278,577	3131	1	2	5	47	1529
#Transactions	728	2	8,278,601	27,170	2	3	6	51	2057
#Transactions sent	115	1	968,906	4687	1	1	1	6	415
#Transactions received	701	1	8,278,171	26,766	1	2	5	45	1974
Retail (N=404,890,866)									
#Blocks active	3	2	164,076	51	1	2	2	2	17
#Transactions	3	2	1,646,639	200	2	2	2	2	22
#Transactions sent	1	1	925,892	125	1	1	1	1	6
#Transactions received	2	1	1,646,639	193	1	1	1	1	18

For L2 miners, we observe that the distribution of user activity is much less dispersed than for L1 miners, with standard deviations in the number of transactions (sent/received) being slightly more than half of what we observe in the L1 miner subsample. Also, the median L2 miner receives five transactions, while sending only one, which is consistent with the interpretation that the second layer of miners (L2) collects multiple rewards from L1 miners and disposes of its holdings only once.

Finally, *Retail* wallets contain very few addresses (average less than two) and most of the wallets participate in less than 17 blocks (99th percentile) and the average of user sends one transaction overall, while receiving two. Only very few retail users use their wallet more than once, with the 99th percentile of outgoing number of transactions being equal to six. That is, retail users exhibit substantially different transaction behavior as compared to wallets that fulfil a specific purpose in the Bitcoin blockchain ecosystem, such as exchanges or miners.

4.2. Estimating wallets' realized return

A wallet's bitcoin balance provides us with information on the distribution of wealth at each point in time but does not take into account the (dollar) costs of entering the blockchain that each individual wallet incurs. We assume that wallets have to exchange value (e.g., denominated in USD) for the bitcoins they receive and receive value when they send their bitcoins to other wallets. That is, we make the assumption that users transact to exchange value similar to exchanging bitcoins for fiat denominated currencies on an exchange platform. This is a simplifying assumption as in practice we do not know whether a wallet exchanges actual fiat currency for bitcoins or how much costs are incurred for acquiring bitcoins in other ways (e.g., mining). However, when constructing our measure of realized returns of a wallet, we capture the fact that users enter or (partially) leave the Bitcoin blockchain at different points in time and thus, at different prices. Based on differences in their transaction activity profiles and the associated learning that comes with using the network more (or less) frequently, we expect that users of different types should exhibit heterogeneity in their realized returns.

We take a wallet's entire transaction history (all addresses combined at the wallet level) to estimate its balance over time and infer its average realized return per bitcoin in the following way. Each transaction is either "sent" or "received" and thus, will reduce or increase the balance of a wallet, respectively. We assume that each "received" transaction corresponds to a wallet acquiring the respective amount of bitcoin and thus, treat it as an expense equivalent to the price at the time of the transaction times the amount received. In the same way, a "sent" transaction is treated as income generated from exchanging bitcoins for other assets (denominated in USD). For each transaction, we match the last minute-level price prior to the timestamp of the block containing the transaction, i.e., we assume all transactions in that block are traded at that block-level price. To estimate realized returns per bitcoin, we compute the difference in the weighted average prices at which a wallet has bought (received) and sold (sent) bitcoins over its entire transaction history, respectively. More formally, assume wallet *i* has sent *s* transactions at timestamps $t_1^-, \ldots, t_s^-$ and received *r* transactions at timestamps $t_1^+, \ldots, t_s^+$. The corresponding, estimated (real) volumes of transactions are denoted as $V_1^-, \ldots, V_s^-$ and $V_1^+, \ldots, V_r^+$, respectively. Weighted average prices are then given by

$$\overline{P}_{\text{sell}} = \frac{\sum_{k=1,\ldots,s}(V_k^- \times P_{t_k^-})}{\sum_{k=1,\ldots,s} V_k^-} \quad \text{and} \quad \overline{P}_{\text{buy}} = \frac{\sum_{l=1,\ldots,r}(V_l^+ \times P_{t_l^+})}{\sum_{l=1,\ldots,r} V_l^+}$$

and we compute average *realized return* per bitcoin (in percent) as $\overline{P}_{\text{sell}}/\overline{P}_{\text{buy}} - 1$ and also consider the difference between average sell and buy price as the *total realized return* (in USD), $\overline{P}_{\text{sell}} - \overline{P}_{\text{buy}}$. That is, realized returns per bitcoin are the (volume) weighted average of prices that wallets transact their bitcoins at. This measure of realized return captures historical "performance" of users' transaction activity but does not include ongoing, time-varying price changes of their existing holdings (i.e., 'unrealized returns'[19]). However, it does capture whether a user has been profitable per bitcoin transacted. By taking this historical, per bitcoin unit approach to measure returns, we can compare users in the cross-section regardless of the time period they have been actively transacting on the Bitcoin blockchain (e.g., 2014 versus 2020) or whether they have transacted or held 100,000 bitcoin versus just 1 satoshi (10^{-8} bitcoins). If one wishes to take into account the price levels and the period in which these returns are realized, we refer to the *total realized return* (in US dollars) as compared to realized returns (in percent), as the total realized return takes into account whether the price of bitcoins was high or low from a historical perspective.

4.3. Statistics on users' realized returns

Table 6 reports summary statistics of realized returns (in percent) and total realized returns (in US dollars) by user categories, excluding *Rec_Only*, which, by definition do not have any outgoing transactions required to calculate returns.[20]

The realized return of an *Exchanges* wallet is determined by the activity of its user and thus, not due to the entity behind it (i.e., the exchange as a company) controlling the wallet addresses deciding on the timing and sizing of in- and outgoing transactions. That is, as described above, whenever other users wish to deposit or withdraw their bitcoins from the exchange, they will either send bitcoins via a transaction to the an *Exchanges* wallet ("deposit") or the exchange's wallet will initiate a transaction to another user ("withdrawal"). Calculating realized returns of an *Exchanges* wallet therefore provides an estimate of the difference in weighted average prices users deposit and withdraw their funds from the exchange and thus, can be interpreted as a representation of the average realized return for cryptocurrency exchange users. Because different kinds of entities may use cryptocurrency exchanges (for trading), we carefully interpret realized returns as an average across users that are interested in speculative trading of bitcoins (rather than simple retail wallets that may simply buy and hold their bitcoins, as indicated by the low activity profile of *Retail* wallets in Table 5).

In terms of percentage returns, *Exchanges* wallets exhibit a positive mean of 7.93% per bitcoin transacted, i.e., the difference in weighted average prices when users deposit and withdraw their bitcoins from *Exchanges* wallets is 7.93%, or a total realized return of $391.52 on average. Realized returns exhibit a narrow range with 10th and 90th percentiles of −1.3% and +2.8%, respectively, as compared to −3.28%–6.16% for *Retail* wallets. This is also true for the total realized returns of *Exchanges* wallets as compared to *Retail* wallets. Median numbers of *Exchanges* and *Retail* wallets' percentage realized returns are similar (around zero), making these two groups somewhat comparable, despite some extreme outliers existent in the *Retail* wallet subsample, which leads to a higher standard deviation and extreme values on both sides of the distribution.

Both *Retail* and *Exchanges* display realized return characteristics very different from those of miners (L1 and L2). We can see that miners' realized returns are positive on average. L1 miners have a mean return per bitcoin of over 100,000%, due to some extremely high returns miners have realized, especially if they were active since the early years of the Bitcoin blockchain and thus, realized large price appreciations over a ten year time window.[21] After receiving (a share of) the block reward from L1 miners, L2 miner wallets dispose of their Bitcoin at an average profit of over 1575% or $899.9 per Bitcoin transacted. However, the median miner is not as successful in terms of financial returns, with median percentage realized returns of 1% (L1) and 0.5% (L2), respectively. We recall from Table 5 that the median miner is not frequently using the Bitcoin blockchain for transactions but rather, few large miners are

[19] This measure is highly dependent on the current USD price of bitcoin and does not necessarily provide insightful information on the "performance" of an individual wallet when it comes to timing and sizing transactions. Assessing unrealized return at the time of a price drop without a sale, e.g., in 2022 at the end of our sample period, is more revealing about the current price levels of bitcoin and thus, would not allow us to meaningfully compare users that are still active versus historical activity (i.e., by considering unrealized returns with current price levels, we would not be able to compare users active in 2014 versus users that have been active in 2022). The realized return measure allows for a fair comparison in the cross-section and over the entire sample period.

[20] To remove extreme outliers, we winsorize realized returns at the 0.5% and 99.5% and remove transactions in which bitcoins were acquired at a price below $1.

[21] For example, the maximum return observed for L1 miners is extremely high because the owner of this wallet (that has only one address in it) mined the block #56181 and received 50 Bitcoin as the reward and transferred out all of the 50 Bitcoin at block #706203. The Bitcoin-USD price at #56181 and #706203 was $0.004 and $60,870.18, respectively.

Table 6
Summary statistics of (Total) realized returns.
This table reports the realized returns (in percent) and total realized returns (in US dollars) per bitcoin transacted by wallets of different entity types. Realized returns are estimated as the difference in the weighted average prices at which a wallet has bought (received) and sold (sent) bitcoins over its entire transaction history (until end of April 2022). The total realized return is calculated as the difference between average sell and buy price (excluding transactions with purchase price below $1). We winsorize returns (within entity type) at the 0.5% and 99.5% level, respectively.

Realized Returns (in %)	Mean	SD	Min	P10	P50	P90	Max
Exchanges	7.37	41.58	−16.74	−1.32	0.11	2.79	317.71
Services	3.83	15.16	−7.47	−0.84	0.23	6.61	132.33
Miners L1	262.92	1680.44	−51.2	−8.59	1.02	149.95	19,779.16
Miners L2	127.86	814.13	−53.31	−7.45	0.55	78.06	9149.11
Retails	4.37	31.48	−32.13	−3.28	0.09	6.16	345.82
Total Realized Returns (in USD)	Mean	SD	Min	P10	P50	P90	Max
Exchanges	389.85	2534.76	−2827.38	−27.83	0.65	203.33	19,040.8
Services	23.08	68.02	−41.74	−3.44	0.71	84.02	382.04
Miners L1	689.88	3777.17	−457.54	−6.52	0.09	357.13	38,987.26
Miners L2	885.32	4413.74	−4961.95	−76.92	1.13	1140.25	39,054.71
Retails	304.58	2579.96	−7683.77	−266.13	1.86	540.52	24,879.02

dominating the block validation process and thus, receiving rewards from the coinbase more often and thus, driving the higher values of the realized return distribution we observe. However, L1 miners have the highest 90th percentile of realized returns, 215.85% over the sample period, followed by 79.5% for L2 miners. However, they also exhibit the lowest returns based on the 10th percentile, with −8.3% and −7.4%, respectively.[22]

Interpreting realized returns of *Services* wallets is challenging due to the fact that this already small wallet category comprises a variety of different services (with overall less important magnitude of wealth in terms of bitcoins held). *Services* have the lowest volatility when considering total realized returns in US dollar terms, as these wallets have been most active around 2012, rather than towards the end of our sample period where bitcoin USD price levels were much higher. In terms of realized returns (in percent), *Services* wallets exhibit a similar distribution to that of *Exchanges* wallets. The nexus between those groups lies in the interpretation of such realized returns: *Services* wallets as these comprise a variety of applications and platforms, such as gambling or marketplaces (cf. appendix for a list of services), and thus, do not allow for a uniform interpretation of users' realized returns. For example, *Services* wallets related to gambling may be interpreted as users depositing bitcoins as funds to use for gambling, which is a "received transaction" for the *Services* wallet, and the user withdrawing funds or getting paid out after gambling is completed, which is a "sent transaction" from the *Services* wallet's perspective. Realized return in this case is the difference in weighted average prices before and after using the service, aggregated for its average user.

Fig. 6 shows estimated boxplots of realized returns based on an expanding window of transaction history to estimate average buy and sell transaction prices. By this way, we are able to observe whether users' realized return distributions have changed over time, and in particular, whether the shape of the return distribution co-moves with bitcoin USD price fluctuations.

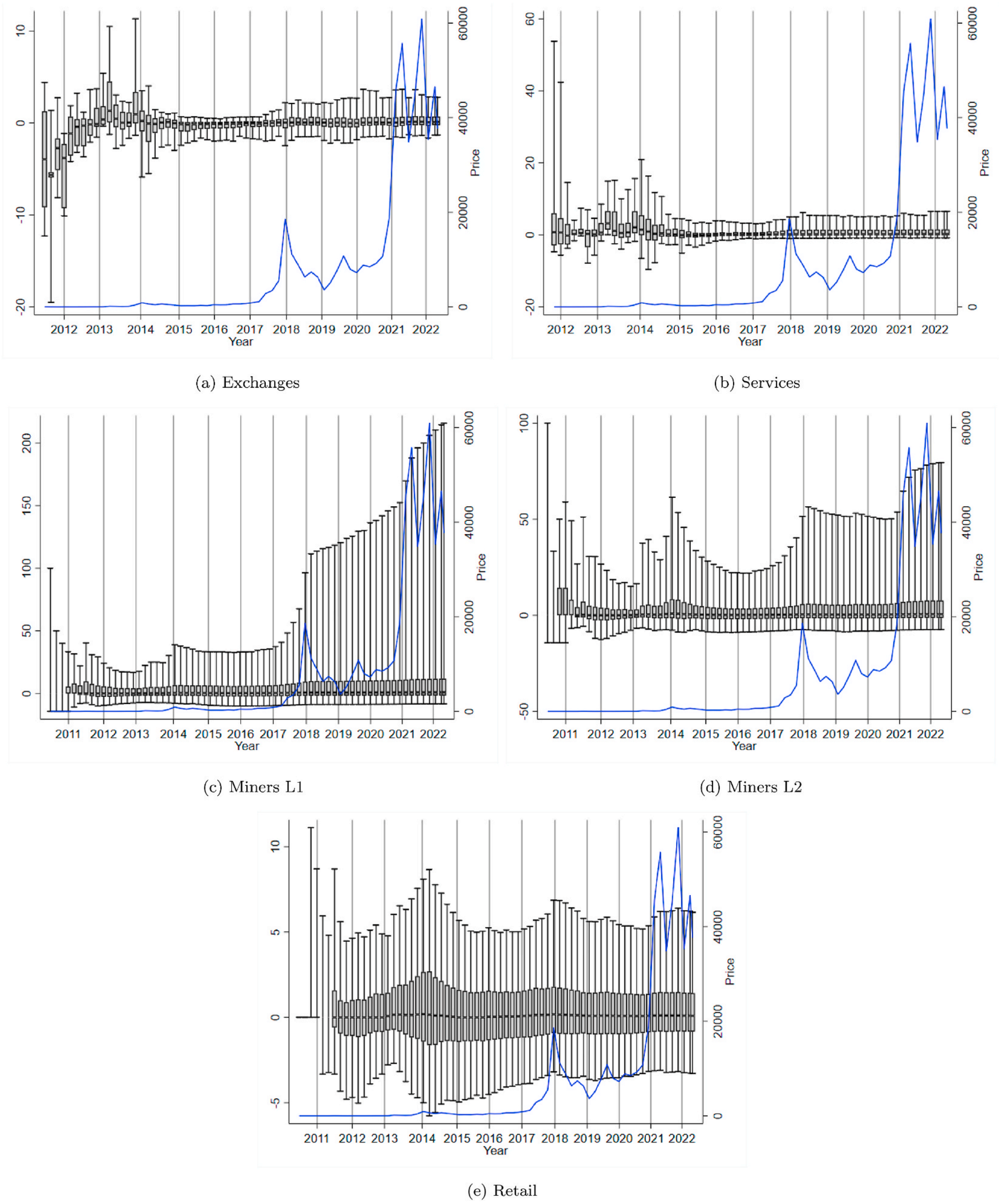
First, realized returns recorded in *Exchanges* wallets' were much more dispersed and for the most part negative when they started to emerge in the second half of 2011. This was followed by a more positive but volatile realized return distribution in 2013 and 2014, but has since stabilized, with slightly larger 10th and 90th percentiles from 2018 as compared to the years prior (2015–2017). The median realized returns estimated for these wallets has been relatively stable, not deviating much from zero, since 2015. Overall, spikes in the bitcoin USD price over time do not correlate much with the realized return distribution of *Exchange* wallets. Second, *Services* wallets exhibit a similar evolution of the realized return distribution, with a stable median and percentiles starting from around 2016.

Third, *L1 Miners* wallets exhibit an increasing trend in median, 75th and 90th percentiles of realized returns, which correlates with the rapid spikes in bitcoin USD prices in 2017 and from 2020. That is, miners' wallets have become more profitable over time in terms of their realized transaction returns.[23] Fourth, *L2 Miners* wallets have more fluctuations in their realized return distribution over time, with higher wallet-level profitability around 2014 and from 2018, but having narrower realized return ranges in the years between.

Finally, we observe that *Retail* user wallets range of realized returns is relatively narrow, with 25th and 75th percentiles remaining between −2.5% and +2.5% throughout the entire sample period. Although there are minor fluctuations over time, the 90th percentiles remain below 10% realized returns while the 10th percentile does not fall below −5% realized return after 2015. The median realized

[22] Note that in Table 6 we may observe realized returns of −100%, which is due to rounding of numbers in our calculation of returns (two decimal points). In early days of Bitcoin, the bitcoin price was smaller than 1 cent of a US dollar, thus, in some cases, the return could be −100%. For example, a wallet that includes three addresses of 1PGBD4cdhFAJ7pS8Wh6uZjcDS69UWq8gPp received 25 bitcoin at block 61377, where the USD price of bitcoin was $0.005, and has then sent these bitcoins out at block 61823, where the price of bitcoin was at $0.004975. Since we round our price to 2 decimal points, the buy price for this wallet was $0.005 ≈ $0.01 and the sell price for this wallet was $0.004975 ≈ $0.00, which translates to a 100% loss.

[23] Note that we do not observe actual dollar costs of mining units used by respective miners and thus, do not infer profitability in the broader sense, but rather assume that the costs of entering the Bitcoin blockchain can be estimated using receiving transactions, i.e., we consider 'wallet-level profitability' rather than 'mining-profitability'.



(a) Exchanges

(b) Services

(c) Miners L1

(d) Miners L2

(e) Retail

Fig. 6. Evolution of realized returns (in percent)
This figure shows boxplots of wallets' realized returns per bitcoin transacted by entity type (left y-axis, in percent). Realized returns are calculated as the difference in (estimated transaction volume) weighted average price of "buy" (received) and sell (sent) transactions. Minute-level prices are matched to each transaction's block timestamp. Return distributions are estimated using an expanding window every 10,000 blocks with each boxplot shown using wallets' transaction history up until that point in time. Boxplots show median (solid line), 25th/75th percentiles (boxes), and 10th/90th percentiles (whiskers) of the realized return distribution. For illustration purposes, even though *Services* wallets were active from 2011, we remove the initial months of 2011 due to extreme values. *Exchanges* wallets only exist from 2011. Blue solid lines indicate bitcoin USD price levels (right y-axis). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

return is stable and close to zero throughout the sample period. From these findings we can also see that *Retail* wallets' realized returns (in percent) do not fluctuate significantly along with bitcoin USD price levels over time.

5. Conclusion

This paper examines, at a granular level, on-chain transaction data on the Bitcoin blockchain to identify and analyze heterogeneity in user activity. Specifically, we divide wallets in different types of stakeholders: miners, exchanges, services, retail wallets and 'receiving-only' addresses and explore their transaction behavior and financial returns, which differ significantly. We observe that ownership concentration is changing over time, with miners owning relatively stable bitcoin shares over time and retail wallets making up a large proportion of all bitcoins owned, although individually, they hold very few bitcoins. We also see that there is a wide range of financial performance achieved by the panel of users entering and leaving the Bitcoin network, with some miner wallets achieving significantly higher financial returns than all other wallets.

In this paper, we show how Bitcoin blockchain data can be utilized to analyze various categories of users' activity. Availability of such detailed data on each address, wallet, and their transaction activity opens significant opportunity for future research, such as the following.

5.1. Miner behavior

Lehar and Parlour (2022) show that most blocks within the Bitcoin blockchain are not at capacity and consistent with revenue enhancing strategic capacity management. The rise of fees coincide with the rise of mining pools which effectively reduces the set of strategic players and so makes it easier to enhance revenue. Cong et al., (2021) analyze the incentives for miners to form pools to trade-off risky mining against the amount pools charge to miners. Nevertheless, there is a need for more detailed analysis of the on-chain behavior, incentives, and actions of individual miner wallets and how they influence the Bitcoin blockchain.

5.2. Pricing across exchanges

There is a growing literature documenting the mispricing of cryptocurrencies across exchanges and the potential risk-less profit available to investors. Makarov and Schoar (2020) show that the price deviations are much larger across countries while countries with higher bitcoin premia over the US bitcoin price see widening arbitrage deviations when bitcoin appreciates. Jain et al. (2019) show that Bitcoin obeys the theory related to commonality, liquidity, and price discovery while Cong et al., (2021) demonstrates that regulated exchanges feature patterns consistently observed in financial markets and nature while unregulated exchanges reveal rampant manipulations unlikely driven by strategy or exchange heterogeneity and quantify this wash trading at 70% of the reported volume. With user-specific time series, researchers could delve deeper in the reasons for this mispricing and identify the market participants who take advantage of such inefficiencies.

5.3. Blockchain economics

Research to date has focused somewhat on transaction fees, with Easley et al. (2019) documenting the varying magnitude of transaction fees on the blockchain while Chiu and Koeppl (2018) estimate that the current Bitcoin scheme generates a large welfare loss of 1.4% of consumption. Future research could focus on the key drivers of transaction fees and who in the blockchain are able to benefit most from these varying fees. Further, the use of detailed on-chain transaction-level data would enable an examination of why certain transactions are added to a block at a certain point in time and whether transaction fees are important determinants for transactions being added to the blockchain from the memory pool.

5.4. Pricing models

Biais et al. (2023) generate a model where estimated transactional net benefits explain a statistically significant fraction of bitcoin returns, while in the model of Pagnotta (2022), price–security feedback effects can amplify or moderate the price volatility effect of demand shocks. Further, they show rational patterns of price momentum, and that small and large stochastic bubbles can exist in general equilibrium and show how the probability of bursting decreases with the bitcoin price. Future research can use this granular data to propose and calibrate models that help understand the blockchain ecosystem and determine the relevance of on-chain metrics for bitcoin prices.

Data availability

The authors do not have permission to share data.

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Appendix I. Known Entities

Known Entities (Exchanges & Services)

Type	ServiceName	#Addresses	#Wallet	First Active Date	Last Active Date
DarknetMarket	AbraxasMarket	119,119	1	2014/12/22	2020/03/23
DarknetMarket	AgoraMarket	498,001	1	2013/12/04	2021/01/09
DarknetMarket	AlphaBayMarket	196,927	2	2015/04/30	2020/10/30
DarknetMarket	BabylonMarket	1471	1	2014/07/11	2021/11/12
DarknetMarket	BlackBankMarket	50,878	1	2014/02/19	2016/08/23
DarknetMarket	BlueSkyMarketplace	18,997	1	2013/12/06	2017/07/10
DarknetMarket	CannabisRoadMarket	2829	1	2014/04/01	2016/08/23
DarknetMarket	CrimeNetwork.cc	23,707	8	2013/12/09	2021/11/20
DarknetMarket	DoctorDMarket	5762	1	2015/02/24	2017/02/09
DarknetMarket	EvolutionMarket	420,632	1	2014/01/16	2020/11/28
DarknetMarket	GermanPlazaMarket	4629	1	2015/05/22	2018/10/23
DarknetMarket	MiddleEarthMarketplace	34,149	1	2014/06/24	2018/11/29
DarknetMarket	NucleusMarket	146,381	1	2014/11/13	2021/01/01
DarknetMarket	PandoraOpenMarket	55,757	1	2013/10/22	2018/01/16
DarknetMarket	SheepMarketplace	53,639	1	2013/02/01	2018/11/29
DarknetMarket	SilkRoad2Market	350,036	1	2013/11/11	2022/01/17
DarknetMarket	SilkRoadMarketplace	372,753	1	2012/06/18	2021/02/28
Exchange	796.com	7848	1	2014/07/02	2017/01/20
Exchange	AllCoin.com	6309	1	2014/01/26	2020/08/31
Exchange	AllCrypt.com	4775	1	2014/03/01	2017/02/05
Exchange	AnxPro.com	2,738,850	1	2012/05/27	2022/04/28
Exchange	CoinTrader.net	2,738,850	1	2012/05/27	2022/04/28
Exchange	LocalBitcoins.com	2,738,850	1	2012/05/27	2022/04/28
Exchange	Banx.io	3622	3	2014/01/18	2021/08/16
Exchange	Binance	4,852,763	13	2017/06/23	2022/04/30
Exchange	Bitbank	130	1	2020/06/18	2022/04/27
Exchange	BitBargain.co.uk	31,940	1	2012/03/02	2020/08/28
Exchange	BitBay	251,151	2	2014/03/29	2022/04/30
Exchange	Bitcash.cz	1804	1	2011/08/04	2020/03/28
Exchange	Bitcoin.de	392,708	2	2011/08/26	2022/04/30
Exchange	Bitcoin-24.com	6019	2	2012/11/06	2017/04/02
Exchange	Bitcoinica.com	4279	2	2011/09/17	2020/04/05
Exchange	BitcoinP2P.com.br	2	1	2015/12/30	2022/04/30
Exchange	BitcoinVietnam.com.vn	2276	1	2014/07/29	2019/05/06
Exchange	Bitcurex.com	4355	1	2014/08/29	2021/11/24
Exchange	Bitfinex	1,720,412	8	2012/10/09	2022/04/30
Exchange	Bitflyer	253,388	1	2015/05/01	2022/04/30
Exchange	BitKonan.com	4530	1	2013/07/02	2021/06/23
Exchange	BITMEX	1	1	2017/07/18	2021/05/14
Exchange	Bitso.com	1188	1	2014/07/16	2015/10/30
Exchange	Bitstamp.net	898,239	5	2011/08/17	2022/04/30
Exchange	Bittrex	3,341,925	4	2014/02/13	2022/04/30
Exchange	BitVC.com	5024	1	2014/09/28	2017/09/28
Exchange	Bit-x.com	27,937	1	2014/08/08	2022/04/27
Exchange	BitYes.com	3086	1	2014/08/30	2015/11/19
Exchange	BitZlato.com	246,211	1	2018/05/03	2022/04/30
Exchange	Bleutrade.com	117,215	1	2013/11/21	2022/04/26
Exchange	BlockTrades.us	33,928	1	2015/02/10	2022/04/30
Exchange	Btc38.com	7585	1	2014/06/06	2021/04/04
Exchange	BTCC.com	124,131	3	2011/07/31	2021/11/03
Exchange	BTC-e.com	659,306	3	2011/08/08	2022/03/21
Exchange	BtcExchange.ro	1699	1	2014/04/24	2015/05/17
Exchange	BtcMarkets.net	15,260	1	2013/09/04	2021/10/02
Exchange	BtcTrade.com	83,724	1	2014/09/25	2021/08/19
Exchange	BTCTurk	127,311	1	2020/02/12	2022/04/30
Exchange	Bter.com	129,896	5	2014/03/07	2021/02/16
Exchange	BTradeAustralia.com	78	2	2013/06/08	2020/04/05

Known Entities (Exchanges & Services)

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Type	ServiceName	#Addresses	#Wallet	First Active Date	Last Active Date
Exchange	BX.in.th	48,602	1	2014/04/23	2022/04/11
Exchange	Bybit	1,094,514	1	2018/11/12	2022/04/30
Exchange	CampBX.com	22,532	2	2011/07/06	2021/01/16
Exchange	Cavirtex.com	53,102	1	2011/06/09	2021/03/06
Exchange	Ccedk.com	1040	1	2014/06/19	2017/04/29
Exchange	C-Cex.com	41,009	2	2014/02/07	2019/08/24
Exchange	Cex.io	238,480	1	2013/09/17	2022/03/07
Exchange	ChBtc.com	2744	1	2014/11/10	2020/12/19
Exchange	CleverCoin.com	2614	1	2014/09/10	2017/11/15
Exchange	Coin.mx	6242	1	2013/12/13	2018/07/08
Exchange	CoinArch.com	2713	1	2014/03/15	2016/01/22
Exchange	Coinbase	99,644,935	9	2012/04/02	2022/04/30
Exchange	Coinbene	87,697	1	2018/02/15	2022/04/30
Exchange	Coinbroker.io	668	1	2014/01/25	2018/03/18
Exchange	CoinCafe.com	4564	1	2014/04/15	2022/04/30
Exchange	CoinCheck	1	1	2019/10/01	2022/04/30
Exchange	CoinChimp.com	1704	1	2014/11/24	2017/05/23
Exchange	Coinfloor	6023	1	2014/03/25	2022/04/02
Exchange	Coingi.com	2316	1	2017/02/02	2022/04/28
Exchange	CoinHako.com	35,866	1	2015/04/23	2022/04/30
Exchange	Coinimal.com	1	1	2014/12/08	2016/08/17
Exchange	Coinmate.io	5297	1	2014/10/10	2021/05/28
Exchange	CoinMkt.com	2575	1	2013/09/03	2017/11/30
Exchange	CoinMotion.com	52,399	1	2014/03/08	2022/04/30
Exchange	Coinomat.com	5481	1	2013/11/13	2020/04/03
Exchange	Coins-e.com	11,221	1	2013/06/25	2021/01/31
Exchange	CoinSpot.com.au	170,023	1	2014/01/02	2022/04/30
Exchange	Coin-Swap.net	17,705	1	2014/03/27	2021/02/01
Exchange	Comkort.com	2645	1	2014/02/20	2020/04/04
Exchange	CryptoCom	646,752	1	2019/04/04	2022/04/30
Exchange	Cryptonit.net	1548	2	2012/09/09	2021/03/02
Exchange	Cryptorush.in	9165	1	2011/09/30	2018/01/23
Exchange	Crypto-Trade.com	9512	1	2013/05/19	2022/04/18
Exchange	Cryptsy.com	393,964	2	2013/05/20	2022/04/26
Exchange	Dgex.com	1277	2	2014/03/06	2015/06/21
Exchange	EmpoEX.com	741	1	2014/10/12	2017/12/17
Exchange	Europex.eu	527	1	2014/03/16	2015/07/19
Exchange	Exchange-Credit.ru	1	1	2014/10/30	2017/06/11
Exchange	Exchanging.ir	5	1	2013/10/29	2020/03/28
Exchange	Exmo.com	8430	1	2015/02/17	2020/08/24
Exchange	FoxBit.com.br	3670	4	2014/10/14	2020/04/04
Exchange	FTX	1,788,626	1	2019/06/10	2022/04/30
Exchange	FYBSG.com	20,504	1	2013/01/02	2022/02/06

Known Entities (Exchanges & Services)

Type	ServiceName	#Addresses	#Wallet	First Active Date	Last Active Date
Exchange	Gatecoin.com	1711	2	2014/11/10	2018/03/29
Exchange	Gemini	1,541,976	2	2015/05/05	2022/04/30
Exchange	HappyCoins.com	6763	1	2012/08/25	2022/04/27
Exchange	Hashnest.com	85,590	1	2014/07/23	2022/02/23
Exchange	Hitbtc	194,805	4	2014/05/26	2022/04/30
Exchange	Huobi	2,524,259	3	2013/09/02	2022/04/30
Exchange	Igot.com	11,220	1	2013/12/21	2021/10/11
Exchange	Indacoin.com	2221	1	2014/02/07	2017/01/24
Exchange	Justcoin.com	36,999	1	2012/12/01	2022/03/28
Exchange	Korbit.co.kr	3545	1	2013/04/30	2022/03/27
Exchange	Kraken	1,560,068	2	2013/09/09	2022/04/30
Exchange	LakeBTC.com	6046	1	2014/07/03	2021/01/27
Exchange	LiteBit.eu	7109	1	2014/01/15	2016/11/13
Exchange	LocalBitcoins.com	523,330	1	2016/01/21	2022/04/25
Exchange	Luno	1,951,100	2	2013/03/22	2022/04/30
Exchange	MaiCoin.com	57,770	1	2014/05/25	2022/03/31
Exchange	MasterXchange.com	4605	1	2013/12/16	2017/04/03
Exchange	Matbea.com	47,295	1	2014/05/28	2022/04/20
Exchange	McxNOW.com	35,453	1	2013/04/27	2019/12/23

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Type	ServiceName	#Addresses	#Wallet	First Active Date	Last Active Date
Exchange	MercadoBitcoin.com.br	394,871	1	2011/07/27	2022/04/30
Exchange	MeXBT.com	4232	1	2014/05/07	2022/04/18
Exchange	MintPal.com	85,637	1	2014/02/02	2020/05/24
Exchange	OKCoin.com	159,106	2	2013/08/01	2021/12/20
Exchange	OKEX	1,027,239	2	2016/03/14	2022/04/30
Exchange	OrderBook.net	4377	1	2012/03/01	2016/05/01
Exchange	Paxful	1,898,886	3	2015/03/06	2022/04/30
Exchange	Phemex	102,886	1	2019/11/24	2022/04/30
Exchange	Poloniex	1,025,253	2	2014/01/14	2022/04/30
Exchange	QuadrigaCX.com	424,913	2	2014/05/11	2022/03/09
Exchange	SimpleCoin.cz	39	6	2013/12/01	2020/04/20
Exchange	SpectroCoin.com	4495	1	2014/07/17	2022/04/30
Exchange	TheRockTrading.com	38,280	2	2011/10/31	2022/04/30
Exchange	UrduBit.com-cold	1	1	2014/10/11	2018/11/09
Exchange	UseCryptos.com	700	1	2014/02/16	2019/03/17
Exchange	VaultOfSatoshi.com	8120	1	2014/01/29	2017/12/02
Exchange	Vaultoro.com	13,713	1	2015/02/12	2021/09/23
Exchange	Vircurex.com	33,439	1	2013/05/11	2022/04/13
Exchange	VirWoX.com	68,982	1	2011/04/24	2022/01/22
Exchange	WebMoneyRU	101,178	1	2013/04/16	2022/04/30
Exchange	YoBit.net	263,074	1	2014/12/29	2022/04/08
Exchange	Zyado	590	2	2014/05/08	2019/03/27
Gambling	10xBitco.in	473	1	2014/07/02	2021/10/22
Gambling	777Coin.com	5966	1	2013/11/13	2017/07/27
Gambling	999Dice.com	813,818	1	2013/12/28	2022/04/29
Gambling	AdmiralCoin.com	1690	1	2014/12/02	2017/03/13
Gambling	AnoniBet.com	15,965	1	2013/11/20	2017/09/07
Gambling	BetChain.com-old	1508	1	2014/01/13	2020/04/05
Gambling	Betcoin.ag	30,318	2	2013/11/12	2018/10/08
Gambling	Betcoin.tm	4292	1	2014/04/15	2020/03/27
Gambling	BetcoinDice.tm	77	1	2013/07/26	2019/01/05

Known Entities (Exchanges & Services)

Type	ServiceName	#Addresses	#Wallet	First Active Date	Last Active Date
Gambling	Betcoins.net	7479	1	2013/02/27	2014/09/04
Gambling	BetMoose.com	3956	1	2014/04/25	2022/04/24
Gambling	BetsOfBitco.in	3861	1	2011/08/12	2017/07/10
Gambling	Birwo.com	377	1	2014/04/10	2015/03/30
Gambling	BitAces.me	16,808	2	2010/07/12	2017/07/09
Gambling	BitcoinPokerTables.com	293	1	2013/06/27	2017/10/25
Gambling	Bitcoin-Roulette.com	6477	1	2013/04/08	2020/12/23
Gambling	BitcoinVideoCasino.com	46,736	3	2014/01/02	2017/07/10
Gambling	BitElfin.com	4451	1	2012/12/16	2017/01/16
Gambling	BitMillions.com	170	1	2013/02/01	2020/04/04
Gambling	BIToomBa.com	3121	1	2013/07/30	2017/07/10
Gambling	BitStarz.com	1076	1	2014/04/08	2017/01/04
Gambling	BitZillions.com	3609	1	2013/09/18	2021/03/08
Gambling	BitZino.com	78,849	1	2012/06/08	2021/11/01
Gambling	BtcDice.com	26,643	1	2011/05/21	2021/07/05
Gambling	BTCOracle.com	9122	1	2013/04/05	2017/09/22
Gambling	Chainroll.com	1315	2	2015/01/03	2015/11/04
Gambling	CloudBet.com	135,417	1	2014/05/29	2022/04/30
Gambling	CoinGaming.io	659,822	1	2013/12/05	2022/03/23
Gambling	Coinichiwa.com	4338	1	2014/11/13	2018/06/24
Gambling	Coinroll.com	22,304	1	2013/04/25	2017/08/15
Gambling	CoinRoyale.com	2980	3	2014/07/03	2015/05/20
Gambling	Coin-Sweeper.com	1992	1	2014/08/27	2020/04/07
Gambling	CryptoBounty.com	950	1	2014/02/18	2016/03/06
Gambling	Crypto-Games.net	18,489	1	2014/08/12	2018/08/26
Gambling	DaDice.com	1176	1	2015/02/02	2015/10/23
Gambling	DiceBitco.in	2355	1	2014/07/15	2017/03/01
Gambling	DiceCoin.io	390	1	2014/08/18	2016/01/15
Gambling	DiceNow.com	648	1	2013/11/04	2016/07/01
Gambling	DiceOnCrack.com	28	1	2012/10/14	2020/04/04
Gambling	EveryDice.com	515	1	2014/02/15	2020/04/05

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Type	ServiceName	#Addresses	#Wallet	First Active Date	Last Active Date
Gambling	FairProof.com	729	1	2013/11/01	2020/03/28
Gambling	FortuneJack.com	120,563	1	2014/09/01	2022/03/10
Gambling	Ice-Dice.com	2760	1	2013/09/22	2017/04/02
Gambling	JetWin.com	3840	1	2013/11/25	2016/07/21
Gambling	Just-Dice.com	980	3	2011/01/11	2021/04/11
Gambling	LuckyB.it	7	2	2013/10/19	2020/06/07
Gambling	MineField.BitcoinLab.org	279	1	2014/08/21	2015/10/15
Gambling	NitrogenSports.eu	197,164	1	2013/11/29	2020/08/31
Gambling	Peerbet.org	7857	1	2013/10/12	2020/03/07
Gambling	PinballCoin.com	12	1	2013/03/07	2020/04/05
Gambling	PocketDice.io	125,004	1	2014/07/10	2021/10/24
Gambling	PocketRocketsCasino.eu	1189	1	2014/01/30	2020/01/30
Gambling	PrimeDice.com	204,797	5	2014/06/16	2021/09/27
Gambling	Rollin.io	74,602	1	2014/09/18	2019/12/20
Gambling	SafeDice.com	35,573	1	2014/11/02	2021/09/01
Gambling	SatoshiBet.com	32,701	1	2013/12/10	2016/01/09
Gambling	SatoshiCircle.com	4996	1	2014/03/12	2020/04/01
Gambling	SatoshiDice.com	43,936	2	2012/04/18	2021/11/24
Gambling	Satoshi-Karoshi.com	2961	2	2013/05/28	2021/05/16

Known Entities (Exchanges & Services)

Type	ServiceName	#Addresses	#Wallet	First Active Date	Last Active Date
Gambling	SatoshiMines.com	269,248	1	2014/08/16	2022/04/30
Gambling	SatoshiRoulette.com	10,901	1	2013/10/07	2019/06/01
Gambling	SealsWithClubs.eu	30,965	1	2011/10/08	2021/01/03
Gambling	SecondsTrade.com	96,890	1	2014/10/05	2020/04/05
Gambling	Stake.com	47,130	1	2021/01/04	2022/04/30
Gambling	SuzukiDice.com	341	1	2013/04/04	2020/04/05
Gambling	SwCPoker.eu	32,017	1	2015/02/24	2020/03/29
Gambling	YABTCL.com	3242	1	2013/09/12	2022/04/30
Mixer	BitcoinFog	244,975	1	2011/11/10	2022/02/23
Mixer	BitLaunder.com	190	1	2014/06/20	2016/08/23
Mixer	HelixMixer	246,116	35	2014/12/05	2017/10/23
Scam	Btcst.com-pirateat40	1246	1	2011/07/22	2013/08/25
Scam	CoinVault	9428	1	2012/11/03	2021/01/08
Scam	CryptoLocker	968	1	2013/09/07	2017/07/10
Services	CryptcoMiner.com	1	1	2014/08/27	2014/09/25
Services	Leancy.com	1	1	2013/12/16	2017/11/23
Services	ActionCrypto.com	20	1	2014/02/10	2020/04/04
Services	ASICMiner	15	1	2012/08/25	2020/10/21
Services	Bitbond.com	6790	1	2013/06/18	2021/09/14
Services	BitClix.com	2023	1	2014/04/24	2016/09/05
Services	BitcoinWallet.com	90,169	1	2014/03/26	2022/04/30
Services	BitcoinWeBank.com	1244	1	2014/01/05	2021/12/27
Services	Bitmit.net	15,757	1	2011/08/03	2017/01/07
Services	BitNZ.com	2618	1	2013/03/06	2021/03/03
Services	BitoEX.com	87,424	1	2014/09/27	2022/04/26
Services	BitPay.com	686,464	4	2011/07/02	2022/04/20
Services	Brawker.com	499	1	2014/01/27	2015/06/24
Services	BTCJam.com	82,695	1	2012/07/26	2020/05/30
Services	BTCLend.org	1713	1	2015/03/23	2017/01/12
Services	BTCPop.co	3485	1	2015/07/24	2017/08/21
Services	BTCt.com	1178	1	2013/09/11	2017/07/10
Services	Bylls.com	1314	1	2013/11/23	2016/05/04
Services	ChangeTip.com	15,905	1	2014/06/25	2020/02/03
Services	CloudHashing.com	572	1	2013/10/04	2016/02/12
Services	CoinApult.com	15,589	2	2015/02/27	2020/07/11
Services	CoinBox.me	1	1	2013/05/17	2020/04/05
Services	CoinJar.com	207,911	1	2013/06/01	2022/04/04
Services	CoinKite.com	115,775	1	2013/09/27	2022/03/14
Services	CoinPayments.net	9,655,220	1	2013/08/05	2022/04/30
Services	CoinURL.com	2998	1	2013/01/28	2020/06/28
Services	CoinWorker.com	2	1	2014/08/28	2018/02/16
Services	Cryptomine.io	1	1	2014/10/23	2015/01/12
Services	Cryptonator.com	1,000,310	2	2014/11/12	2022/04/30

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Type	ServiceName	#Addresses	#Wallet	First Active Date	Last Active Date
Services	Cryptopay.me	404,534	2	2014/08/22	2022/04/30
Services	CryptoStocks.com	12,494	1	2013/05/12	2022/04/01
Services	Cubits.com	1,630,483	1	2014/12/08	2022/04/06
Services	Dagensia.eu	643	1	2012/12/15	2017/03/27
Services	Dispenser.tf	2	1	2014/04/29	2016/01/02
Services	FaucetBOX.com	21,693	1	2012/09/04	2022/02/17
Services	Genesis-Mining.com	8967	1	2014/04/25	2018/08/17

Known Entities (Exchanges & Services)

Type	ServiceName	#Addresses	#Wallet	First Active Date	Last Active Date
Services	GoCelery.com	1948	1	2015/01/10	2021/03/05
Services	GreenRoadMarket	965	1	2015/07/13	2018/06/08
Services	HaoBTC.com	50,818	1	2014/10/30	2022/04/30
Services	HolyTransaction.com	101,644	1	2014/02/05	2022/04/30
Services	Inputs.io	14,566	1	2013/06/25	2022/02/14
Services	Instawallet.org	109,151	1	2011/05/03	2021/05/05
Services	Loanbase.com	22,597	1	2014/06/24	2020/03/30
Services	MoonBit.co.in	51,156	1	2015/01/30	2022/04/30
Services	MPEx.co	604	1	2011/07/22	2020/04/05
Services	MyBitcoin.com	4896	1	2011/06/18	2017/11/29
Services	OkLink.com	30,187	1	2014/10/30	2019/02/18
Services	Paymium.com	24,060	1	2013/09/26	2021/02/20
Services	Playt.in	1812	1	2013/01/30	2020/04/04
Services	Xapo.com	2,184,754	2	2013/06/12	2022/04/30

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