An Anatomy of Crypto-Enabled Cybercrimes

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Abstract

While the advent of cryptocurrencies and digital assets holds promise for improving and disrupting financial systems through offering cheap, quick, and secure transfer of value, it also opens up new payment channels for cybercrimes. A prerequisite to solving a problem is understanding the nature of the problem. Assembling a diverse set of public, proprietary, and hand-collected data including dark web conversations in Russian, we conduct the first detailed anatomy of crypto-enabled cybercrimes and highlight relevant economic issues. Our analyses reveal that a few organized ransomware gangs dominate the space and have evolved into sophisticated corporate-like operations with physical offices, franchising, and affiliation programs. Their techniques also have become more aggressive over time, entailing multiple layers of extortion and reputation management. Blanket restrictions on cryptocurrency usage may prove ineffective in tackling crypto-enabled cybercrime and hinder innovations. Instead, blockchain transparency and digital footprints enable effective forensics for tracking, monitoring, and shutting down dominant cybercriminal organizations.

1 Crypto-Enabled Cybercrimes

Decentralization, privacy, and anonymity have been the building blocks of the cryptocurrency movement since its inception over a decade ago (Nakamoto, 2008). While the technology has spurred many innovations, cybercriminals' adoption of cryptocurrencies has become a central issue in the crypto-regulation debate. Ransomware attacks, money laundering activities, and various crypto-based scams have recently surged, prompting the U.S. president to issue an executive order requiring agencies to establish a course of action.[1] According to Federal Trade Commission (2022), Cryptocurrency is the most reported payment method in frauds—surpassing bank transfers, wire transfers, and credit cards—accounting for $728.8M (33.5%) of the 2022 year to date reports.[2] The first step in the protection of consumers, investors, and businesses is to scientifically analyze the nature of the problem which is the goal of our research.

The problem. The growth of cryptocurrencies has provided two new opportunities for criminals. In the first, hackers exploit weaknesses in either centralized organizations such as crypto-exchanges or decentralized algorithms, using this to siphon out cryptocurrency. For example, Mt. Gox, a Japanese crypto-exchange, was the victim of multiple attacks–the last one in 2014 led to loss of almost 850,000 bitcoins ($17b at the time of writing).[3] In these types of attacks, coins are transferred to a blockchain address. Given that these transactions and addresses do not require real names, the attackers are initially anonymous. Indeed, the exploit is available for anyone to see given that the ledger of all transactions is public here. While the original exploit is completely anonymous (assuming the address has not been used before), the exploiter needs to somehow "cash out." Every further transaction from that address is also public, allowing for potential deployment of blockchain forensics to track down the attacker.

Beyond stealing cryptocurrency via exchange and protocol exploits, traditional cybercriminal activities are now also enabled with a new payment channel using the new technology—the second opportunity our research focuses on. The use of cryptocurrencies replaces potentially traceable wire transfers or the traditional suitcase of cash, and is popular for extortion. Criminal organizations also use cryptocurrencies to launder money.[4] According to Europol, criminals in Europe laundered approximately $125b in currency in 2018 and more than $5.5 billion through cryptocurrencies.[5] The increasing cryptocurrency adoption also facilitates many other forms cybercrimes.

Information about crypto-enabled cybercrimes is typi-

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[1] President Biden stated on March 9, 2022, "The United States should ensure that safeguards are in place and promote the responsible development of digital assets to protect consumers, investors, and businesses.' https://www.whitehouse.gov/briefing-room/statements-releases/2022/03/09/fact-sheet-president-biden-to-sign-executive-order-on-ensuring-responsible-innovation-in-digital-assets/.

[2] See Appendix A, Table A1. Cryptocurrencies also present the fastest growth rate among all categories since 2019.

[3] See https://crystalblockchain.com/articles/the-10-biggest-crypto-exchange-hacks-in-history/.

[4] Analytics firm Elliptic says RenBridge (a cross-chain platform) was used to transfer $540M of illicit crypto funds (see https://www.coindesk.com/tech/2022/08/10/elliptic-says-renbridge-was-used-to-launder-540m-illicit-funds/).

[5] See https://www.businessinsider.com/europol-criminals-using-cryptocurrency-to-launder-55-billion-2018-2.

AbuseType	Addresss	ReportCount	Transactions	TotalReceived (USD)	ReportCount (per address)
Bitcoin Tumbler	476 (2.2%)	3,011 (1.7%)	4,343,281 (32.0%)	22,972,900 (6.9%)	6.33
Blackmail Scam	6,982 (32.3%)	69,684 (38.3%)	213,804 (1.6%)	607,569 (0.2%)	9.98
Darknet Market	192 (0.9%)	1,244 (0.7%)	161,727 (1.2%)	413,045 (0.1%)	6.48
Ransomware	5,163 (23.9%)	41,919 (23.1%)	5,771,718 (42.5%)	156,366,213 (47.1%)	8.12
Sextortion	7,306 (33.8%)	59,906 (33.0%)	44,236 (0.3%)	34,162 (0.0%)	8.20
Other	1,531 (7.1%)	5,924 (3.3%)	3,034,165 (22.4%)	151,548,126 (45.7%)	3.87
Grand Total	21,650 (100.0%)	181,688 (100.0%)	13,568,931 (100.0%)	331,942,018 (100.0%)	8.39

Table 1: 2017-2022 Reported Bitcoin Addresses Linked to Criminal Activities
(Source: Compiled from BitcoinAbuse.com—Additional information involved checking addresses history at Blockchain.com)

cally dispersed, private, and incomplete. We assemble the most comprehensive dataset from public (leaked) and proprietary data sources, and expand it with manual search, information collection, and data processing. This endeavor allows us to quantify crypto-enabled cybercrimes, learn the operations of dominant cybercriminals, and offer an economic perspective on various issues entailed, especially those related to ransomware attacks.

Sizing up crypto-enabled cybercrimes. We first estimate the size of crypto-based cybercrimes in the Bitcoin ecosystem by extracting essential information from thousands of reports from *BitCoin Abuse*, a service platform for victims of cyberattacks to disclose the Bitcoin address criminals use for receiving payments.

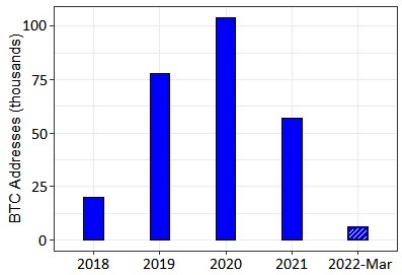

Figure 1: Cybercrime Reports (Source: BitcoinAbuse.com)

BitCoin Abuse registers on average 5,000 cybercrime reports a month (see Figure 1) with information on the report counts per address, the latest report date, a short description and the type of reported cybercrime, the total BTC paid, and the number of on-chain transactions. Note that the reports are broken down into five categories: *Tumbler* (mixing bitcoins among users and several addresses to eliminate on-chain trail), *Blackmail Scams* (sending threatening emails to victims asking for bitcoin payments), *Darknet Market* (digital marketplace for exchanging illicit goods and services), *Ransomware*, (malicious software used by cybercriminals to encrypt data and locks victims out of their files and folders—payments are exchanged for a key to decrypt the data and the promise not to release sensitive information), *Sextortion* (emails threatening victims that evidence of their navigating adult content will be leaked to email contacts), and *Other* (a mix of cybercrime explained above or cases for which victims did not find an appropriate category).[6]

Table 1 shows the distribution of these reports. Out of the 21,650 reported addresses, sextortion leads the cybercrime report counts (33.8%), followed by blackmail scams (32.3%) and ransomware (23.9%).[7] These three types of cybercrimes jointly account for 94.4% of all reported entries on the Bitcoin Abuse system. The number of reported related transactions provides a different picture concerning the most active type of cybercrime on the Bitcoin blockchain. Out of the total 13.6 million crypto-crime-related transactions, ransomware leads most of the on-chain activity (42.5%), followed by bitcoin tumbler (32.0%) and others (22.4%). The intense transaction activity relates to on-chain money laundering techniques, which consist of reshuffling crime-related bitcoins into hundreds of fragmented transfers and mixing these transfers with other bitcoins to eliminate the trail on the blockchain. A similar on-chain activity is observed when accounting for the total BTC received. As of April 2022, *Ransomware* leads BTC payments with (42.5%), followed by *Other* (45.7%), and *Bitcoin Tumbler* (6.9%). If *Other*

[6]Some abuse reports reveal that a crypto sextortion typically goes as follows: *"As you may have noticed, I sent this email from your email account (if you didn't see, check the from email id). In other words, I have full access to your email account. I infected you with a malware a few months back when you visited an adult site, and since then, I have been observing your actions.... To stop me, transfer $979 to my bitcoin address. If you do not know how to do this, Google - 'Buy Bitcoin'. My bitcoin address (BTC Wallet) is 1BC2fkA47etRPRRjWt3oB5yYo8ZSCkEznU."*

[7]See Online Appendix A for the distribution of reports across categories.

is excluded, *Ransomware* dominates cybercrime-related bitcoin activity with 86.7% of the total BTC payments.[8]

The last column of Table 1 provides additional insights; for instance, the average report count is larger for blackmail scams and sextortion than other cybercrimes, perhaps because some of these crimes are just mass scam emails—the attacker is unlikely to have sensitive information on the victim—generating a large volume of reports. These types of attacks are considered "street crimes" and are not relevant for our analysis. Bitcoin tumbler and darknet markets are also not suitable for our research for three reasons: First, they provide bitcoin services. Second, their overall impact on the on-chain activity is relatively small. Third, these services have been subject to regulatory actions.[9] In contrast, ransomware is the type of cybercrime that dominates on-chain activity, frequently causing economic distress and financial damage to the victims.

Besides having recently surfaced as the most threatening cybercrime to U.S. national security, ransomware attacks have created a crisis for companies and organizations in the United States.[10] The severity of attacks in 2021 alone, including Colonial Pipeline, a JBS meat processing plant, and a major agricultural cooperative, may be just the tip of the iceberg. Attacks against U.S. corporations led Biden's administration to announce a series of steps to combat the growing number of ransomware attacks.[11] Some of these actions include: attempting to disrupt criminal networks and virtual currency exchanges responsible for laundering ransoms, encouraging improved cyber security across the private sector, and increasing incident and ransomware payment reporting to U.S. government agencies, including both the Treasury and law enforcement. In addition, President Biden's executive order to governmental agencies demands short-term planning and mid-term actions for a better understanding of cryptocurrency's risks to national security, financial stability, and investors protection.

In light of these issues, the remainder of the article delves deeper into the economics of ransomware, the most threatening and consequential form of crypto-enabled cybercrime, to provide insights relevant for digital asset owners and investors, as well as regulatory agencies and policymakers.

2 Most Dangerous Ransomware Groups

Ransomware attacks are undoubtedly the most rampant cybercrime, amassing hundreds of millions of dollars in 2021 alone, according to Chainlysis's most recent report.[12] It emerges as one of several new challenges U.S. corporations face. However, the number of attacks are likely underestimated because the victims, often large corporations, seek to avoid disclosure that may trigger negative market reactions.[13] Only a tiny portion of attacks on large U.S. corporations come to light.[14]

Cybercrimes by revenue. According to the data compiled from Ransomwhe.re, a ransomware tracking website, the top three ransomware gangs (by revenue) are Conti, Netwalker, and Locky, receiving in 2021–2022 $50.88, $27.36, and $14.01 million, respectively (Figure 2). Chainlysis' crypto crime report estimates slightly larger numbers, with Conti, DarkSide, and Phoenix Cryptolocker collecting about $170, $70, and $55 million in 2021 (Figure 3).

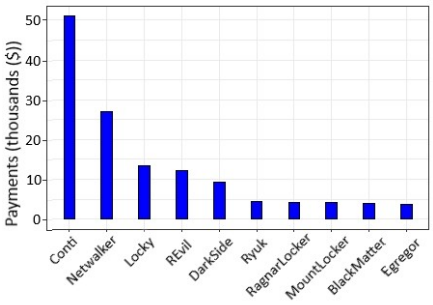

Figure 2: 2021-2022* Aggregated ransom payments (Source: Compiled from Ransomwhe.re)

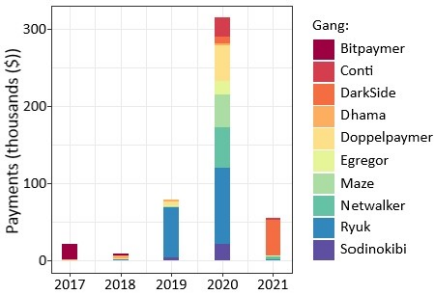

Figure 3: 2017-2021 Top ransomware gangs by revenue (Source: Reported by Chainalysis)

Double extortion game. In addition to revenue, an alternative proxy is the activity level (i.e., number of attacks) among these gangs. We exploit a recent shift in ransomware gangs' disclosure strategy, consisting of the following double extortion game. Before 2019, ransomware attacks were based on locking victims' files and exchanging the key to unlock the data for payments. However, since 2019, coupled with increasing professionalization (see our discussion in the next section), ransomware gangs have also started to threaten to leak sensitive data.

The double extortion game—encrypting victims' data and also threatening to leak it—proved to be an effective tool to increase the gangs' revenue. More importantly, ransomware gangs also enjoy reputation benefits for leaking the data, which attracts supporters. Ransomware gangs have

[8]Note that not all BTC received relates to direct payments. A large portion of these payments is likely part of reshuffling activities by cybercriminals. However, it is very difficult to disentangle subsequent payments from reshuffling activities.

[9]On April 2022, German authorities announced the takedown of the Hydra marketplace, the world's largest darknet market trading in illicit drugs, cyberattack tools, forged documents and stolen data (See https://securityintelligence.com/news/hydra-darknet-shut-down/).

[10]See https://www.whitehouse.gov/briefing-room/statements-releases/2021/10/13/fact-sheet-ongoing-public-u-s-efforts-to-counter-ransomware/.

[11]See https://home.treasury.gov/news/press-releases/jy0364.

[12]See https://go.chainalysis.com/2022-Crypto-Crime-Report.html.

[13]The usual approach for the victim is to hire an external crisis management firm, letting it decide how the information should be released to the public.

[14]Because managers often withhold negative information, and investors cannot independently discover security breaches, firms have incentives to underreport cyberattacks (Amir et al., 2018).

been spreading large amounts of data on the dark web from victims who refused to pay. These data provide a complementary assessment of our goal of estimating the most dangerous ransomware gangs. Based on the leaked data of attacks from DarkTracer, a dark web-based website that tracked information on ransomware gangs' disclosed attacks, the top three active gangs from May 2019 to July 2021 are Conti, Sodinok (also known as REvil), and Maze. Table 2 list the specific numbers of victims.

Name	Victims	Active Period
Conti	457	Jan-20 to Jun-21
Sodinokibi (REvil)	282	May-20 to Jun-21
MAZE	266	Dec-19 to Nov-20
Egregor	206	Sep-19 to Dec-20
DoppelPaymer	203	Feb-20 to May-21

Table 2: Most active ransomware gangs from May 2019 to July 2021 (Source: Compiled from DarkTracer)

The richness of the DarkTracer data allows us to examine other dimensions of ransomware activity. The data contain 2,690 attacks carried out by 43 unique ransomware gangs.[15] Figure 4 shows the heatmap for the distribution of victims per gang over time. As perceived by an intensification of ransomware activities from the summer of 2020, the double extortion game likely became mainstream among the ransomware gangs, boosting their expansion. For instance, the Egregor ransomware gang recorded 111 claimed attacks in November 2021. The heatmap also suggests that small gangs have likely implemented similar systems following the successful double extortion model executed by large gangs.

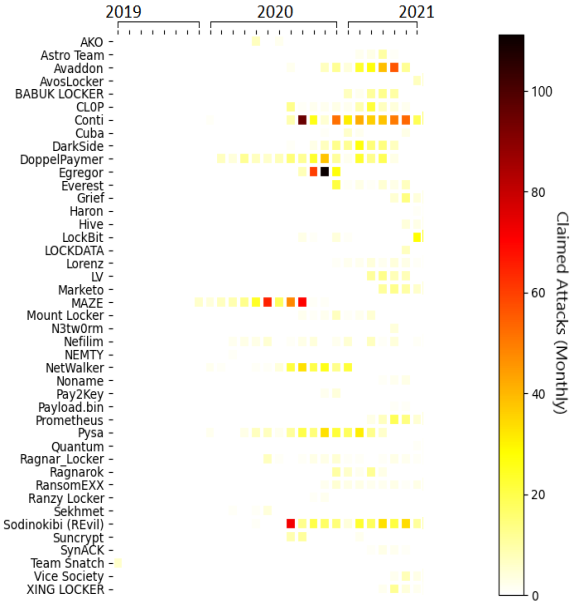

Figure 4: Distribution of claimed attacks from May 2019 to July 2021 (Source: Compiled from DarkTracer)

Although the assessment of attacks disclosed by ransomware gangs provides a more accurate picture than estimating attacks from disclosed BTC addresses, the method has several limitations. First, leaked lists of attacks likely include only victims that did not pay the ransom. Second, even for victims that refused to pay the ransom, the ransomware gang may refrain from leaking the data because: (i) the data can be sold, (ii) the gang did not succeed in copying the victim's data, or (iii) —according to anecdotal evidence—the gang mismanaged copied data. Finally, as we will see, ransomware gangs often re-brand after getting too much attention, complicating tracking their attacks. Re-branding has become a common tactic to remain off the authorities' radar and to sustain the business in the long run. Noticeably, ransomware re-brands are usually consequences of sanctions (U.S. Department of the Treasury, 2019), infrastructure takedown (Europol, 2021), wallet seizure (U.S. Department of Justice, 2021a), and arrests (Department of the National Police of Ukraine, 2021).

Triple extortion game. Recently, ransomware gangs have started to use an additional layer of extortion concerning victims' obtained data. The triple extortion game entails using affiliated journalists to spread the threat (ContiLeaks, 2022), as well as threatening the victim to expose the data to stockholders (Paganini, 2021), business partners (Wellons & Javers, 2021), and employees and customers (Duncan, 2021). To employ the new tactic, ransomware gangs run sophisticated business-like operations, such as maintaining call centers to contact the victims' stakeholders and operatives to conduct research on victims' business.[16]

Our analysis suggests that a few gangs, such as Conti, REvil, MAZE, and DarkSide, are among the most active ransomware gangs. These gangs not only implemented additional layers of extortion but also developed corporate-like organizations. Such professionalized crypto-enabled cybercrimes are a major contributor to the current surge of ransomware attacks.

3 The Economics of Ransomware

Riding on the wave of global digitization and widespread access to cryptocurrencies, experienced cybercrime gangs, as well as electronic engineers and computer science experts, have been exploiting the chance to make money by weaponizing an idea that was born out of scientific curiosity two decades ago. Cryptovirology, or the combination of cryptographic technology with malware, was first detailed at Columbia University in 1995 (Young & Yung, 1996).

The idea has been transformed into a digital extortion scheme that denies victims access to data and services using a piece of malicious software known as Ransomware. The attack combines different extortion strategies, including stealing sensitive data and threatening to leak the data to stakeholders or to sell it on the darknet, to persuade payments during the negotiation phase.

[15] See Appendix E for the full list of gangs in this dataset.

[16] See FBI report at https://www.ic3.gov/Media/News/2020/201215-1.pdf.

[17] The report is based on two datasets. The first consisted of 681 negotiations collected in 2019. The second dataset consisted of 30 negotiations collected at the end of 2020 and the first few months of 2021. See https://research.nccgroup.com/2021/11/12/we-wait-because-we-know-you-inside-the-ransomware-negotiation-economics/.

Negotiation. We assess proprietary data from over 700 negotiations and document ransomware gangs' overwhelming ability to maximize their attack revenue.[17] The negotiation with ransomware gangs is not an easy one. These gangs know precisely the financial health of their victims and whether the victims have cybercrime insurance policies, charging ransomware payments accordingly and leaving little room for negotiation.[18] Following double and triple extortion techniques—applied to convince the victim to remain quiet and comply with the gang's demands—payments often occur in a couple of days following the attack and are mostly made in crypto. See below an example of a negotiation between a victim and a ransomware gang.[19]

–victim: "We thought we have almost 6 days left. Our leadership is currently reviewing the situation and determining the best resolution."

–attacker: "Until we waiting for your reply on situation. We stopped DDoS attack to your domain, you can switch on your website. As well your blog, where hidden. Nobody will see information about that, until we will not get in deal. We stopped already other instruments which already where processed today."

–victim: "Okay, thank you. We want to cooperate with you. We just need some time during this difficult situation."

–victim: "Can you please tell us what we will receive once payment is made?"

–attacker: "You will get: 1) full decrypt of your systems and files 2) full file tree 3) we will delete files which we taken from you 4) audit of your network"

–victim: "This situation is very difficult for us and we are worried we may get attacked again or pay and you will still post our data. What assurances or proof of file deletion can you give us?"

–attacker: "We have reputation and word, we worry about our reputation as well. After successful deal you will get: 1) full file trees of your files 2) after you will confirm we will delete all information and send you as proof video, we are not interested in to give to someone other your own data. We never work like that."

Although negotiations are limited, victims can avoid pitfalls, such as leaking information on cybercrime insurance or misstepping the negotiation which all lead the attacker to increase the ransomware price. Victims who respect the attacker and focus the conversation on obtaining certification that the data will be decrypted and not leaked after the payment is made are more likely to minimize the consequences of the attack and gain extra time to organize ransom payments (Hack & Wu, 2021).

Indirect revenue model. Cyber attackers have been using sophisticated methods to receive payments online since the Banking Trojan era in the 2000s.[20] The activity then provided a relatively small amount of illicit money at a high cost of investing resources into exploiting web browsers' fragility and maintaining botnets. Yet, as technology has advanced, the gains from infamous banking malware trojans have become significantly inferior compared to just a few ransom payments nowadays (U.S. Department of Justice, 2014). Part of the reason is that ransomware is usually developed by a large gang that rents services to affiliates in a revenue-sharing model known as Ransomware-as-a-Service (RaaS).

Given that the online fraud ecosystem had been developed, the ransomware ecosystem quickly adapted its franchising.[21] A platform provides several services, including ransomware packages to buyers (i.e., affiliates) under several types of subscription models. Once the victim pays a ransom, the platform automatically splits the revenue between the primary service provider (i.e., ransomware gang) and the affiliates. The revenue split is often based on a previously agreed-upon percentage (see our analysis below).

DarkSide RaaS model. The ransomware gang behind the Colonial Pipeline attack used ransomware branded as "DarkSide Ransomware" to lock down Colonial Pipeline systems. DarkSide RaaS first appeared in September 2020 in a trackable payment (0.02836771 BTC) to the wallet bc1qxqc8nv6x3gz77x7xy2me02fyxnwr6u80n5v5av.[22] Since then, it has established a rewarding system in which the gang provides malware software and additional supporting services in exchange for a fee on successful ransom payments. DarkSide's revenue split depends on estimated revenue size or a fixed fee negotiated beforehand. Table 3 reports the compensation scheme based on ransom payments range.[23]

Ransom	Split (%)
<500k	25%
500k to 2m	20%
2m to 5m	15%
>5m	10%
fixed	20%

Table 3: DarkSide revenue splits
(Source: Compiled from dark web forums)

Daskside RaaS model is seemingly very profitable, with a particular affiliate managing to receive 470 BTC (around $14m at the moment they negotiated) from a single victim. A network analysis permits us to investigate the trail of this large ransom payment (Figure 5). The attack occurred in January 2021, and two payments were made to a single wallet (bc1qkx825waskn90fufvq435djq6tzn5qdqwjdfvhp). The first transaction was made at 2021-01-28 07:03 from bc1quq29mutxkgxmjfdr7ayj3zd9ad0ld5mrhh89l2 with 241 BTC followed by 330 BTC from 1F4esB7CTYt17Yr T1AuadXTqr8BrXxyQeB at 22:18. A noticeable 9 to 1 split (%11.11) was made on both transactions to an affiliate (bc1qsp7ryd008aefzflmsk8lhv3nv7acrckwjq25wt)

[18] This insight is based on conversations with cybersecurity crisis management experts.

[19] Excerpt provided by the cyber security firm FoxIT.

[20] See https://www.europol.europa.eu/sites/default/files/documents/banking_trojans_from_stone_age_to_space_era.pdf.

[21] The revenue-sharing model has been proved sustainable in conducting online frauds (Lusthaus, 2018).

[22] Anyone can access information on these addresses, such as transaction history, via block explorers. Currently, there are three different Bitcoin address formats: addresses starting with: 1 (Legacy Format), 3 (Compatibility Format), and bc1 (Segwit Format). For example, see https://www.blockchain.com/btc/address/bc1qxqc8nv6x3gz77x7xy2me02fyxnwr6u80n5v5av.

[23] A large portion of the information in this section was hand collected by the authors in dark web forums.

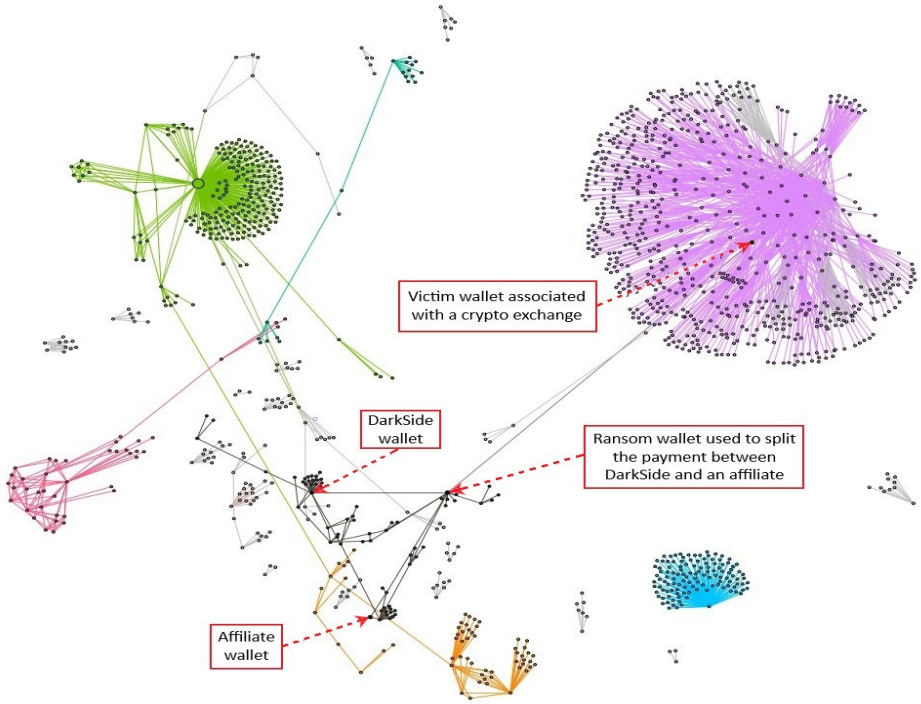

Figure 5: A Ransomware Gang's (DarkSide) Network Analysis

and to the service provider (i.e., ransomware gang) (bc1qmjvqd5njk5y2w3w4wu88m2uan6hf9jz0u475p8).

Following these transfers in the Bitcoin blockchain, another three addresses emerge (bc1qsp7ryd008aefzflmsk8lhv3nv7acrckwjq25wt, bc1qr9kqwkfdyssvv6t36vz88308yswdy422tynsdu, and bc1qwn5xack4nvzhxrpgkyaxpmf7ejsapzmyluw8s7), which were used to collect revenue splits by the DarkSide gang across different points in time. Although the network analysis suggests that the ransomware gang used mixing activities to hide ransom payments trail, blockchain transparency allows agencies to track these transfers, identify connected wallets, and potentially seize funds. Nevertheless, DarkSide's affiliates managed to raise at least $42.3 million, with the service provider received $4.8 million (around 10%), from September 2019 to February 2021 (Robinson, 2021).[24]

Direct revenue model. The RaaS model has shown to be very profitable for the ransomware gangs as it allows them to have an indirect role in the ransomware attacks—as a service provider—while amassing fees from the increasing number of affiliates. Meanwhile, some cybercrime gangs choose to only work with trusted partners. Unlike the DarkSide ransomware gang, which openly recruits affiliates and models their business as a franchise, other gangs prefer to have in-house operations. These gangs prefer to work only with people they hire and have even set up physical offices to conduct their ransomware business (Carr et al., 2021), just like regular high-tech companies.

To assess the revenue of gangs using the direct revenue model, we track a large gang and collect data from April 2018 to April 2020—we refer to this gang as an unidentified ransomware gang (URG).[25] URG is a large ransomware gang that operates through several subsidiaries. Our analysis is based on two datasets. The first dataset focuses on the operations carried out by a subsidiary and includes information on each attacker, the negotiation between attacker and victim, and the victim's payment outcome. The second dataset resembles the first dataset, but the information is extracted from the URG umbrella group.

The subsidiary gang raised $45m in ransom payments during the period. Analyzing the effectiveness of ransom payments, we find that 122 of 687 (17%) of the victims decided to pay (Figure 6). The most active months were June and July 2019, when over a hundred attacks were launched. The subsidiary gang also hit a record high in ransom earnings in June and July of 2019 when $10.4m and $10.7m, respectively, were generated in a dozen attacks.[26] The largest documented payment ($7.7m) was received in June 2019. Although a seemingly profitable business, when these data were collected, the double extortion game—namely, locking down systems and threatening to leak sensitive data—had not yet been developed. Interestingly, unlike most recent payment requests in opaque cryptocurrencies (i.e., Monero and

[24]Elliptic, a blockchain research firm, estimates that Darkside managed to raise over $90m in a longer period of time.

[25]The data was collected and provided by the Netherlands-based Fox-IT, NCC Group, while one of the authors worked for the company. Hereafter, we refer to this data as "Proprietary Data" whose content cannot be shared.

[26]We estimate the corresponding value based on Bitcoin's price on the day the ransom payment was made.

[27]Jason Rebholz, CISO at Boston-based cyber insurance company Corvus, said he has seen threat actors pressure victims into paying in Monero. "When ransomware negotiators push back to pay in Bitcoin due to the anonymity concerns with Monero, the ransomware actors inflate the ransom by as much as 20%." See https://www.techtarget.com/searchsecurity/news/252512142/Ransomware-actors-increasingly-demand-payment-in-Monero.

ZCash), the ransom price was often negotiated in dollars or bitcoin.[27]

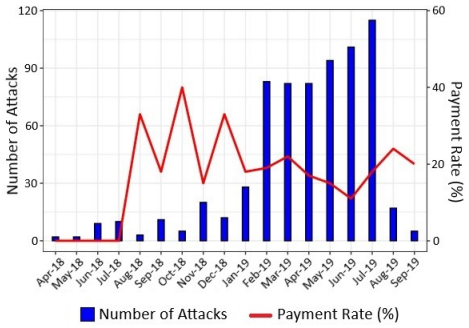

Figure 6: Ransom collection rate
(Source: Proprietary Data)

The data also permit us to gain insights into the subsidiary gang's operations. In the early phase, the gang had a relatively low activity level. It took almost half a year for this subsidiary to establish its operations and increase ransomware revenue. Ransomware revenue started to ramp up after about a year of established operations. In this period, roughly 15% to 20% of the victims paid, and the group was capable of executing around 100 attacks per month. We conclude that the subsidiary took some time to establish its operations. However, as revenue started getting in, the gang quickly expanded—potentially investing in new hires, offices, and darknet operations. The data also shows that criminal activities in this cyberspace, especially organized cybercrime, do not seem to have high entry barriers. It takes just a few months to establish operations and an initial revenue to scale operations drastically. But the subsidiary's lifespan is shorter than URG; as suggested by the data, the focal subsidiary's revenue stream faded away in the last quarter of 2019—potentially due to a re-branding strategy. Finally, the subsidiary is among the initiators of the ransomware epidemic we are currently facing, thus providing substantial insights into understanding the inception of the crypto-based ransomware market.

We now turn to analyze the data on the umbrella gang (URG). The revenue of the umbrella gang is larger than its subsidiary (Figure 7). The reason is twofold. First, not all the subsidiary income is reported because of its short life and potential rebranding. Second, the umbrella also generates revenue from other sources. Yet, a similar ramp-up revenue process is noticeable, suggesting that URG also scaled operations through the period. From 2018 to 2020, URG managed to collect $161.8m in ransom payments. Unlike its subsidiary, URG governance adopts a model based on limited kingpins (Lusthaus, 2018; Sandee et al., 2015). A manager, similar to legitimate businesses, operates each subsidiary. Shared tools and infrastructures are used across subsidiaries under URG supervision. The larger a subsidiary's revenue, the more significant the manager's influence in the umbrella gang. This system aligns well with incentives for both subsidiary and umbrella gangs to scale operations and become more effective in the long run. However, the system also influences the aggressiveness of the subsidiaries to increase total ransom payments. The latter led to what we now observe as the multiple layers of extortion tactics.

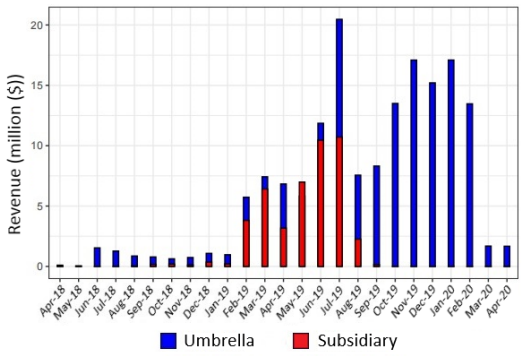

Figure 7: URG - Umbrella and subsidiary monthly income
(Source: Proprietary Data)

Target characteristics and disclosure. DarkTracer's list of ransomware attacks discloses the names of the victims that suffered security breaches. Using the firm's name, we collect additional information, such as location and listing status, whether it has disclosed any information that might increase the likelihood of being attacked (e.g., cybersecurity insurance), and whether it revealed being subject of attack to the public.

Based on our collected information we document several insights. We start by assessing the worldwide distribution of attacks. The United States leads the number of corporations victims of ransomware, concentrating more than 50% of worldwide attacks (see Figure 8). The U.S. is followed by the United Kingdom (5.9%), France (5.8%), Canada (5.4%), Italy (3.8%), Germany (3.7%), Australia (1.9%), Spain (1.7%), Brazil (1.5%), India (1.4%), and Japan (1.2%). Interestingly, Russia, Iran, and North Korea, countries known for established links with local ransomware gangs, do not appear on the list. Out of the gangs with more than 100 attacks worldwide, Conti (63%), Maze (62.9%), DoppelPaymer (55.4%), and Sodinokibi (53%) mainly target businesses headquartered in the United States—all these gangs are self-declared, investigated or associated with Russia or Russian hackers.[28]

We also investigate whether victims' past disclosures affects their probability of being attacked. For instance, firms with previous security breaches or whose cybersecurity insurance was made public may attract the attention of ransomware gangs. Indeed, the data show that 13.6% of these firms had disclosed security breaches before being attacked by the large ransomware gangs. However, contrary to conventional wisdom, we find that only seven firms (less than 0.1%) disclosed having cybersecurity insurance.[29] Likewise, holding Bitcoin, holding other cryptocurrencies, or using blockchain technology does not seem to attract the attention of ransomware gangs.

Finally, we check whether publicly listed firms disclose being victims of ransomware attacks. Unlike other studies

[28] See: https://www.justice.gov/opa/pr/latvian-national-charged-alleged-role-transnational-cybercrime-organization, https://www.hhs.gov/sites/default/files/maze-ransomware.pdf, https://www.justice.gov/opa/pr/ukrainian-arrested-and-charged-ransomware-attack-kaseya, https://www.bbc.co.uk/news/technology-59297187, and https://home.treasury.gov/news/press-releases/sm845.

[29] See https://corpgov.law.harvard.edu/2020/08/25/what-companies-are-disclosing-about-cybersecurity-risk-and-oversight/.

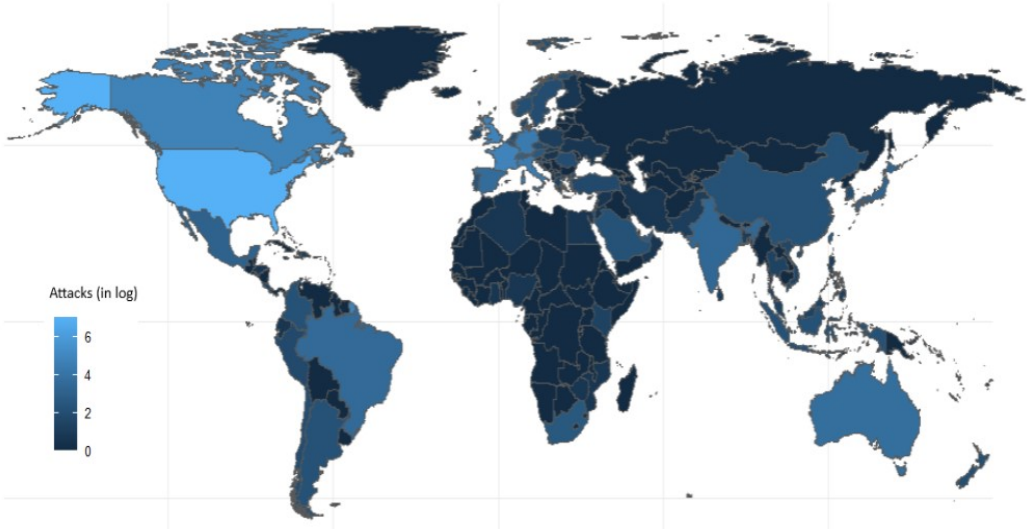

Figure 8: Worldwide Ransomware Attacks
(Source: Compiled from DarkTracer—Additional compilation involved researching firm's details)

that rely on disclosures forms such as 10Ks or information intermediaries (e.g., news and blogs) to access the information that a firm has been attacked (e.g., Amir et al. (2018) and Chen et al. (2022)), our analysis utilizes ransomware gang disclosures. Including all internet sources—such as specialized data breach websites and blogs—41% of the attacks worldwide and 42% in the United States were made public. Conditioned on these attacks, only 10.5% (11.1%) of worldwide (U.S.) disclosures are initiated by the victims (i.e., firms). Our results suggest that firms overwhelmingly underreport security breaches. Perhaps more importantly, our results show the important role of information intermediaries, especially data breach websites and blogs, in revealing cybersecurity risks to the public—together these sources cover about 90% of the disclosed breaches.

Attackers' reputation. Despite an increase in the aggressiveness of extortion games, ransomware gangs appear to value reputation. These gangs strive to make victims treat the ransomware attacks as business regularities rather than criminal activities. In addition, the gang's reputation depends not only on fulfilling its promises, such as decrypting data and deleting copied files, but also on an ex-ante analysis of victims' profitability to come up with the optimal sizing of the ransom payment. The reputation game is a learning process rather than a pre-operations establishment strategy. It is likely that ransomware gangs have learned that a reasonable price coupled with the reputation of keeping their promises maximizes profits.

To some extent, each ransomware gang appears to have its own pricing formula and target preference (Hack & Wu, 2021). Some gangs have geographical preferences. Others use analytical models to come up with the optimal ransom ask price. For instance, a ransomware gang based in China uses the number of computers the victim possesses to estimate the size of the ransom payment (Table 4). Using victims' assets to optimize the ransom ask is becoming increasingly common among large ransomware gangs. It is consistent with recently leaked pricing strategy of Conti, the largest ransomware gang.

Number of Computers	Price/Computer (USD)
1-9	3,000
10-49	1,500
50-99	1,120
100-499	750
500-999	560
1,000-4,999	380
5,000-9,999	260

Table 4: Pricing estimates based on the target's assets
(Source: Proprietary Data)

The Colonial Pipeline attack. As part of the reputation game, missteps may lead to drastic consequences to ransomware gangs, with some cases even leading to their extinction (i.e., forced re-branding or members leaving to join other gangs).

The most well-known ransomware attack of recent times, the Colonial Pipeline Ransomware Attack, is an example of how a ransomware gang can, on the one hand, cause substantial economic damages but, on the other hand, expose itself to the scrutiny of governments and agencies. The attack affected the service provider's critical internal IT infrastructure, halting the U.S. East Coast gasoline supply infrastructure and leading 17 states to declare an emergency.[30]

As mentioned earlier, the ransomware gang hit the company using a ransomware-as-a-service provided by "DarkSide" in May 2021. The company decided to pay the ransom and made the transaction on May 9th to the wallet address 15JFh88FcE4WL6qeMLgX5VEAFCbRXjc9fr. The total amount of the BTC was 75 ($4.4 Million). Soon after the payment was made, all of the 75 BTC were transferred to 1DToN8Q6y31TGAz75Df729Bnujk6Xg7q5X and then to bc1q7eqww9dmm9p48hx5yz5gcvmncu65w43wfytpsf.

A profit sharing was then made according to DarkSide's own split policy. In this case, 15% of ransom (11.2 BTC) went to the platform's wallet address

[30]See https://news.yahoo.com/colonial-pipeline-17-states-declare-191426265.html.

at bc1qu57hnxf0c65fsdd5kewcsfeag6sljgfhz99zwt and 85% (63.7 BTC) to 3EYkxQ-SUv2KcuRTnHQA8tNuG7S2pKcdNxB.[31] The proceedings from the last transaction subsequently moved to bc1qq2euq8pw950klpjcawuy4uj39ym43hs6cfsegq.

In response, the Department of Justice of the United States tracked these bitcoin transfers and eventually seized a large portion of it (U.S. Department of Justice, 2021a).[32] The DarkSide ransomware gang went offline soon after U.S. government actions.[33] However, the group re-grouped under a different brand "BlackMatter" (CISA, 2021). As the group was also exposed to blockchain researchers, additional information regarding their front company got exposed (Loui & Reynolds, 2021; Carr & Gyler, 2021), leading to its further re-branding, now as "Black Cat" (Gallagher, 2022).

Conti's corporate-like operations. Conti, a Russian-based cybercriminal gang, publicly announced their support for Russian cyberwarfare soon after the Russia-Ukraine conflict started. In retaliation to Conti's Russian support, a claimed Ukrainian individual, who uses the Twitter handle @ContiLeaks, leaked Conti's internal data. These data included thousands of members' chats, BTC addresses used for ransom payments, and pieces of ransomware code. Although the verification process is still undergoing, cybersecurity experts have confirmed the legitimacy of the data.[34]

Having extracted all of the mentioned bitcoin addresses from the dialogues (Online Appendix B), we identify a critical bitcoin wallet address 1AXiwETqqQoA52Jk5CmJkbAPuW8nR7VUYz, which is used to maintain infrastructure expenses and also for paying employee salaries (Appendix B). Following the first transaction in July 2017, the address accommodated 39 transactions responsible for moving more than 7.9 bitcoins.[35] Examining connected addresses on the chain, we identified two addresses involved with previous ransomware payments. Further scrutiny attributes two addresses, 3CjmkEZhNrnSzkQKXo5BHWQF6erG7CRXnt and 3LE4u2csMS9y1MdfgBZ3pDmnDg7VCtX322, to Ryuk, the precursor gang's name, which received victims' payments in May and June 2019. Following these payments trail help us learn the mechanics of Conti's corporate-like behavior.

Ransomware 2.0. Conti's leaked data also include text messages—in Russian language—between group members. Analyzing the content of these messages, we identify an account named "Stern," which seems to be managed by Conti's leader. The data encompasses 168,661 chat logs and 448 unique handles (account names) from June 2020 to March 2022.

Stern's messages with other gang members reveal interesting plans for the organization's future. First, Conti's leader is interested in developing blockchain-based applications to wash ransomware proceeds. This step is essential for developing decentralized finance applications, such as lending, swapping, and depositing cryptocurrencies. The first messages on this subject started appearing in August 2020, perhaps motivated by the increasing demand for decentralized financing applications. Beyond just discussing ideas, Conti's leader urged the technical team to learn more about blockchain cloud storage (Appendices C and D). Next, we analyze the word frequency used by Conti's leader. The data consists of large files containing a long list of entries in JSON format, which includes the timestamp, sender, receiver, and message. Here is an example.

```
{
''ts'': ''2020-08-20T16:11:05.356576'',
''from'' : ''stern@q3mcco35auwcstmt.onion'',
''to'': ''strix@q3mcco35auwcstmt.onion'',
''body'' : ''по кстате блокчейн хранилищем уже
          полностью разобрался ? можно
          запускать что инбудь?''
}
```

The analysis of Conti's leader chats provides further insights into the head of the largest ransomware gang. Since Stern (Conti's leader) is in the position of approving the gang's budget, vouching for new members, and drafting business plans, we focus our analysis on this handle. We find that Stern was quite involved in the decision-making of the gang in 2020—as perceived by Stern's chat dominance, with more than 1,000 messages sent in the period.[36] Conti's leader involvement became less evident in 2021; however, the content of the messages also changed. In 2021, Conti's leader moved the focus from directing ransom attacks and payments to establishing a plan for the gang's future, namely the development of blockchain-based projects.

Labeling the sentences where the keyword "блокчейн" (blockchain in Russian) appears, we found a spike in this topic in June 2021—this period is also coupled with a spike in the launch of decentralised finance (DeFi) applications, known as the DeFi boom. Analyzing the content of these messages, we conclude that Conti's leader sought to employ personnel with expertise in blockchain programming, especially for managing cloud applications (Appendix B). This is consistent with the gang leveraging their programming skills to diversify into legit (and less risky) activities.

4 Contribution

Our study contributes to the literature in at least three ways. First, we add to the evolving literature on blockchain forensics. This literature exploits the transparency of blockchain ecosystems, such as Bitcoin, to study the behavior of on-chain transactions among market participants. Foley et al. (2019) in a early study highlights that a large share of Bitcoin activities are illicit, including reshuffling activities that may show up as "noise." A recent estimate by Makarov & Schoar

[31] Presumably the subsidiary wallet.

[32] According to ThomsonReuters (https://www.thomsonreuters.com/en-us/posts/investigation-fraud-and-risk/colonial-pipeline-ransom-funds/), 52.3% of ransom was recovered by the authorities.

[33] Although the affiliate responsible for the attack was located in the US, DarkSide is claimed to be based in Eastern Europe, likely Russia. However, unlike other hacking groups responsible for high-profile cyberattacks (e.g., Conti) it is not believed to be directly state-sponsored (See https://www.wsj.com/articles/fbi-suspects-criminal-group-with-ties-to-eastern-europe-in-pipeline-hack-11620664720).

[34] The leaked conversations also include Conti's management plan to bail out former arrested employees (U.S. Department of Justice, 2021b).

[35] Although a small amount, the information on the wallet address is verifiable—we abstain from reporting larger quantities from unverifiable sources.

[36] We filtered messages containing less than three words.

(2021) uses a different algorithm and additional off-chain information to obtain a much lower estimate. Sokolov (2021) finds that surges in ransomware activity are associated with blockchain congestion. Amiram et al. (2022) assesses of predictability of abnormal on-chain transfers in the vicinity of large-scale terrorist attacks. Tsuchiya & Hiramoto (2021) measures the activity of dark web marketplaces and find that the Operation Onymous—an international law enforcement operation targeting darknet markets—did not deter their activity. We complement this by uncovering the landscape and economics of crypto-enabled cybercrime. Consistent with Makarov & Schoar (2021), blockchain forensics emerges as a powerful tool for researchers, market participants, agencies, and regulators to examine, monitor, and contain on-chain illicit activities.

We also contribute to the literature examining cybersecurity risk and disclosure. Because managers have incentives to withhold negative information, and investors cannot discover most cyberattacks independently, firms may underreport security breaches. Studying the extent to which firms withhold information on cyberattacks, Amir et al. (2018) finds that firms under-report cyberattacks and are more likely to disclose when the probability of the event coming out to the public is high. Using a sample of firms experiencing data breaches, Chen et al. (2022) finds that risk factor disclosures are informative. However, they are more likely to happen after firms have a severe data breach event. Our findings complement this literature by examining a list of attacked firms leaked directly by the ransomware gangs. Our results support the evidence that firms overwhelmingly under-report cyberattacks. Moreover, our results suggest that information intermediaries play a crucial role in uncovering firms' cybersecurity risks to the public.

Finally, our study joins studies providing timely economic insights for crypto regulation. For instance, Cong et al. 2021; Amiram et al. 2021; Aloosh & Li 2021 produce substantial evidence that some crypto exchanges mislead customers by inflating volume and discuss issues on regulating exchanges. Cong et al. (2022) examines how traders exploit tax-loop holes and harvest losses by engaging in wash trades and their move to gray areas of taxation due to the lack of policy coordination. Our discourse on crypto-enabled cybercrimes is the first of its nature and informs the ongoing regulatory debate and law enforcement.

5 Conclusion

Cryptocurrencies and decentralized finance potentially promote financial inclusion, reduce transactions costs, increase security and provide new capital for startups. But, as with any technological innovation, there are risks of abuse. In particular, the anonymity of wallet ownership permits cybercrime organizations to scale their operations. In this study, we collect information from multiple datasets and information sources to provide an anatomy of crypto-enabled cybercrimes. In addition to sizing up the scale and describing basic patterns, we highlight key economic issues entailed in crypto-enabled cybercrimes including revenue models, reputation management, negotiation, and extortion techniques. Our insights hopefully inform the conversation as to how digital assets should be regulated and how the unintended consequences of FinTech innovations can be mitigated.

Ransomware attacks dominate the crypto-enabled cybercrime space, and although the overall market grew exponentially in the last few years, activity is dominated by a handful of sophisticated ransomeware gangs. These gangs often rebrand themselves, usually following an investigation episode. We also show that these gangs' operations evolved from simple attacks to sophisticated corporate-like operations, including franchising, physical offices, call centers, and investments in blockchain technology, such as DeFi, to wash the attack proceeds. Finally, we also demonstrate that these gangs become more effective over time, employing several layers of extortion which limit room for negotiation. Ransomware gangs, however, also value reputation, a feature that victims can leverage to contain the damages of a ransomware attack.

A one-size-fits-all solution, such as restricting or banning cryptocurrency usage by individuals or organizations is problematic for three major reasons. First, this is not a national problem. Blockchains exist across multiple countries and harsh regulations in a particular country or jurisdiction have little or no effect outside that country. As we have seen from other global initiatives (e.g., carbon tax proposals), it is nearly impossible to get global agreement. Second, while an important problem, cryptocurrency plays a small role in the big picture of illegal payments. Physical cash is truly anonymous and, indeed, this may account for the fact that 80.2% of the value of U.S. currency is in $100 notes. It is rare the consumers use $100 bills and it is equally rare that retailers are willing to accept them. Third, and most importantly, expunging all cryptocurrency use in a country eliminates all of the benefits of the new technology. Even further, it puts the country at a potential competitive disadvantage. For example, a ban on crypto effectively eliminates both citizens and companies from participating in web3 innovation.[37]

The analysis in our paper points to a different tactic. While addresses are anonymous initially, funds are often transferred from one address to another in order to "cash out." All transactions are viewable and immutable - a key feature of blockchain technology. This opens the possibility of deploying forensic tools with a focus on tracking, monitoring, and identifying the crypto transactions attributed to criminals. Indeed, our research provides a glimpse of what is possible given the transparent nature of blockchains.

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[37] Web3 is a version of the internet that enables users to pay or be paid without using traditional methods such as credit cards or ACH. There is no web3 without decentralized finance.

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Appendix A
Complementary Tables

	2018	2019	2020	2021	2022-06
Bank Transfer or Payment	154.6	179.8	320.5	762.0	703.1
	15.6%	17.0%	21.1%	24.8%	32.3%
Cash	116.7	118.4	149.2	191.8	101.4
	11.8%	11.2%	9.8%	6.2%	4.7%
Check	78.4	71.4	87.6	153.4	82.2
	7.9%	6.8%	5.8%	5.0%	3.8%
Credit Cards	140.3	121.9	152.1	181.6	110.4
	14.2%	11.5%	10.0%	5.9%	5.1%
Cryptocurrency	12.1	33.5	132.8	755.4	728.8
	1.2%	3.2%	8.7%	24.6%	33.5%
Debit Card	77.5	89.2	117.4	140.6	90.6
	7.8%	8.4%	7.7%	4.6%	4.2%
Gift Card or Reload Card	78.0	103.0	125.4	233.1	113.5
	7.9%	9.8%	8.2%	7.6%	5.2%
Money Order	20.5	22.9	26.3	38.7	18.9
	2.1%	2.2%	1.7%	1.3%	0.9%
Other	8.9	5.9	5.8		
	0.9%	0.6%	0.4%	-	-
Payment App or Service	28.5	50.2	87.9	130.9	82.2
	2.9%	4.8%	5.8%	4.3%	3.8%
Wire Transfer	272.6	259.0	315.6	482.9	147.3
	27.6%	24.6%	20.8%	15.7%	6.8%
Total	988.1	1055.1	1520.7	3070.4	2178.5

Table A1: Fraud Report (Source: Compiled from the Federal Trade Commission (See Federal Trade Commission (2022))

Month	Attacks	Paid (%)	BTC	USD
Apr-2018	2	0 (0%)	0	$0
May-2018	2	0 (0%)	0	$0
Jun-2018	9	0 (0%)	0	$0
Jul-2018	10	0 (0%)	0	$0
Aug-2018	3	1 (33.3%)	5	$34,869.85
Sep-2018	11	2 (18.2%)	25	$164,498.40
Oct-2018	5	2 (40%)	40	$191,390.96
Nov-2018	20	3 (15%)	25	$130,253.90
Dec-2018	12	4 (33.3%)	88	$353,911.52
Jan-2019	28	5 (17.9%)	58	$208,339.50
Feb-2019	83	16 (19.3%)	1026.75	$3,810,643.93
Mar-2019	82	18 (22.0%)	1,611.32	$6,409,714.78
April-2019	82	14 (17.1%)	611.32	$3,170,654.26
May-2019	94	14 (14.9%)	1,146	$6,986,710.59
Jun-2019	101	11 (10.9%)	1,291.50	$10,454,868.36
Jul-2019	115	21 (18.3%)	977	$10,711,931.78
Aug-2019	17	4 (23.5%)	201	$2,255,378.88
Sep-2019	5	1 (20%)	14	$144,861.12
Total	681	116 (17%)	7,109.89	$45,028,033.83

Table A2: Ransomware gang balance sheet - subsidiary operations
(Source: Proprietary)

Month	BTC	**USD**
Apr-2018	10.8	$101,801.99
May-2018	6.94	$49,498.48
Jun-2018	214.56	$1,535,261.49
Jul-2018	172.34	$1,273,163.71
Aug-2018	136.41	$863,066.08
Sep-2018	120.78	$784,149.70
Oct-2018	98.03	$629,077.39
Nov-2018	143.04	$736,753.42
Dec-2018	272.00	$1,083,045.80
Jan-2019	268.30	$967,861.19
Feb-2019	1559.70	$5,733,383.91
Mar-2019	1874.57	$7,423,461.17
Apr-2019	1311.31	$6,829,461.58
May-2019	863.59	$5,822,328.66
Jun-2019	1450.85	$11,859,023.88
Jul-2019	1877.49	$20,469,207.08
Aug-2019	726.97	$7,560,106.32
Sep-2019	857.44	$8,313,096.59
Oct-2019	1601.26	$13,499,635.78
Nov-2019	2043.75	$17,093,244.81
Dec-2019	2079.35	$15,206,475.97
Jan-2020	1963.41	$17,096,847.69
Feb-2020	1329.21	$13,469,848.97
Mar-2020	315.00	$1,684,387.30
Apr-2020	253.00	$1,671,514.46
Total	21550.17	$161,755,703.50

Table A3: Ransomware gang balance sheet - umbrella operations
(Source: Proprietary)

Appendix B
Conti group internal dialogue (sample)

2021-05-07T06:51:42.746008
bentley@q3mcco35auwcstmt.onion: Скажи, у Арматы брать ботов или возврат денег?
(translated: Tell me, do we buy bots from Armata or do we return the money?)

2021-05-07T12:54:34.685218
bentley@q3mcco35auwcstmt.onion: <Pulya> $5200 отправил, все что было.
(translated: <Pulya> Sent you $5200, that's all I had)

2021-05-07T12:54:34.685860
bentley@q3mcco35auwcstmt.onion: <Pulya> с меня $7300 верно? [21:32:59] <volhvb> Да верно.
(translated: <Pulya> I owe you $7300 right? [21:32:59] <volhvb> Yes, correct)

2021-05-07T12:54:34.686854
bentley@q3mcco35auwcstmt.onion: Куда переслать?
(translated: "Where do I send it to?")

2021-05-07T12:56:45.499523
stern@q3mcco35auwcstmt.onion: ботов надо.
(translated: We need the bots)

2021-05-07T12:57:09.894275
bentley@q3mcco35auwcstmt.onion: Понял. Куда закинуть что мне пуля вчера скинул?
(translated: Got it. Where do I send what Pulya sent me yesterday?)

2021-05-07T12:57:28.860578
stern@q3mcco35auwcstmt.onion: 1AXiwETqqQoA52Jk5CmJkbAPuW8nR7VUYz

Appendix C
Conti leader recruiting taskforce for blockchain project

2021-06-08T12:13:14.308514
Кто нибудь из нас есть кто считает себя гуру блокчейна, и трендов. Кто может знает куда идти в этом направлении и что разрабатывать... Какие у кого идеи.
(translated: Any of us who consider himself as guru of blockchain and trends. Who might know where to go in this direction and what to develop... What ideas anyone has.")

Appendix D
Conti leader stern urged technical team to get block-chain storage ready

2020-08-20T16:17:47.583774
strix@q3mcco35auwcstmt.onion: Уже поднял Sia + Nextcloud на дедике. Загрузил на Sia несколько файлов для теста. Эти файлы видны через веб-интерфейс Nextcloud и через WebDAV, но, похоже, там какая-то проблема с правами доступа, что ли. При попытке скачать существующие или залить новые файлы возникает ошибка. Пока разбираюсь. Там еще, пришлось даунгрейдить Nextcloud до версии 12 (текущая версия 19), т.к. storage backend для Sia давно не обновлялся. Возможно, придется пообщаться с разработчиками для разбирательства, почему не работает.
(translated: Already got Sia + Nextcloud up on the deck. Uploaded some files to Sia for the test. These files are visible through the Nextcloud web interface and through WebDAV, but there seems to be some access rights issue or something. When trying to download existing files or upload new files an error occurs. I am still figuring it out. There also, I had to downgrade Nextcloud to version 12 (the current version is 19), because the storage backend for Sia hasn't been updated in a long time. May have to talk to the developers to figure out why it's not working.)

2020-08-20T16:18:17.212121
stern@q3mcco35auwcstmt.onion: ага поня
(translated: alright, got it)

2020-08-20T16:18:21.683602
stern@q3mcco35auwcstmt.onion: надо систему наладить эту
(translated: we need to get this system up and running)

2020-08-20T16:18:23.687287
stern@q3mcco35auwcstmt.onion: это будущее
(translated: this is the future)

Appendix E
Ransomware gangs tracked by DarkTracer, from 2019-05 to 2021-07

AKO
Astro Team
Avaddon
AvosLocker
BABUK LOCKER
CL0P
Conti
Cuba
DarkSide
DoppelPaymer
Egregor
Everest
Grief
Haron
Hive
LOCKDATA
LV
LockBit
Lorenz
MAZE
Marketo
Mount Locker
N3tw0rm
NEMTY
Nefilim
NetWalker
Noname
Pay2Key
Payload.bin
Prometheus
Pysa
Quantum
Ragnar_Locker
Ragnarok
RansomEXX
Ranzy Locker
Sekhmet
Sodinokibi (REvil)
Suncrypt
SynACK
Team Snatch
Vice Society
XING LOCKER

Online Apendix A
Bitcoin Abuse—Reported Addresses per Category

Panel A: Bitcoin Tumbler

Year-Month	Addresss	ReportCount	Transactions	TotalReceived (USD)	ReportCount (per address)
2018-Apr	3	6	8	1	2.0
2018-May	1	2	6	114	2.0
2018-Sep	1	2	12	1	2.0
2018-Oct	1	2	2	0	2.0
2018-Nov	1	10	0	0	10.0
2018-Dec	2	11	0	0	5.5
2019-Jan	8	21	2	0	2.6
2019-Feb	4	10	1,214	5	2.5
2019-Mar	7	27	3	0	3.9
2019-Apr	5	26	34	2	5.2
2019-May	3	21	0	0	7.0
2019-Jun	3	14	309	10	4.7
2019-Jul	1	20	0	0	20.0
2019-Aug	5	54	8	0	10.8
2019-Sep	5	10	232	263,979	2.0
2019-Oct	4	16	18	0	4.0
2019-Nov	3	59	21	0	19.7
2019-Dec	3	25	31,492	1,595	8.3
2020-Jan	3	17	323,919	575,743	5.7
2020-Feb	8	103	104,910	503,630	12.9
2020-Mar	8	22	321	20	2.7
2020-Apr	46	214	20,949	357,505	4.6
2020-May	17	54	562	3	3.2
2020-Jun	21	58	2,296	29	2.8
2020-Jul	20	57	124,769	411	2.8
2020-Aug	29	77	7,878	88,745	2.7
2020-Sep	21	178	4,800	29	8.5
2020-Oct	38	126	9,247	154	3.3
2020-Nov	29	263	4,211	86	9.1
2020-Dec	30	88	145,6176	3,884,375	2.9
2021-Jan	30	90	70,664	46,869	3.0
2021-Feb	33	108	8,632	304	3.3
2021-Mar	39	216	27,294	149,003	5.5
2021-Apr	26	81	52,979	34,841	3.1
2021-May	7	62	2,796	29,688	8.9
2021-Jun	2	9	412	279,905	4.5
2021-Jul	1	6	561	7	6.0
2022-Jan	3	45	894,519	1,101,168	15.0
2022-Feb	5	801	1,192,025	15,654,679	160.2
Grand Total	476	3,011	4,343,281	22,972,901	6.3

Table AO1: Bitcoin Abuse: Reported Addresses
(Source: Compiled from BitcoinAbuse.com—Additional information involved checking addresses history at Blockchain.com)

Panel B: Blackmail Scam

Year-Month	Addresss	ReportCount	Transactions	TotalReceived (USD)	ReportCount (per address)
2018-Sep	13	61	63	2	4.7
2018-Oct	143	739	258	15	5.2
2018-Nov	226	1,485	1,911	62	6.6
2018-Dec	199	2,222	376	22	11.2
2019-Jan	280	2,809	496	89	10.0
2019-Feb	241	2,608	2,006	552	10.8
2019-Mar	299	3,151	69,217	6,403	10.5
2019-Apr	298	3,926	272	24	13.2
2019-May	316	2,824	971	44,955	8.9
2019-Jun	142	2,533	429	25	17.8
2019-Jul	70	1,673	808	27	23.9
2019-Aug	107	2,811	3,657	134,371	26.3
2019-Sep	91	1,706	304	16	18.7
2019-Oct	66	924	471	13	14.0
2019-Nov	70	837	138	6	12.0
2019-Dec	48	1,325	444	11	27.6
2020-Jan	92	1,297	255	8	14.1
2020-Feb	58	516	228	7	8.9
2020-Mar	85	1,206	15,850	386,132	14.2
2020-Apr	2,326	11,496	6,563	522	5.0
2020-May	557	3,096	4,332	114	5.6
2020-Jun	94	1,286	3,293	7,041	13.7
2020-Jul	91	1,411	3,346	98	15.5
2020-Aug	84	1,245	1,715	121	14.8
2020-Sep	83	1,002	25,471	2,103	12.1
2020-Oct	116	1,058	3,010	166	9.1
2020-Nov	126	1,959	32,707	2,171	15.5
2020-Dec	79	1,712	8,595	458	21.7
2021-Jan	104	2,182	2,424	2,096	21.0
2021-Feb	128	2,010	6,068	8,678	15.7
2021-Mar	144	2,124	3,921	84	14.7
2021-Apr	118	1,493	2,606	92	12.6
2021-May	50	689	5,173	169	13.8
2021-Jun	17	524	451	8	30.8
2021-Jul	4	1,087	106	5	271.7
2021-Aug	8	461	127	3	57.6
2021-Sep	1	89	2	-	89.0
2021-Oct	2	57	9	1	28.5
2021-Dec	4	35	3,826	1,699	8.7
2022-Jan	1	5	-	-	5.0
2022-Feb	1	10	1,905	9,201	10.0
Grand Total	6,982	69,684	213,804	607,570	10.0

Table AO1: Bitcoin Abuse: Reported Addresses (Continued)

Panel C: Darknet Market

Year-Month	Addresss	ReportCount	Transactions	TotalReceived (USD)	ReportCount (per address)
2018-Sep	1	2	2	0	2.0
2018-Dec	2	8	-	-	4.0
2019-Jan	3	10	-	-	3.3
2019-Feb	6	376	54	4	62.7
2019-Apr	1	29	5	0	29.0
2019-Jun	3	16	828	35	5.3
2019-Jul	2	15	-	-	7.5
2019-Aug	3	6	15	0	2.0
2019-Sep	4	10	1,773	55	2.5
2019-Oct	2	6	37	0	3.0
2019-Nov	2	7	86	3	3.5
2019-Dec	3	9	57	13	3.0
2020-Jan	2	6	4	0	3.0
2020-Feb	6	21	1,313	21	3.5
2020-Mar	6	148	396	297,352	24.7
2020-Apr	3	32	-	-	10.7
2020-May	3	8	14	2	2.7
2020-Jun	3	6	185	1	2.0
2020-Jul	13	86	1,532	32	6.6
2020-Aug	13	48	19,210	777	3.7
2020-Sep	22	49	10,814	63	2.2
2020-Oct	10	35	111,084	68	3.5
2020-Nov	15	34	1,323	21	2.3
2020-Dec	19	55	2,573	101,651	2.9
2021-Jan	15	38	2,443	1,438	2.5
2021-Feb	11	33	3,454	11,418	3.0
2021-Mar	6	14	222	9	2.3
2021-Apr	10	81	3,491	74	8.1
2021-May	1	2	492	6	2.0
2021-Jul	1	24	4	0	24.0
2022-Jan	1	30	316	1	30.0
Grand Total	192	1,244	161,727	413,046	6.5

Table AO1: Bitcoin Abuse: Reported Addresses (Continued)

Panel D: Other

Year-Month	Addresss	ReportCount	Transactions	TotalReceived (USD)	ReportCount (per address)
2018-Aug	3	6	-	-	2.0
2018-Sep	5	14	18	1	2.8
2018-Nov	5	12	20	0	2.4
2018-Dec	7	21	21	1	3.0
2019-Jan	8	24	17	4	3.0
2019-Feb	7	19	168	4	2.7
2019-Mar	7	19	249	23	2.7
2019-Apr	8	21	365	13	2.6
2019-May	14	81	327	50,059	5.8
2019-Jun	10	34	240	18	3.4
2019-Jul	9	41	182	105	4.6
2019-Aug	9	20	499	584	2.2
2019-Sep	25	131	172,746	1,264,657	5.2
2019-Oct	8	42	230	6	5.2
2019-Nov	15	48	833	129	3.2
2019-Dec	12	35	39,066	3,397	2.9
2020-Jan	52	175	4,115	191	3.4
2020-Feb	58	186	900	94	3.2
2020-Mar	107	504	2,113	180	4.7
2020-Apr	173	872	4,173	3,743	5.0
2020-May	215	793	19,393	61,344	3.7
2020-Jun	76	245	4,023	489	3.2
2020-Jul	52	152	38,578	109,755	2.9
2020-Aug	74	275	277,464	5,106,884	3.7
2020-Sep	49	162	380,631	833,474	3.3
2020-Oct	70	206	15,194	642	2.9
2020-Nov	78	244	11,106	1,019,732	3.1
2020-Dec	46	136	57,543	1,538	3.0
2021-Jan	84	222	218,720	232,906	2.6
2021-Feb	73	225	10,179	1,104	3.1
2021-Mar	78	214	91,416	5,327,933	2.7
2021-Apr	63	199	20,818	6,530	3.2
2021-May	18	144	138,204	40,038	8.0
2021-Jun	1	10	108	35	10.0
2021-Jul	3	329	687	491	109.7
2021-Aug	2	14	30	0	7.0
2021-Sep	1	4	327	2	4.0
2021-Oct	4	25	1,176,552	37,019,698	6.2
2021-Nov	1	13	346,779	100,462,323	13.0
2022-Jan	1	7	131	1	7.0
Grand Total	1531	5,924	3,034,165	151,548,126	3.9

Table AO1: Bitcoin Abuse: Reported Addresses (Continued)

Panel E: Ransomware

Year-Month	Addresss	ReportCount	Transactions	TotalReceived (USD)	ReportCount (per address)
2017-Nov	1	2	27	1	2.0
2018-Jun	1	2	-	-	2.0
2018-Jul	2	4	-	-	2.0
2018-Aug	23	48	7	0	2.1
2018-Sep	58	265	87	11	4.6
2018-Oct	98	445	100	7	4.5
2018-Nov	147	611	49	2	4.2
2018-Dec	120	589	120	5	4.9
2019-Jan	289	2,588	629	46	8.5
2019-Feb	136	1,219	5,024	26,189	9.0
2019-Mar	142	1,476	13,935	53,437	10.4
2019-Apr	145	1,512	132	9	10.4
2019-May	140	2,066	404	27	14.8
2019-Jun	75	727	596	54	9.7
2019-Jul	48	995	163	10	20.7
2019-Aug	57	839	49	1	14.7
2019-Sep	83	1,189	4,308,846	127,108	14.3
2019-Oct	40	509	5,314	250	12.7
2019-Nov	46	581	57	2	12.6
2019-Dec	43	583	269	22	13.6
2020-Jan	46	1,479	78,159	29,460	32.1
2020-Feb	45	468	986	11	10.4
2020-Mar	57	976	864	23	17.1
2020-Apr	1979	9,702	3,491	1,950	4.9
2020-May	461	2,154	2,157	125	4.7
2020-Jun	69	840	2,217	120	12.2
2020-Jul	58	599	67,076	11,140,191	10.3
2020-Aug	69	905	3,999	575	13.1
2020-Sep	70	1,544	33,574	208,862	22.1
2020-Oct	71	522	7,423	244	7.3
2020-Nov	79	936	1,794	41	11.8
2020-Dec	53	708	11,895	1,836	13.4
2021-Jan	87	643	36,073	96,355	7.4
2021-Feb	79	710	8,588	13,724	9.0
2021-Mar	102	1,079	8,253	170	10.6
2021-Apr	71	630	3,337	68	8.9
2021-May	22	360	2,328	229	16.4
2021-Jun	6	265	7,618	118	44.2
2021-Jul	6	61	1,671	288	10.2
2021-Aug	6	81	391	5	13.5
2021-Sep	1	4	542	25	4.0
2021-Oct	2	24	17,212	150,376	12.0
2021-Nov	8	254	18,855	1,611,096	31.7
2021-Dec	15	591	1,047,264	142,579,357	39.4
2022-Jan	4	48	31,666	291,312	12.0
2022-Feb	3	86	38,477	32,472	28.7
Grand Total	5163	41,919	5,771,718	156,366,213	8.1

Table AO1: Bitcoin Abuse: Reported Addresses (Continued)

Panel F: Sextortion

Year-Month	Addresss	ReportCount	Transactions	TotalReceived (USD)	ReportCount (per address)
2019-Feb	6	29	2	-	4.8
2019-Mar	247	1,556	171	15	6.3
2019-Apr	239	2,365	211	17	9.9
2019-May	334	3,240	376	31	9.7
2019-Jun	102	1,335	147	9	13.1
2019-Jul	68	1,721	124	7	25.3
2019-Aug	105	926	31,511	33,804	8.8
2019-Sep	155	1,535	192	11	9.9
2019-Oct	62	927	111	4	14.9
2019-Nov	86	1,841	270	19	21.4
2019-Dec	68	1,038	199	13	15.3
2020-Jan	90	1,246	261	12	13.8
2020-Feb	55	1,008	354	9	18.3
2020-Mar	74	890	73	3	12.0
2020-Apr	4097	19,454	389	26	4.7
2020-May	602	2,898	311	11	4.8
2020-Jun	69	1,075	6,234	92	15.6
2020-Jul	42	1,248	100	5	29.7
2020-Aug	52	726	122	4	14.0
2020-Sep	51	909	475	10	17.8
2020-Oct	64	876	151	6	13.7
2020-Nov	105	1,863	422	15	17.7
2020-Dec	57	1,242	566	13	21.8
2021-Jan	77	1,373	110	3	17.8
2021-Feb	80	1,495	142	4	18.7
2021-Mar	125	2,227	228	3	17.8
2021-Apr	105	1,147	127	2	10.9
2021-May	40	959	683	8	24.0
2021-Jun	25	724	107	2	29.0
2021-Jul	5	236	11	0	47.2
2021-Aug	5	1,219	25	1	243.8
2021-Sep	1	137	7	1	137.0
2021-Oct	3	44	2	0	14.7
2021-Nov	2	202	6	0	101.0
2021-Dec	2	8	-	-	4.0
2022-Jan	4	177	16	2	44.2
2022-Feb	2	10	-	-	5.0
Grand Total	7306	59,906	44,236	34,163	8.2

Table AO1: Bitcoin Abuse: Reported Addresses (Continued)

Online Appendix B
Bitcoin addresses extracted from Conti leaks

112qJRWfQCAqKzSk3ZcQnq1A1YwqyfLbgp
12KHi1L1KUNDjSvkG5j56FRNbFrud3ZjUU
12V63PHiX8FvEgyewX5W1D2QrdJJSawqQM
12YQDqmq3t6bCKPKMRWFmqrju4UMXbcqvF
12bsh5bc7wkVSRv25Qw6x3JYzuQDpZZ4zi
1347fBtFzZCrPq29yjRpct5f6Kq5uHZHHy
14HnaQfsQdtgVSNR91jLcbcKtdyddDfP6D
15QULY9y2HJj1i85LiJGMYWChhAqnGkCSx
15gjb8F5Zd8XRKBCgVxsr8ZuVzr7yBtnCN
169J9MvXSjJZUjarG7JXDD8qiQXZS4jj6A
16evvEiZ6HKkV9WAbysJfJG1Qa7DzJGUFp
172KVKhMqL5CU1HN884RbArzu5DDL5hwE3
17mc4Qm7ka9jhQEUB5LTxP3gW3tsDYUJGQ
1AXiwETqqQoA52Jk5CmJkbAPuW8nR7VUYz
1B8sFxkPtMqR86dkfd3rFT38A5tncCDZD8
1CwbkiHug1yw7HGdYxEtXk9nQFUc6GKxzj
1DF9qtzbja79o3yBAmgoX5wdsSSpaPD2mE
1DS9DVVD4K86ppQhg8ta9XFVEaaW7NXZfA
1DSp4woswZECAL9zdmmGeu1s7k1sGExFDh
1FWWRT88WjYbZp4NoRNEBgTGjRxhi2J9YM
1G5LWXMN42ueD2eWvm4zMrhXGihghHDgMq
1G5wLGHbsMmbRT7CdfmBA4aeR7RNwiG8FY
1GXrHar42EHxHNXM2nFkXQ5gpTMxdR5q5j
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Online Appendix C
Ryuk Addresses extract from ransomwhere.re

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Online Appendix D
Conti members' email addresses

0x00lord@q3mcco35auwcstmt.onion
8383@q3mcco35auwcstmt.onion
Hash@q3mcco35auwcstmt.onion
Stern@q3mcco35auwcstmt.onion
admin@q3mcco35auwcstmt.onion
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admu@q3mcco35auwcstmt.onion
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