

The shift of DarkNet illegal drug trade preferences in cryptocurrency: The question of traceability and deterrence

Original

The shift of DarkNet illegal drug trade preferences in cryptocurrency: The question of traceability and deterrence / Bahamazava, Katsiaryna; Nanda, Rohan. - In: FORENSIC SCIENCE INTERNATIONAL. DIGITAL INVESTIGATION. - ISSN 2666-2825. - 40:(2022). [10.1016/j.fsidi.2022.301377]

Availability:

This version is available at: 11583/2984787 since: 2024-01-01T12:59:55Z

Publisher:

Elsevier

Published

DOI:10.1016/j.fsidi.2022.301377

Terms of use:

This article is made available under terms and conditions as specified in the corresponding bibliographic description in the repository

Publisher copyright

Elsevier preprint/submitted version

Preprint (submitted version) of an article published in FORENSIC SCIENCE INTERNATIONAL. DIGITAL INVESTIGATION © 2022, <http://doi.org/10.1016/j.fsidi.2022.301377>

(Article begins on next page)

The shift of DarkNet Illegal Drug Trade Preferences in Cryptocurrency: The Question of Traceability and Deterrence

Katsiaryna Bahamazava^{a,*}, Rohan Nanda^b

^a*Collegio Carlo Alberto, University of Turin, Lungo Dora Siena 62, 10149, Torino, Italy*

^b*Maastricht Law and Tech Lab and Institute of Data Science, Maastricht University,
Netherlands*

Abstract

DarkNet markets (DNMs) are flourishing, exploiting cryptocurrencies' pseudo-anonymity feature. To fight the illegal drug trade, it is necessary to understand the factors influencing choices made by DNM consumers. ClearNet forums facilitate interactions among new and experienced DarkNet users, thus serving as an ideal source of investigation and research. The methodology of temporal topic models (CorEx) and Sentiment analysis were applied to the ClearNet forum data to explore DNM drug users' behavior over time. We inspected the development of major topics from the forum over eight years (2012-19) to study the evolution of the motivation and challenges faced by DNM users. The extracted temporal topic models successfully captured the apparent dynamics of critical events in the crypto world, showing the shift in the DNM drug users' cryptocurrency preferences. Our analysis demonstrates that Bitcoin traceability (made public in 2015) did not have a deterrent effect. This declaration instead acted as an advertisement for DNMs. Drug buyers used Bitcoin despite its traceability until Monero became untraceable in 2017 due to its privacy update. The analysis indicates that the cryptocurrency preferences have shifted from Bitcoin to Monero.

Keywords: DarkNet markets, temporal topic modeling, Sentiment analysis, NLP, drugs, Bitcoin, Monero, DNM

1. Introduction

DarkNet markets (DNMs), also known as cryptomarkets, are collections of Dark Web (DarkNet) websites that function similarly to other online platforms facilitating trades, such as eBay or Amazon (EMCDDA and Europol (2017)).

*Corresponding author

Email address: katyabogomazova@gmail.com, katsiaryna.bahamazava@unito.it
(Katsiaryna Bahamazava)

Users' anonymity is the main feature that distinguishes DNMs from traditional e-commerce platforms. To enhance anonymity, only cryptocurrencies are accepted as a method of payment on DarkNet Markets. DNM administrators build trust between participants by introducing review, dispute, escrow systems, and sanctions for scammers (Demant et al. (2018)).

According to Europol, approximately 1 billion USD was spent on DNMs in 2018 (Europol (2019)). While drugs are the number one category offered on DNMs, which account for 62% of the deals, the remaining sales consist of fraud and counterfeit, guides and tutorials, hacking and malware, firearms and explosives, along with other illegal activities (EMCDDA and Europol (2017)).

Customers choose to buy illegal goods and services on DNMs because of perceived anonymity, protection, and higher quality (Caudevilla et al. (2016)) of goods sold. Also, during the COVID-19 lockdowns, the "usual" places (streets and clubs) have been inaccessible; hence, the access to the products became an issue, which spiked the DNMs' attractiveness (UNODC (2020)).

This paper assumes that apprehending criminals on the Dark Web is challenging due to the following reasons:

- 1) limited amount of research compared to the conventional drug sale markets,
- 2) continually evolving technologies that DNMs are based on,
- 3) the involvement of multiple jurisdictions, not always supporting each other and/or working together.¹

Let us examine the first reason of a fairly new phenomenon with a limited amount of research. American R.W. Ulbricht created the earliest DNM "Silk Road" in 2011, which functioned until 2013.² At the same time, the traditional illegal drug trade possibly appeared as early as narcotics were outlawed. Being a unique phenomenon, the DNM requires time to be recognized, researched, and analyzed (EMCDDA and Europol (2017)).

The second issue of the difficulty to apprehend DNM's illegal activities is the continuously evolving technology utilized by DNM participants. For instance, the first DNM, "Silk Road," only controlled specific Bitcoins³ addresses to manage sales. However, in recent years, the DNM platforms started utilizing escrows,⁴ PGP's,⁵ along with numerous cryptocurrency wallets and anonymous

¹An example of multiple jurisdictions' involvement is recently shut down "Wall Street Market" (WSM). It was a market owned by three Germans, administrated by Brazilian with sales all over the world (<https://www.justice.gov/opa/press-release/file/1159706/download> (Last accessed: July 13, 2021)).

²<https://www.justice.gov/usao-sdny/pr/manhattan-us-attorney-announces-indictment-ross-ulbricht-creator-and-owner-silk-road> (Last accessed: July 13, 2021)

³Bitcoin is a virtual currency created, managed, and transferred via a peer-to-peer (P2P) network over the Internet via users running the specific software Stokes (2012).

⁴Escrow is the use of a neutral third party that holds the money until the vendor delivers the good.

⁵Pretty Good Privacy is the encryption technique used to code the shipping address before sending it to the vendor.

exchanges.

Finally, the third reason is that buyers and vendors are in different locations during the transactions: they could even be on different continents. The absence of physical links impedes investigations and requires collaboration between countries. This kind of deep cooperation between jurisdictions with different political and economic regimes is not always possible. One of the few successful illustrations of coordinated actions was the seize of European DNM "Italian-MafiaBrussels" with Romanian members who sent drugs primarily to the US and Canada (EMCDDA and Europol (2019)). This operation is one example of how much effort and how many countries are needed to cooperate in shutting down just one DNM.

Considering the complications of the three reasons mentioned above, the presumed weakest link in the whole scheme is the transition from the online world to the real one or vice versa. These transition points are drug deliveries, the exchange between fiat money (i.e., fiduciary currency) and cryptocurrency, and crypto-laundering. The ClearNet forums discussing DNM's experience also should be considered as transitional points, since they represent the current state of DNMs. On these forums, beginners ask questions about accessing Dark Web, cryptocurrency usage, specific markets, and reasons to buy drugs on DNMs. In contrast, on the Dark Web forums, we find people who already understood the whole process of buying DNM's illegal products. Therefore, it is more beneficial to analyze ClearNet forums since they provide an understanding of new DNM users' motivations and challenges.

This paper examines the ClearNet forums' information to study DarkNet drug users' behavior shift for policy decision-making. Since the cryptocurrency acquisition is another transition point between ClearNet and Dark Web, the change in cryptocurrency preferences is studied. Then, we hypothesize that Bitcoin is not the preferred cryptocurrency for DarkNet drug users.

Bitcoin is the first successful cryptocurrency, and it is still the most popular one among the general public. However, as it became known in recent years, the data in bitcoin blockchain⁶ is traceable, and anyone with proper tools and expertise can analyze it. This traceability feature means that it is possible to identify DNM users on both sides. In 2015, the FBI announced⁷ the usage of blockchain analysis to trace Bitcoins back to the Ross Ulbricht personal wallet. Even if the user utilized mixers,⁸ it became possible to disentangle its output. Therefore, Bitcoin is traceable now. What is the alternative?

⁶Blockchain is a mechanism that employs cryptography and mathematical algorithms to create and verify continuously growing data, which functions as a distributed ledger (Houben & Snyers (2018)).

⁷<https://www.wired.com/2015/01/prosecutors-trace-13-4-million-bitcoins-silk-road-ulbrichts-laptop/> (Last accessed: July 13, 2021)

⁸Mixer (tumbler) is a service that enables customers, for a fee, to send cryptocurrency to designated recipients in a manner that was designed to conceal and obfuscate the owner (or the source) of the cryptocurrency (<https://www.justice.gov/opa/pr/ohio-resident-charged-operating-darknet-based-bitcoin-mixer-which-laundered-over-300-million> (Last accessed: July 13, 2021)).

To answer this question, Natural Language Processing (NLP) techniques are used. NLP is a "branch of Artificial Intelligence that applies machine learning methods to text" (Hovy (2021)). One of the most successful implementations of NLP is topic models. In our case, to analyze the forum's posts and comments, we used a temporal topic model. We consider a topic model as a model that connects documents and words through variables (L'huillier et al. (2011)). The topic itself is defined as a distribution of words with a document constructed as a mixture of topics (Curiskis et al. (2020)). We utilize the Correlation Explanation model (CorEx) to discover latent topics over the documents, which does not assume any specific data generating model (Gallagher et al. (2017)).

For testing the hypothesis empirically, the CorEx model is utilized to answer the following questions:

RQ1: What was the most recommended cryptocurrency by forum users for buying drugs from DNMs?

RQ2: How did the announcement of Bitcoin traceability (2015) and Monero's privacy update (2017) influence topics' evolution over time?

RQ3: What were the most popular topics discussed by new drug buyers on the forum?

The rest of the paper is organized as follows. Section 2 provides an overview of the related literature. In Section 3, we explain the methodology. The results are demonstrated in the 4th Section. Section 5 discusses the paper's implications and its limitations. Finally, the 6th Section concludes.

2. Related work

We will focus on works that have applied topic models or NLP to study ClearNet or DarkNet forums. These works were grouped into three categories.

The first group consists of papers examining ClearNet forums related to the illegal drug trade.

Porter (2018) applied Latent Dirichlet allocation (LDA) to derive the main topics from the Reddit forum "DarkNetMarkets." The author analyzed the forum's topics for one year since November 2016, paying attention to the users' reaction to the DNM "AlphaBay" shut down . Porter emphasized the DNM users' feelings of uncertainty and concerns after law enforcement and hackers' intrusions on the DarkNet. Moreover, he discussed the specific security measures which DNM users employed.

Shah et al. (2019) utilized the GloVe embedding algorithm to evaluate community similarity and detect anomalies, signaling the advent of disturbing events. They studied 118 million posts created on Reddit, including posts from "AlphaBayMarket" and "DarkNetMarket," on the period between March 2016 and September 2017 . The authors proposed an unsupervised approach to detect disturbances on Reddit automatically.

Hazel Kwon and Shao Chun (2020) examined the Reddit forum "AlphabayMarket" for two months in 2017 to identify key participants in the community and topic clusters. To determine critical players, authors used degree centrality and frequency methods; the LDA model was utilized to identify topic clusters .

Cho & Wright (2019) compared the Reddit forums related to illegal trade with the DarkNet forums for one year dating from 2017. The authors utilized LDA for the topic modeling and TextBlob for Sentiment Analysis . They revealed that topics discussed on Reddit were also discussed on the DarkNet forum. However, on DarkNet, users also talked about additional topics related to security. Both on ClearNet and DarkNet forums, users manifested more positive than negative sentiments. The authors showed that users were willing to help each other in the time of uncertainty and absence of information.

The second group comprises works studying DarkNet forums.

Tavabi et al. (2019) applied LDA with the non-parametric Hidden Markov Model (HMM) to explore DarkNet forums' evolution in 2016-2017. Scraping 250 DarkNet forums, they found that the most common languages were English, Russian, and Chinese. After obtaining the most discussed topics with LDA, the authors modeled the topics' activity with HMM and clustered the results. They got four clusters: vending, security, gaming, and others.

Park et al. (2016) applied a sentiment analysis tool, namely SentiStrength, to discover radical tendencies on DarkWeb forums. Then the authors calculated the average monthly sentiment score and examined its evolution through time correlation with major terrorist attacks.

The authors of the third group studied ClearNet forums unrelated to DarkNet activity.

To recognize anxiety disorders on Reddit forums, Shen & Rudzicz (2017) utilized n-grams, vector embedding models as Word2Vec and Doc2Vec, and LDA topic modeling. For classification purposes, authors employed LR, Support Vector Machine (SVM), and a neural network (NN).

Nizzoli et al. (2020) employed the Anchored Correlation Explanation model to perform topic modeling on Twitter, Telegram, and Discord for 2019 to reveal cryptocurrency manipulations, namely pump-and-dump and Ponzi schemes. They found that 15 Twitter botnets were responsible for 75.4% of invite links related to deceptive schemes.

Grayson & Greene (2019) analyzed 16 different Reddit forums for the nine months of 2014 to explore the evolution of users' social roles. The authors applied struc2vec embedding algorithms. They found that community roles were mainly static.

In contrast with the previous research, this paper considers the evolution of the cryptocurrency's preferences of DNM drug users as the determinant of perceived traceability. Since cryptocurrency is the only way to buy drugs online, the attitude towards it among the specific public could be used to analyze the state-of-art of the online drug market. Moreover, in terms of methodology, we decided to use the CorEx⁹ model instead of LDA since it does not limit us to a specific data generation process. Indeed, CorEx treats each word as a random variable and attempts to discover topics that best explain the data.

⁹More in Section 3.

3. Methodology

On the ClearNet, some forums exist where experienced and new DNM users interact. The main is r/darknet¹⁰ on Reddit. The data from such open forums yields more benefits for research than the DarkNet forums themselves. These ClearNet public platforms operate as a gateway and a guide to the DarkNet. The particular interest for researching them is to perform quantitative and qualitative analysis since beginners on these forums ask questions about DNMs' functionality, updates, payments, and security among other things.

The public subreddit r/darknet was chosen for this research project because of its size (174, 000 registered members) and the length of time it has been in operation (it was created on December 26, 2009). We utilized the Reddit Scrapper¹¹ to obtain the r/darknet data from the open archive.¹²

The overall number of posts used in the paper is 26,884, dating from January 1, 2012 to December 31, 2019. As for comments, the final count is 192,530, which dates from January 1, 2012 to December 31, 2019.

To analyze the behavioral shift of the r/darknet users, we use temporal topic modeling and Sentiment analysis.

The usual temporal topic model's approach examines documents over time with different topics where a topic is a probability distribution over the words (Sohrabi et al. (2018)). Instead, we use a Correlation Explanation (CorEx) model, which does not assume any specific mechanism of how topics emerged (Gallagher et al. (2017)). CorEx discovers independent latent factors that explain correlations between observed variables. In this model, X is a group of words, and Y is a topic to be learned. The Total Correlation is zero only when there is no dependence between variables X and Y.

The data was divided into sixteen datasets as we have eight years of posts and comments. Before applying CorEx, the text was cleaned by lemmatization,¹³ removing stop words, lowercasing, removing punctuation, deleting NaN values, and erasing bot entries. We defined the stop words as pronouns, swear words, adjectives, and auxiliary verbs.

The number of the topics for each dataset was chosen in such a way as to explain 70% of all entries since extra topics contribute insignificant correlation to the learned models. All the topics with the related terms can be found in Appendix A. The topics distribution over the years and their evolution are presented in Figure 1. We normalized all the data due to differences in the number of posts and comments in each year.

To answer the first question, we utilized the comments dataset since we are interested in the other users' recommendations but not in questions.

¹⁰<https://www.reddit.com/r/darknet/> (Last accessed: July 13, 2021).

¹¹<https://www.labnol.org/internet/web-scraping-reddit/28369/> (Last accessed: July 13, 2021)

¹²<https://pushshift.io/> (Last accessed: July 13, 2021)

¹³Spacy and nltk python packages are used.

To reply to the second question, we examined the posts dataset because we wanted to understand in which topics DNM users were interested at the specific time.

To answer the third question, the new users' posts were separated from the other posts. From the forum, we know that new users identify themselves as "newbie", "noob", "new", "beginner", or "n00b". We utilized the flashtext¹⁴ module to retrieve the posts with the aforementioned keywords. After obtaining the datasets only with new users' posts, we applied CorEx to locate prevalent topics.

To confirm the shift from Bitcoin to Monero through the change of emotions, we use the Sentiment analysis tool, namely VADER (Hutto & Gilbert (2014)). Before using VADER, we expand its lexicon with specific to the Dark Web community words, like "untraceable," "anonymous," and "legit" among others. Afterward, we apply the Sentiment analysis tool to Monero and Bitcoin topics starting from 2016 to analyze the evolution of emotions.

4. Results

4.1. Temporal topic modeling

We are interested in the behavioral shift in cryptocurrency preferences. Figure 1 presents the evolution of topics for all users from 2012 to 2019. As we can see, in 2012, the popularity of the "Advertisement" topic was much higher than other discussions. In 2013, not only the most discussed topic changed to "Security," but the new themes as "Illegal products" and "Police actions" arose. In 2014, two prominent discussions were "Police actions" and "Security." New topics as "Delivery" and "DNM payments" emerged. "Illegal products" was the main topic in 2015 and 2016. Users discussed mainly "Security" and "Advertisement" in 2017 and 2018. In 2019, "Security" and "DNM payments" topics were the most popular discussions. Unsurprisingly, DNM users argued extensively about security issues ("Security") almost every year. The cryptocurrency usage ("DNM payments") and "Delivery" discussions became popular topics since 2014. All transitional points, which could be used for tracing the illegal drug trade, were discussed on the forum.

After exploring the main topics, we can confirm that cryptocurrency usage, in general, was discussed. Thus, we ask:

RQ1: What was the most recommended cryptocurrency by forum users for buying drugs from DNMs?

To answer this question, we utilized the comments dataset. In posts, users ask for recommendations. The recommendations themselves could be found only in the comments dataset. We can see that from 2017 (Figure 2), Monero was the most recommended cryptocurrency for the illegal drug trade.¹⁵ It is

¹⁴<https://pypi.org/project/flashtext/> (Last accessed: July 13, 2021)

¹⁵Monero is a P2P cryptocurrency focusing on private and censorship-resistant transactions (Houben & Snyers (2018)).

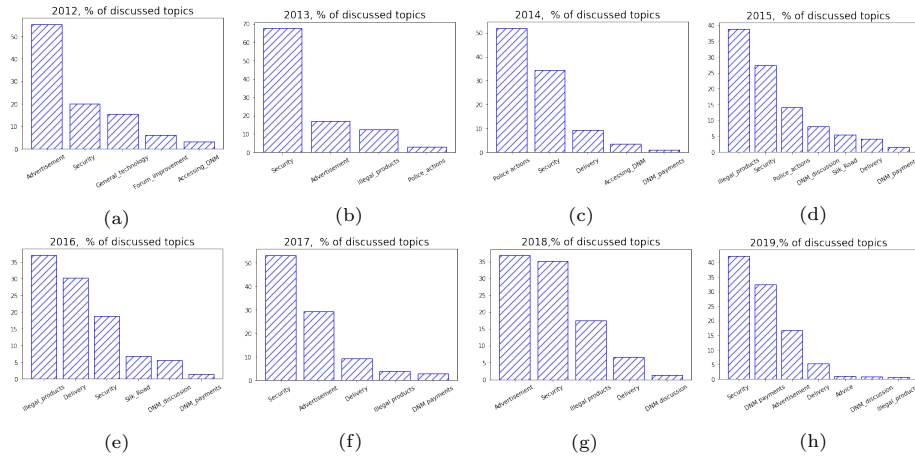


Figure 1: Posts topics evolution of all users

worth mentioning that also users discussed the usage of Bitcoin. We know from the forum that the usual way to get Monero is to buy Bitcoin from the automated teller machines or crypto exchange and then convert Bitcoin to Monero in specific wallets. The confrontation of the discussion of the two mentioned above cryptocurrencies is represented in Figure 2.

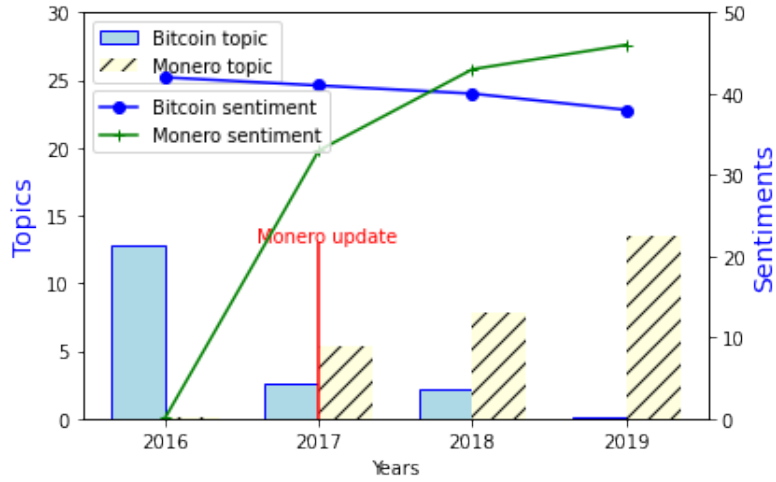


Figure 2: Evolution of "Bitcoin" and "Monero" topics in comments dataset.

We defined "Monero" as a topic about Monero, special wallet "Electrum"

that used only to exchange Bitcoin to Monero, key¹⁶, encryption, fee, atm. The "Bitcoin" topic is defined as a discussion about Bitcoin, address, buy, buying, sending, order, and account.¹⁷

As presented in Figure 2, in 2016, the unsupervised technique did not reveal the "Monero" topic. After 2017, this discussion intensified. In 2017, Monero Network was upgraded by introducing RingCT¹⁸ transactions. This update made it impossible to deduce the transaction amount from the Monero blockchain, which is not valid for Bitcoin. Therefore, Monero became untraceable, which is the main advantage of cryptocurrency for the DarkNet illegal drug trade. Along with this advantage, the difficulty of acquiring it with additional fee payments comes in the package. Still, from the performed analysis, it appears that the DNM users recommended using Monero instead of Bitcoin.

The topics' change after Monero's privacy improvement and the FBI announcement of Bitcoin traceability are examined in the next step. We want to explore how these two events influenced topics' evolution on the forum. It is known that the deterrent effect of increased probability of apprehension is more significant than of increased severity of punishment (Fader (2016)). Possibly, the motivation behind the FBI announcement was to show their increased skills in incarcerating criminals on the Dark Web.¹⁹ The "Security" topic was one of the most popular topics (Figure 1). This topic is directly correlated with Monero's privacy update and Bitcoin traceability. The "Security" topic is defined as a discussion related to tails²⁰, vpn²¹, tor²², pgp²³, key, encryption, and attacks. Another considered topic is "Illegal products." We chose this topic as it reflects DarkNet drug users' interests. The "Illegal products" topic is defined as a discussion about drugs, counterfeit documents and money, illegal devices, guns, credit cards and their pins. The evolution of "Security" and "Illegal products" discussions, in conjunction with the aforementioned events, can be found in Figure 3. Now we are ready to answer the second question:

RQ2: How did the announcement of Bitcoin traceability (2015) and Monero's privacy update (2017) influence topics' evolution over time?

The "Security" topic was the most discussed one in 2013 after the "Silk Road" closure. As seen from Figure 3, in 2012, the "Security" topic occupied only 20% of all topics. In 2013, the percentage was 67.7%. However, afterward, the interest in this topic was declining until the news about the Monero privacy update. Even the announcement of Bitcoin traceability did not change the

¹⁶Public and private keys for encryption.

¹⁷The complete list of terms that constitutes "Monero" and "Bitcoin" topics can be found in the Appendix Appendix A.

¹⁸<https://www.getmonero.org/resources/roadmap/> (Last accessed: July 13, 2021)

¹⁹<https://www.justice.gov/usao-sdny/pr/ross-ulbricht-aka-dread-pirate-roberts-sentenced-manhattan-federal-court-life-prison> (Last accessed: July 13, 2021)

²⁰Tails is a program against censorship and surveillance.

²¹VPN is an application that makes the Internet connection more private.

²²TOR is a free network designed to anonymize the real Internet Protocol address by routing the traffic through many servers of the TOR network.

²³PGP - encryption program for data communication.

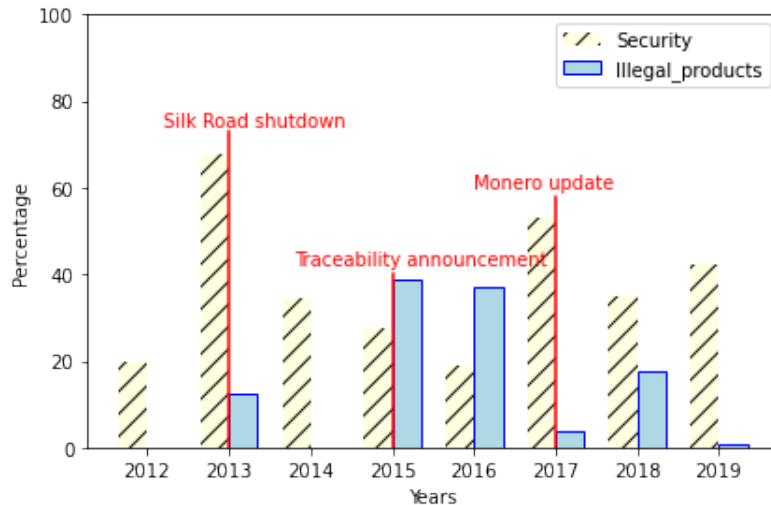


Figure 3: Evolution of "Security", "Illegal products" topics

trend. As seen from the graph, the discussion percentage decreased from 34.3% in 2014 to 27.4% in 2015. The news about the increased probability of apprehension due to Bitcoin traceability did not intensify the discussion about avoiding surveillance. Instead, after the Monero privacy update in 2017, the percentage increased from 18.9% in 2016 to 53.18% in 2017. The "Security" topic again gained popularity. Before Monero became untraceable in 2017, DNM drug users did not have a better alternative to Bitcoin. Possible ways to make Bitcoin more anonymous had not changed for years. DNM drug users did not have any choice but to take the risk associated with Bitcoin's traceability. This example shows us that the announcement of apprehension's increased probability did not influence the "Security" topic evolution. Instead, the Monero major privacy update announcement did. After this event, security-related discussions revived. It confirms the drug offenders' "restrictive deterrence" theory. This theory states that actual or anticipated sanctions instead of deterring drug offenders make them adopt a more innovative strategy for reducing the risk of apprehension (Fader (2016)).

Analyzing the "Illegal products" topic evolution, we can observe that the Bitcoin traceability announcement impacted it. Right after this announcement, in 2015 and 2016, "Illegal products" was the most discussed topic on the DarkNet drug users forum. Possibly, this announcement worked as an advertisement for the DarkNet markets. After this statement, more people became aware of DNM's existence and wondered which illegal products they could buy there.

Now we respond to the RQ3: What were the most popular topics discussed by *new* drug buyers on the forum?

New DarkNet users were interested in "Security" only during the first two years of analysis. Afterward, the most popular topics were related to the Dark-

Net market functionalities (Appendix B). We defined "DNM discussion" as a topic related to vendors, orders, markets, alphabay²⁴, advice about vendors, questions about escrows, offers, and recommendations about markets. As seen from Figure 4, after the FBI announcement, in 2015, the percentage of the "DNM discussion" spiked in the new users' dataset. This declaration brought new users to the DNMs.

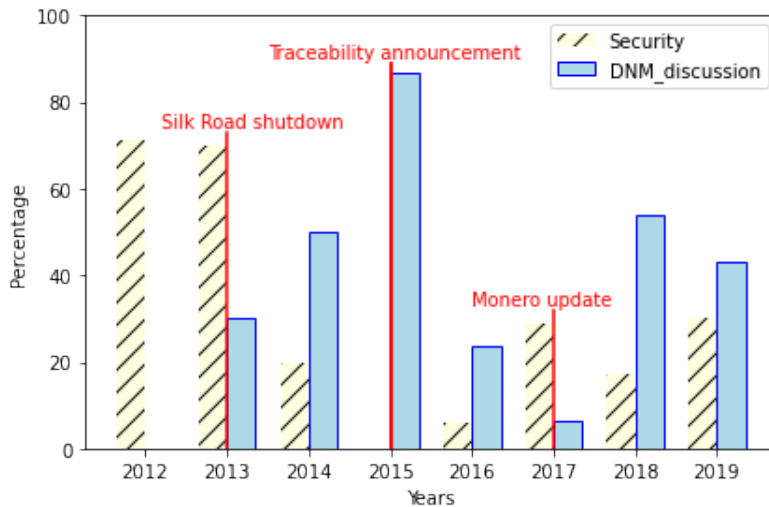


Figure 4: Evolution of "Security", "DNM discussion" topics in new users posts dataset

4.2. Sentiment analysis

We applied Vader to analyze the evolution of the forum users' emotions towards "Bitcoin" and "Monero" topics, constructed with the CorEx model. Beginning from 2016, the change in emotions in both cryptocurrencies was traced to test our hypothesis of shifting preferences. In Figure 2, the right Y-axis represents a normalized, weighted composite score ranging from -100% to 100%, corresponding to the maximum negative and positive scores, respectively. As seen from Figure, emotions to both cryptocurrencies have been changed. More precisely, Monero sentiments display a positive trend while Bitcoin's sentiments are in decreasing tendency. Also, this analysis shows us the shift in cryptocurrency preferences of forum users.

5. Discussion and limitations

It appears that the DNM drug users have shifted to a new cryptocurrency called Monero. The shift began as early as 2017 when the new Monero privacy feature was introduced. The DNM drug users are constantly searching to

²⁴Alphabay is the name of the DarkNet market.

improve their anonymity. Moreover, they have the motivation and skills to employ new technologies. It is worth mentioning that the current DarkNet-related statistics do not mention Monero (Chainalysis (2020)).

The DNM drug users reacted to the FBI announcement differently than was expected. This statement did not have a deterrent effect on drug users but instead brought new customers to DNMs, acting purely like an advertisement. Moreover, this announcement disclosed the techniques utilized by law enforcement agencies and pushed drug offenders to search for new and innovative ways to buy narcotics online.

In the present study, we examined the posts and comments of users who presumably buy drugs from the Dark Web on a regular basis. Although these users wrote that they acquire drugs on DNMs, we did not have access to the actual transactions on Dark Web to confirm their purchases. Therefore, the major limitation is the possible discrepancies between users' words on the forum and the actions on the Dark Web.

One of the possible paths in future work could be considering non-English speaking forums to confront the differences in cryptocurrencies perception of DNM drug users. For example, it would be interesting to analyze Russian forums since the Russian-speaking DNM "Hydra" has 2.5 million registered accounts and earned at least \$1 billion from 2016 till 2019.²⁵

6. Conclusion

Motivated by the increasing popularity of DNMs, we studied the switch in the cryptocurrency preferences for the illegal drug trade and the influence of real-world events on DarkNet users' discussions. ClearNet forum was chosen for performed analysis since it gives the perspective of the experienced and new users.

By applying temporal topic modeling on over 219,000 posts and comments, we confirmed the hypothesis of changed preferred cryptocurrency for the illegal DarkNet drug trade. We examined the influence of Bitcoin traceability announcement and Monero privacy update on the topic's evolution of DNM drug users. Moreover, we used the Sentiment analysis to examine the change in emotions toward the cryptocurrencies.

Possibly, the announcement of a law enforcement agency's ability to trace Bitcoin did not influence users in an anticipated way. Contrary to general deterrence theory prediction, the increased probability of apprehension did not stop people from buying drugs on DarkNet markets. This announcement acted as an advertisement for new users. Also, it pushed users to search for a new way to purchase drugs on DNM, confirming the restrictive deterrence theory of drug offenders. Bitcoin's utilization was a forced choice in the absence of an alternative. As early as the Monero privacy update was implemented, the shift

²⁵<https://www.proekt.media/research/narkotiki-v-darknete/> (Last accessed: July 13, 2021)

from Bitcoin to Monero had begun. For now, Monero is untraceable. However, it is probably only a matter of time and effort before it changes. In the beginning, everyone thought that also Bitcoin was untraceable. Due to blockchain nature, transactions are immutable. This means that when the tracing solutions are found, it would be possible to go back in time and find all the participant's trades on the Dark Web. Still, as we saw with Bitcoins, this will only lead to new and innovative ways to buy narcotics online. Perhaps, it could be more beneficial for law enforcement agencies not to announce the achievements in the apprehension techniques of DarkNet drug users.

Declaration of interests

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

Acknowledgment

The authors received no financial support for the research, authorship, and/or publication of this article.

References

- Caudevilla, F., Ventura, M., Fornís, I., Barratt, M. J., Vidal, C., lladanosa, C. G., Quintana, P., Muñoz, A., & Calzada, N. (2016). Results of an international drug testing service for cryptomarket users. *Int. J. Drug Pol.*, *35*, 38–41.
- Chainalysis (2020). The 2020 state of crypto crime. URL: <https://go.chainalysis.com/rs/503-FAP-074/images/2020-Crypto-Crime-Report.pdf> (Accessed 13 July 2021).
- Cho, S. Y., & Wright, J. (2019). Into the dark: A case study of banned darknet drug forums. In *International Conference on Social Informatics* (pp. 109–127). Springer.
- Curiskis, S. A., Drake, B., Osborn, T. R., & Kennedy, P. J. (2020). An evaluation of document clustering and topic modelling in two online social networks: Twitter and reddit. *Information Processing & Management*, *57*, 102034.
- Demant, J., Munksgaard, R., Décary-Hétu, D., & Aldridge, J. (2018). Going local on a global platform: A critical analysis of the transformative potential of cryptomarkets for organized illicit drug crime. *International Criminal Justice Review*, *28*, 255–274.

- EMCDDA and Europol (2017). Drugs and the darknet: Perspectives for enforcement, research and policy. URL: https://www.emcdda.europa.eu/publications/joint-publications/drugs-and-the-darknet_en (Accessed 13 July 2021).
- EMCDDA and Europol (2019). EU Drug Markets Report 2019. URL: https://www.emcdda.europa.eu/publications/joint-publications/eu-drug-markets-report-2019_en (Accessed 13 July 2021).
- Europol (2019). Internet organised crime threat assessment. URL: <https://www.europol.europa.eu/activities-services/main-reports/internet-organised-crime-threat-assessment-iocta-2019> (Accessed 13 July 2021).
- Fader, J. J. (2016). Selling smarter, not harder”: Life course effects on drug sellers’ risk perceptions and management. *Int. J. Drug Pol.*, 36, 120–129.
- Gallagher, R. J., Reing, K., Kale, D., & Ver Steeg, G. (2017). Anchored correlation explanation: Topic modeling with minimal domain knowledge. *Transactions of the Association for Computational Linguistics*, 5, 529–542.
- Grayson, S., & Greene, D. (2019). Temporal analysis of reddit networks via role embeddings. *arXiv preprint arXiv:1908.05192*, .
- Hazel Kwon and Shao Chun (2020). Communicative constitution of illicit online trade collectives: An exploration of darkweb market subreddits. In *International Conference on Social Media and Society* (pp. 65–72).
- Houben, R., & Snyers, A. (2018). *Cryptocurrencies and blockchain: Legal context and implications for financial crime, money laundering and tax evasion*. European Parliament. URL: <https://www.europarl.europa.eu/cmsdata/150761/TAX3%20Study%20on%20cryptocurrencies%20and%20blockchain.pdf> (Accessed 13 July 2021).
- Hovy, D. (2021). *Text Analysis in Python for Social Scientists: Discovery and Exploration*. Elements in Quantitative and Computational Methods for the Social Sciences. Cambridge University Press. doi:10.1017/9781108873352.
- Hutto, C., & Gilbert, E. (2014). Vader: A parsimonious rule-based model for sentiment analysis of social media text. In *Proceedings of the International AAAI Conference on Web and Social Media*.
- L’huillier, G., Alvarez, H., Ríos, S. A., & Aguilera, F. (2011). Topic-based social network analysis for virtual communities of interests in the dark web. *ACM SIGKDD Explorations Newsletter*, 12, 66–73.
- Nizzoli, L., Tardelli, S., Avvenuti, M., Cresci, S., Tesconi, M., & Ferrara, E. (2020). Charting the landscape of online cryptocurrency manipulation. *IEEE Access*, 8, 113230–113245. URL: <http://dx.doi.org/10.1109/ACCESS.2020.3003370>. doi:10.1109/access.2020.3003370.

- Park, A. J., Beck, B., Fletche, D., Lam, P., & Tsang, H. H. (2016). Temporal analysis of radical dark web forum users. In *2016 IEEE/ACM International Conference on Advances in Social Networks Analysis and Mining (ASONAM)* (pp. 880–883). IEEE.
- Porter, K. (2018). Analyzing the DarkNetMarkets subreddit for evolutions of tools and trends using LDA topic modeling. *Digital Investigation*, *26*, S87–S97.
- Shah, D., Hurley, M., Liu, J., & Daggett, M. (2019). Unsupervised content-based characterization and anomaly detection of online community dynamics. In *Proceedings of the 52nd Hawaii International Conference on System Sciences*.
- Shen, J. H., & Rudzicz, F. (2017). Detecting anxiety through reddit. In *Proceedings of the Fourth Workshop on Computational Linguistics and Clinical Psychology—From Linguistic Signal to Clinical Reality* (pp. 58–65).
- Sohrabi, B., Vanani, I. R., & Shineh, M. B. (2018). Topic modeling and classification of cyberspace papers using text mining. *Journal of Cyberspace Studies*, *2*, 103–125.
- Stokes, R. (2012). Virtual money laundering: the case of bitcoin and the linden dollar. *Information & Communications Technology Law*, *21*, 221–236.
- Tavabi, N., Bartley, N., Abeliuk, A., Soni, S., Ferrara, E., & Lerman, K. (2019). Characterizing activity on the deep and dark web. In *The WEB conference*. Association for Computing Machinery. [arXiv:1903.00156](https://arxiv.org/abs/1903.00156).
- UNODC (2020). World drug report 2020. URL: <https://www.unodc.org/unodc/en/data-and-analysis/wdr2021.html> (Accessed 13 July 2021).

Appendix A. Appendix

Topic 2012	Terms
Security	privacy, app, encrypt, download, alternative, use, idea, propose
Advertisement	search, information, control, internet, distance, pay, profit, integrate
General technology	state, read, edit, copy, system, fire, filter, lose
Forum improvement	interface, list, file, connect, dns, agency, wireless, community
Accessing DNM	scene, networking, mark, linux, government, byzantium, dark, start
Topic 2013	Terms
Advertisement	involve, network, wiki, work, node, store, untrusted, medium
Security	traffic, vpn, isp, monitor, capture, force, open, connect
Illegal products	waste, list, hidden, device, exist, child, porn, request
Police actions	alternative, android, seize, encryption, direction, darkplan, group, government
Topic 2014	Terms
Police actions	law, user, turn, content, remove, street, follow, enforcement
Security	escrow, prevent, vote, love, party, international, feature, encrypt
Delivery	product, deliver, package, problem, talk, ship, process, personal
Accessing DNM	use, download, find, answer, search, information, access, source
DNMs payments	deposit, communicate, provide, stay, fact, experience, sort, transaction
Topic 2015	Terms
Security	safety, secure, service, basis, aspect, rate, remember, talk
Illegal products	red, hidden, gun, pin, view, bank, military, xanax
Police actions	knowledge, change, intelligence, obtain, paper, policy, contain, dose
DNM discussion	product, pure, listing, stealth, create, score, include, rating
"Silk Road"	road, silk, country, safe, compare, insight, purchase, hell
Delivery	order, receive, package, box, noob, work, public, system
DNM payments	pay, bitcoin, prescription, consider, drug, money, government, buy

Table A.1: Topic for 2012, 2013, 2014

Topic 2016	Terms
Delivery	version, pack, content, carding, sell, jabber, title, cause
Illegal products	passport, card, driver, license, credit, counterfeit, register, guarantee
Security	answer, rule, view, direct, stop, leave, attack, encryption
"Silk Road"	come, grow, effect, case, hear, silk, road, past
DNM discussion	customer, list, drop, reason, reply, clean, purity, request
DNM payments	wallet, bitcoin, dnstatsnet, invite, search, exchange, tumbler, electrum

Table A.2: Topics for 2016

Topic 2017	Terms
Advertisement	stripe,pin,proper,cause,blank,defrauding,score,carding
Police actions	information,notice,value,feature,takedown,law,activity,project
Security	use,pgp,tail,noob,vpn,access,email,computer
DNM discussion	customer,strain,country,choose,charge,hand,claim,purity
Illegal products	license,driver,passport,ssn,server,onion,document,testing
Delivery	receive,ship,private,burn,xtc,sample,perform,cop
Mixing Bitcoin	bitcoin,send,wallet,purchase,tumble,save,anonymous,address
Topic 2018	Terms
Delivery	send,come,receive,ask,product,change,address,customer
Illegal products	driver,license,passport,scan,number,novelty,establish,tracking
Advertisement	digital,handle,chargeback,gtour,bankdrop,dash,handbook,guide
Security	vpn,tail,laptop,phone,download,access,setup>window
DNM payments	decide,noob,brick,talk,value,stop,ethereum,knowledge
DNM discussion	use,know,information,pay,create,marketplace,require,user
Topic 2019	Terms
Security	tail,use,pgp,tor,key,vpn,electrum,download
DNM payments	bitcoin,wallet,send,transfer,deposit,coinbase,transaction,monero
Advertisement	contact,biometric,affordable,lab,watsapp,test,room,certificate
Delivery	order,address,receive,open,ask,wait,check,ampxb
Advice	talk,ban,continue,community,apply,related,world,result
Illegal products	passport,xanax,banknote,counterfeit,duplicate,diploma,fake,ielts
DNM discussion	buy,drug,price,quality,weed,mdma,pill,risk

Table A.3: Topics for 2017, 2018, 2019

Topic 2016	Terms
Bitcoin	tor,vendor,know,bitcoin,address,tail,review,consider,transfer,spend,run,log,end,catch
Topic 2017	Terms
Bitcoin	use,tor,bitcoin,address,noob,tail,access,public,user,vpn,pgp,cash
Monero	search,monero,password,spam,home,idea,prepaid,success,sort,project
Topic 2018	Terms
Bitcoin	use,order,vendor,buy,dark,bitcoin,address,send,account,market,product,noob
Monero	fee,monero,prove,bulk,atm,claim,step,rule,mention,ensure,platform
Topic 2019	Terms
Bitcoin	use,vendor,order,send,market,drug,buy,bitcoin,address,dark
Monero	tail,pgp,key,monero,log,electrum,save,file,encryption,proof

Table A.4: Bitcoin and Monero topics in comments datasets for 2016, 2017, 2018, 2019

Appendix B. Appendix

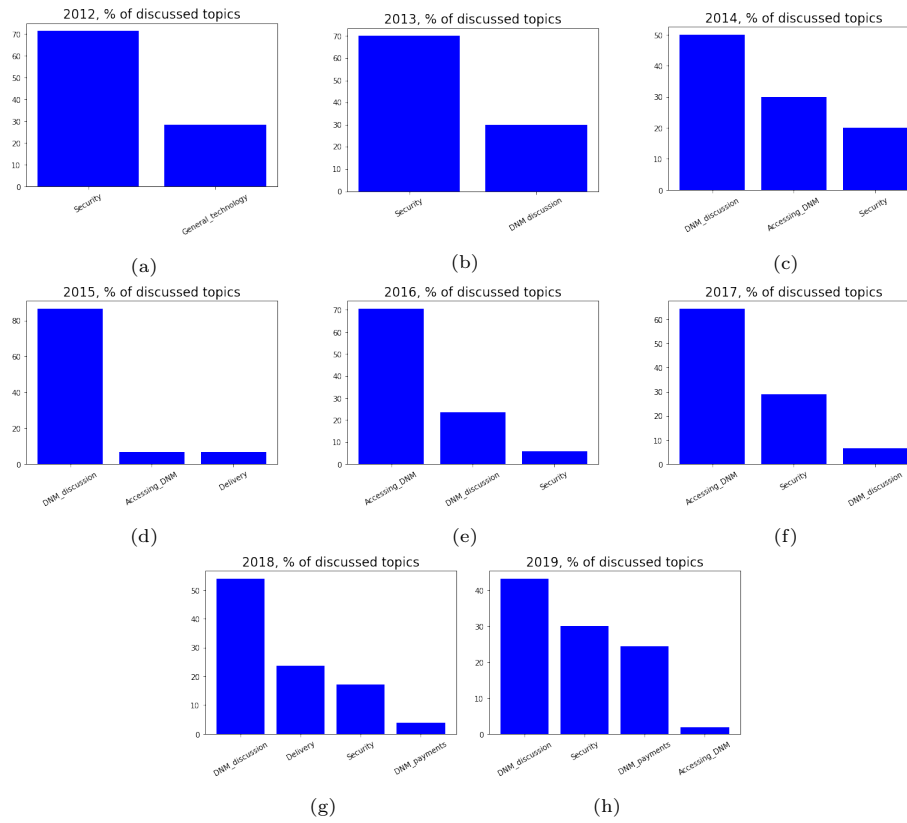


Figure B.5: New users posts topics evolution