

Institution: City, University of London		
Unit of Assessment: UoA 10 Mathematics		
Title of case study: Mapping the ecosystem of dark web marketplaces to help combat illicit online trade		
Period when the underpinning research was undertaken: 2017 - ongoing.		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s): Dr Andrea Baronchelli Dr Abeer ElBahrawy	Role(s) (e.g. job title): Reader in Mathematics PhD researcher	Period(s) employed by submitting HEI: 2013 – present 2016 – 2019
Period when the claimed impact occurred: 2018 - ongoing		
Is this case study continued from a case study submitted in 2014? N		
1. Summary of the impact City, University of London and Chainalysis Inc., the blockchain analysis company which provides data, software and services, have partnered since 2017. Part of this collaboration was Dr Baronchelli's research on dark web marketplaces. The findings impacted Chainalysis methodologies and were embedded in the company's products. [text removed for publication]		
2. Underpinning research Dr Baronchelli's expertise is in understanding and modelling emerging global properties of large socio-technical systems. His research relies on mathematical and multi-agent modelling, big data analysis and experiments with human subjects. Dr Baronchelli's research focuses on two main subjects. In network science, specifically analysis and modelling of temporally evolving networks Baronchelli's research tackled issues such as the complexity of social networks and presented empirical analysis in which such structures are described as temporal multiplex networks, i.e., networks whose edges (1) belong to different layers (representing different kinds of interactions) and (2) have an intrinsic dynamic of creation and annihilation [3.1]. This naturally led to the development of the second, more recent, subject, which focuses on the analysis of blockchain transactions networks and the cryptocurrency ecosystem. The latter includes analysis of long-term and short-term properties of the cryptocurrency market [3.2] [3.3] and the impact of information production and consumption on cryptocurrency prices. [3.4] Given the strength of Dr Baronchelli's research and his continuing engagement with the sector, he and his co-researchers, which included Abeer ElBahrawy, decided to investigate the dynamics of dark web marketplaces. The research programme, which was part of the overall partnership between his team and Chainalysis, aimed to understand the reasons for the dark web marketplaces growth in popularity, despite being extremely unreliable and exposing users to significant monetary losses. Understanding the origin of this apparent paradox is crucial as dark markets have become a focus both for police forces and governments (see, e.g., NYT article "Dark Web Drug Sellers Dodge Police Crackdowns", June 11, 2019), and keep expanding (see e.g., Bloomberg article "Darknet Market Had a Record 2020", Feb. 1, 2021) The work investigated the consequences of 24 episodes of sudden market closures (as a result of a scam or a police seizure), identified as critical events for users. The Chainalysis novel dataset of 138 million Bitcoin transactions allowed the team to follow the behaviour of single individuals. Baronchelli et al. analysed the large temporal network of transactions and showed that, when a market closes, users migrate swiftly and the vast majority coordinate predictably on a single alternative marketplace, despite having multiple choices. Thus, while single markets might appear unreliable, the ecosystem of markets is resilient to single point failures and guarantees continuity to the trading activity. [3.5]		

These results clarify the dynamics of dark web marketplaces and represent a crucial first step to design effective strategies to contrast them. Furthermore, b, they reveal a mechanism of systemic resilience [3.5] that has been thus far overlooked but that will be of interest for researchers in a number of disciplines, the private sector (blockchain firms, intelligence firms, etc) and law enforcement agencies.

The methodologies developed as part of this research were also used to further examine Dark web marketplace behaviour during the covid-19 pandemic, in a project led by Dr. Baronchelli and funded by ESRC as part of UK Research and Innovation's rapid response to COVID-19, through grant ES/V00400X/1, by analysing 472,372 listings extracted from 23 DWMs between January 1, 2020 and July 7, 2020 including 788 COVID-19 specific listings that range from protective masks to hydroxychloroquine medicine. (publication in 2021) Additionally, Dr Baronchelli has continued his research on the overall cryptocurrency ecosystem. By studying the collaboration network of 6341 developer on the code of 298 cryptocurrencies stored in GitHub Baronchelli et al. identified a clear link between the collaborative development of cryptocurrencies and their market behaviour. More broadly, they revealed a so-far overlooked systemic dimension for the transparency of code-based ecosystems that will be of interest for researchers, investors, and regulators. [3.6]

3. References to the research (indicative maximum of six references)

- [3.1] Starnini, M; **Baronchelli**, A; Pastor-Satorras, Ro., "*Temporal correlations in social multiplex networks*.", Scientific Reports · June 2016, DOI: 10.1038/s41598-017-07591-0
 - [3.2] ElBahrawy, A., Alessandretti, L., Kandler, A., Pastor-Satorras, R., **Baronchelli**, A. "*Evolutionary dynamics of the cryptocurrency market*." Royal Society Open Science, 4, pp. 170623–170623. (2017) DOI: 10.1098/rsos.170623
 - [3.3] Laura Alessandretti, L., ElBahrawy, A., Luca Maria Aiello, LM., Baronchelli, A. "*Anticipating Cryptocurrency Prices Using Machine Learning*", Complexity, vol. 2018, DOI: 10.1155/2018/8983590
 - [3.4] ElBahrawy, A., Alessandretti, L., Baronchelli, A., "*Wikipedia and Cryptocurrencies: Interplay Between Collective Attention and Market Performance*", Frontiers in Blockchain, Vol.2, 2019, DOI:10.3389/fbloc.2019.00012
 - [3.5] ElBahrawy, A., Alessandretti, L., Rusnac, L., Goldsmith, D., Teytelboym, A., **Baronchelli**, A., "*Collective Dynamics of Dark Web Marketplaces*", (2019) Scientific Reports 10(1) DOI: 10.1038/s41598-020-74416-y
 - [3.6] Lucchini L, Alessandretti L, Lepri B, Gallo A, **Baronchelli** A., "*From code to market: Network of developers and correlated returns of cryptocurrencies*" Science Advances 6(51) 16 Dec 2020, DOI: 10.1126/sciadv.abd2204
- Research was published in open access, scientific journals that apply a stringent peer-review process prior to accepting articles for publication, such as 'Royal Society Open Science' (IF 2.5, corresponding paper [3.2] collected 33k accesses and 156 citations (Google Scholar), so far), 'Science Advances' (IF 13.1), and Nature 'Scientific Report' (IF 4.0) Part of the research was supported by the Economic and Social Research Council [grant number ES/V00400X/1]. 'COVID-19: Monitoring the effects of the pandemic on illicit online trade', May 20 - Nov 21, PI: Andrea Baronchelli, £218,250

4. Details of the impact

The impact of Dr Baronchelli's research encompasses contribution to innovation, financial benefits for the partner company and indirect impact for the product users.

Translating research to Impact: Building on an initial partnership between Chainalysis and City, University of London, Abeer ElBahrawy, then a PhD researcher, interned at Chainalysis during the summer of 2018. The project was to investigate, with Dr Baronchelli's guidance and supervision, if and how users of darknet markets move between markets when a market closes, by analysing the blockchain transactions involving darknet markets. This project raised a significant challenge: how to identify and track the activity of users

across different markets - that is to say, how to identify the set of transactions that connect darknet markets. [text removed for publication] [5.1]. Utilising the knowledge and insights garnered the company proceed to invest internally and eventually developed techniques that were incorporated in their flagship products Chainalysis KYT & Chainalysis Reactor [5.1][text removed for publication] [5.2]

Impact achieved by project partners: [text removed for publication] [5.1] their revenue growth earned the company a place in the 2019 Forbes Next Billion Dollar Start-up List [5.3] and on the Forbes Fintech 50 2020 [5.4] [text removed for publication] [5.5].

Achievements and benefits for the users: As discussed Chainalysis currently has a client list of 250 organisations in 40 countries across the globe. These include government agencies, exchanges, and financial institutions in the US, UK, etc. Its biggest customers include the US federal government, Barclays and Bittrex among other, all of whom have experienced increased benefits, such as better real-time anti-money laundering (AML) compliance, through the use of Chainalysis updated products.

Specific examples of impact achieved through the Chainalysis tools are quite numerous. [text removed for publication]

Chainalysis is also achieving market impact via collaborations and partnerships such as with Tether in February 2020. Tether is the preeminent stablecoin with the biggest market capitalization, surpassing that of all rival offerings combined. Created in October 2014, Tether has grown to become the most traded cryptocurrency. The collaboration means that the Tether platform can monitor the stablecoin's usage across its blockchain, enabling the real-time tracking of suspicious transactions through integration with Chainalysis KYT via API. This translates to real time risk management on one of the largest digital currency platforms globally, an unquantifiable benefit to users and regulators equally, as well as for the platform itself: "As one of the largest cryptocurrencies by market capitalization, we have a responsibility not just to regulators but also to the cryptocurrency ecosystem to have transparent, automated compliance solutions in place to handle any amount of volume at any given time. This solution allows us to ensure a secure compliance program that fosters trust with regulators, law enforcement agencies and users. This is achieved without sharing our user's identifying information, as such data is only kept on our servers." Chief Technology Officer, Tether. [5.8]

Shaping understanding in the Industry: Dr Baronchelli's research is also having impact in shaping the understanding and perceptions on cryptocurrency and market behaviour. Through his research [3.4] and by leading the discussion through a number of activities and platforms Dr Baronchelli has managed to influence key leaders in the sector. Via the research themes "Economic data science" and "Token economy" that he leads at The Alan Turing Institute, he managed to bring together researchers and industrial partners interested in understanding the socio-economic implications of the token economy and make sense of what is happening in the cryptocurrency ecosystem. This translated in increased overall understanding and impacted on the industry's approach when dealing with the evolution of the cryptocurrency landscape. Industry pioneers such as Coinrule, have "*experienced positive benefits thanks to the research, as well as new partnerships by supporting programmes such as the Token Economy*". [5.9]

The research, being the first of its kind to look at the dark market ecosystems, has helped key industry players in expand their understanding of the dark web. The data and conclusions that the research has generated, have informed industry reports. The Chainalysis "The State of 2020 Crypto Crime" Report serves as an example, since it relies heavily on the underpinning research, especially the "Darknet Markets" chapters. This indicates clear impact on the way blockchain analysis companies understand the dynamics of the dark web and how they subsequently react. [5.10]

5. Sources to corroborate the impact (indicative maximum of 10 references)

[5.1] [text removed for publication]

[5.2] [text removed for publication]

- [5.3] Forbes - Cryptocurrency Crimefighter Chainalysis Becomes First Blockchain Company to Make Next Billion-Dollar Start-ups List (2019-07-16)
- [5.4] Forbes Fintech 50 2020
- [5.5] [text removed for publication]
- [5.6] [text removed for publication]
- [5.7] [text removed for publication]
- [5.8] Chainalysis Provides Anti-Money Laundering Compliance Solution for Tether (Feb 12, 2020, 04:00 ET)
- [5.9] Letter of Support – Chief Executive Officer, Coinrule
- [5.10] Report: “The State of 2020 Crypto Crime: Everything you need to know about darknet markets, exchange hacks, money laundering and more” (January 2020)