Analysis of Darknet Market Activity as a Country-Specific, Socio-Economic and Technological Phenomenon

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***Abstract*—The technological peculiarities of the Darknet as well as the availability of illicit items on the embedded marketplaces have raised heated debates in the media and keen interest by law enforcement and academics. In prior work, researchers have already investigated the infrastructure of Darknet platforms and the global distribution of Darknet market activity.**

In our work, we take a broader perspective by studying the Darknet as a regional, socio-economic and technological phenomenon. Our starting assumption is that there exist cross-country indicators that are related to Darknet market activity. We identify relevant indicators, and discuss their relationship to cybercrime from a theoretical perspective. We apply regression modelling and conduct a qualitative comparative analysis (QCA) to study the impact of the identified indicators on the number of items offered on the Darknet. We find that GDP per capita, the number of Bitcoin downloads per capita, the number of Tor relay users per capita and an education index correlate with market activity on Darknet platforms.

***Index Terms*—Darknet, cybercrime, regression analysis, QCA, cross-country factors, socio-economic factors, technology**

I. Introduction

The term Darknet refers to encrypted communication networks that allow anonymous participation inside the Internet [1]. Within the Darknet, users can access Darknet markets, which act as digital trade platforms. The vast majority of these markets are accessible via Tor (The Onion Router) [2]. Tor allows the user to browse the Internet anonymously, and can be used by everyone that desires privacy, such as journalists, whistleblowers, but also criminals. Additionally, Tor allows users to host Darknet market websites whose locations are hidden, so called hidden services [3]. Next to legal items, Darknet platforms have been shown to offer access to drugs, pornography, weapons, terrorist communities, and human trafficking [4]. According to the Tor Project, two million users access the Internet daily using Tor [5]. However, hidden service traffic is estimated to be only about 3.4% of the total Tor traffic [6]. Although these estimates are modest, they are non-trivial [7].

The Council of Europe together with the United Nations Office on Drugs and Crime tries to counter the increasing number of cyber incidents, and takes action by implementing cross-country law enforcement programs. One of the most acknowledged acts is the Convention on Cybercrime [8]. Cybercrime, as described in the convention, refers to technology-enabled activities. These activities are divided into four groups: 1) Offences against the confidentiality, integrity and availability of computer data and systems; 2) Computer-related offences; 3) Content-related offences (e.g., pornography); and 4) Offences related to infringements of copyright and related rights. Those four groups of activities can also be found on or can be enabled by Darknet platforms.

According to the United Nations, cybercrime takes a form of a transnational crime, which may have its source in different regions and can affect different societies [9]. Further, the core concept of cybercrime stems from traditional crime. Nonetheless, new forms of crime have emerged, such as those related to the Internet [10]. However, since the concept of crime and its cyber-version are not radically different [11], for the purpose of this work, we also draw on research on the crime-sociology relationship and apply those works to cybercrime analogously.

The problem of cybercrime is closely tied to the advent of new and popular communication technologies. Hence, there are several studies focusing on the technological background of cybercrime, in particular, on Darknet platforms [12], [13]. The platform of the greatest interest was the Silk Road, which was extensively researched with respect to sales and transaction volumes [14]. Other studies investigated the usage of cryptocurrencies and its complementary effects on Darknet platforms [15], [16]. A further stream of research focused on explaining trading processes and the distribution of vendors [17]. The bulk of these studies focus on the Darknet being a platform for illegal drugs and pharmaceutical products.

However, research should not solely focus on processes and technologies behind the Darknet, since there is also an offline perspective affecting individuals, who are using Darknet marketplaces or are indirectly influenced by them [18]. This offline perspective includes the environment of cyber-criminals and their motivation to commit cybercrime using Darknet platforms. The environment is related to economic and social triggers, which need to be understood and analyzed to, for example, effectively prepare anti-crime procedures [19]. To put it differently, crime is an integral part of society [20], therefore, cybercrime must not only be understood in the cyberspace, but

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the incentives need to be considered on a social, economic, and regional level. In fact, research has called for understanding the adoption of Darknet markets taking into account socio-economic factors [17].

Our study is focused on this research need. Using an exploratory research approach we seek to evaluate the socio-economic elements influencing cyber-criminals as well as the technology enablers to explain Darknet market activity (as measured by sales offers) across countries. To the best of our knowledge, it is the first study to investigate these effects, focusing not only on drugs, but on all available items on the Darknet that can be associated with a shipping country. We analyze cross-country social factors that influence cybercrime behavior, but we limit our study to activities and offerings on the Darknet. We expect that there are groups of countries with a similar Darknet market activity having comparable socio-economic and technology conditions. Hence, we set the following research question:

RQ: *What regional, socio-economic, or technological factors are related to Darknet market activity across countries?*

Our paper is structured as follows. In Section II, we will provide an overview of related work for three dimensions of crime research: regional, socio-economic, and technological. We will further provide a theoretical background guiding our variable choice. Sections III and IV will give an overview of our data collection process and quantitative approach. In Sections V and VI, we will discuss our results and provide implications. In Section VII, we will offer concluding remarks and present future research possibilities.

II. Related Work

Crime remains "a social and economic phenomenon and is as old as the human society" [11]. In fact, there is a stream in the literature that has demonstrated the existence of a natural crime rate [21], [22]. In other words, crime could be controlled by introducing new forms of security measures or law enforcement, but the resulting crime decay would be visible only in the short run. In the long run, crime returns to its natural level [23], [24]. This crime equilibrium is also visible on the Darknet. In 2017, three of the largest Darknet markets: AlphaBay, Hansa and RAMP were closed by law enforcement agencies [25]. However, this stopped the criminals and the associated trade activities only temporarily, until they migrated to other markets or platforms [25]. However, there must be certain circumstances that regulate the natural crime rate across regions.

Therefore, taking into account achievements of current research, we consider the problem of cybercrime with respect to Darknet market activity and aim to investigate influencing factors. These include the geography, the social and economic conditions of the place of occurrence, and the enabling technologies.

A. Regional dimension

Neither is the distribution of crime uniform across countries, nor are other factors such as economic inequality [26]. Likewise, cybercrime has its source in specific regions in the world and affects victims located in specific locations. In our context, it has already been shown that Darknet trade is geographically distributed [17]. Given that Darknet-related crime is concentrated in several areas around the world [17], we assume that crime-affected regions may hold similar characteristics.

Urbanization Rate and Differences across Countries. Likewise, on a cross-country level, there are differences in the likelihood to commit crime, and also cybercrime. For instance, it has been recorded that Eastern European countries, such as Russia, have a high level of cybercrime [27], [28]. Regional differences may be driven by the rate of urbanization [26], [29]. Given a large number of different cultures and communities as well as economic inequalities within urban societies [30], urban areas are considered to be enhancing crime rates [31].

Corruption. Crime is directly related to the criminal. However, each individual's activity comes from a place of occurrence, i.e., the place where an individual is located [18]. Although the motivation of all criminals across the world may be comparable, in particular those individuals, who are given the opportunity by a country to commit a series of crimes, will be successful [26]. Opportunity, in this context, means that some countries are unable to track cybercrime activities or to provide an appropriate level of cyber security. Hence, criminals are empowered by a low law enforcement level. One factor that indicates countries' low level of law enforcement is corruption. Generally, corruption is associated with the inability to act upon crime. Therefore, corruption may encourage cybercrime activities [18].

B. Socio-economic dimension

The United Nations Office on Drugs and Crime argued that economic factors may influence the evolution of crime trends [32]. Although criminal behavior may be influenced by personal characteristics, criminals are likely also responsive to environmental factors. For instance, there are people who are influenced by society to excel in their studies and to build a successful career. In the same way, there are people, who are pushed to crime by being exposed to a set of economic and social conditions [18]. According to research, crime is to a certain extent an integrated part of a social situation [18], [20]. Therefore, it is crucial to understand how crime and society are interrelated.

GDP and Unemployment. Social and economic inequality as well as social stratification may lead to frustration and exclusion at the lower strata of society. It may further encourage people from lower socio-economic groups to find additional revenue sources or to search for more affordable goods and services. For instance, low-income individuals may be more willing to infringe on copyright, e.g., by not purchasing legal software or content [33]. Hence, they are more likely to seek alternative offers, such as those placed on Darknet platforms.

In contrast, it is assumed that a high GDP indicates an increased general well-being of all participants in the economy. Nonetheless, researchers found that a high GDP per capita and high unemployment play an important role in cybercrime [27], partly as a result of higher economic inequality.

Education. Studies have shown that education effectively reduces income inequality [34]. Furthermore, earnings increase with a worker's degree of education. It has also been shown that schooling significantly reduces criminal activity [35]. Hence, a low education rate, i.e., fewer years of schooling, may increase the probability of individuals engaging in crime. However, a certain level of technology-related education may be required to engage in cybercriminal activities [36].

Money Laundering, Given that criminals typically have economic or financial motives and earn money through their illegal activities, they have to inject their obtained assets into the legal economy through money laundering [37]. While money laundering is a crime by itself, it is also directly related to Darknet sales, i.e., money received from sales has to be laundered [38].

C. Technological dimension

With the advent of new technologies, many forms of cybercrime have emerged. Technologies have led to an efficiency increase of benign everyday activities, but have also contributed to the growth of crime efficiency [39]. Given that cybercrime can be defined as crime enabled by a technology, there is no doubt that cybercrime and technologies co-evolve [40]. For example, technologies that enable criminals to stay anonymous on the Internet, such as Tor, may make cybercrime more attractive than traditional crime, where it is more difficult to hide one's identity.

Tor and Cryptocurrencies. Criminals that act on the Darknet rely on Tor to access Darknet markets. Tor allows users to browse the web and host websites anonymously via hidden services. According to the Tor Project, two million users access the Internet daily using Tor [5], and hidden service traffic is estimated to be about 3.4% of the total Tor traffic [6]. Additionally, cybercriminals often use cryptocurrencies to process their payments. Bitcoin has long been the only means of payment on many Darknet platforms. Studies showed that 46% of Bitcoin transactions were related to illegal activities [41] and that historical transactions can be related to previous Darknet market sales [2].

Patents. The overall technological advancement of a country, which can be measured in the number of patent applications, shows the extent to which people are familiar with the usage of current technologies [42]. Generally, better educated individuals tend to have a superior technology understanding. Likewise, the technological advancement of a country is an indicator, how well-versed citizens are in Internet usage. In fact, unemployed individuals skilled in computer science are argued to be more likely to engage in online crime, given their technical know-how and the poor economic environment [27].

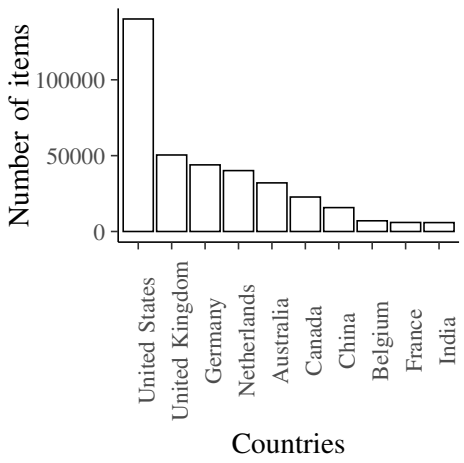

Fig. 1. Distribution of the number of offered items for the top 10 countries

III. Data

Darknet Data: We retrieved Darknet data from the Internet Archive [43], a freely accessible non-profit library, which had an archive of scraped data from Darknet marketplaces collected by the researcher Gwen Branwen. The collection further included data gathered by other researchers. Thus, the entire dataset consisted of 89 Darknet markets and 37+ related forums [44]. The dataset contained mainly HTML and PHP files, image data, CSV files, and different configuration files. For the purpose of our study, we removed the forum data. Furthermore, we focused only on data that held information about product offers on the Darknet.

We extracted data consisting of item names, vendor names and the shipping-from countries. Given that this information was not available for all marketplaces, we ended up with a dataset consisting of 38 markets[1]. The market data had different timestamps from 2013 until 2015, given the different running times of those marketplaces. Since some vendors offered items on multiple markets, we deleted all duplicate appearances of the same item offer, i.e., items that had the same name and same vendor name. Thus, we retrieved 402.093 item offerings (see Figure 1). This dataset comes with certain limitations. Although, we deleted duplicates of the exact same offer, we did not remove postings of the same products, e.g., different doses of the same drug provided by the same vendor. Furthermore, the general quality of the information provided on Darknet platforms remains questionable. Vendors may provide false information, both for their items as well as their shipment location. Similarly, vendors may use different names or identities. Therefore, seemingly disparate item offerings may refer to the same item [45].

[1]1776, Abraxas, Absolem, Agora, Alpaca, AlphaBay, Amazon Dark, Andromeda, Atlantis, Cloud9, Deepzon, Dodge Road, Dream Market, Drugslist, East India Company, Evolution, FreeBay, Free Market, Hansa, Hydra, Kiss, Middle Earth, Nucleus, Outlaw Market, Oxygen, Panacea, Pandora, Pigeon, Sheep, Silkkitie, Silk Road, The Onion Market, The Pirate Market, Tochka, TorEscrow, TorMarket, Utopia, White Rabbit

TABLE I
SOURCES AND DESCRIPTION FOR ADDITIONAL DATA USED IN THE STUDY

List of data sources		
Variable	**Description**	**Reference**
Population	List of countries with respective total population by country	[46]
Corruption index	Perceived levels of public sector corruption in 180 countries and territories. Drawing on 13 surveys of business people and expert assessments, the index scores on a scale of zero (highly corrupt) to 100 (very clean)	[47]
AML	Compliance with the Anti-Money Laundering and Countering Terrorism Financing International Standard (AML)	[48]
Gini index	Economic inequality, i.e., the distribution of income across income percentiles in a population	[49], [50]
Urbanization rate	Percentage of population living in urban areas	[51]
Education index	Mean years of schooling and expected years of schooling	[52]
GDP	Gross domestic product per capita	[53]
Unemployment rate	Rate of unemployment	[54]
Number of patents	Number of patent grants for direct applications	[55]
Number of Tor relay users	Number of Tor relay users	[56]
Number of Tor bridge users	Number of Tor bridge users	[57]
Number of Bitcoin downloads	Number of Bitcoin downloads	[58]
Number of bitnodes	Number of bitnodes	[59]

Other Data: In order to explain the number of items per country, we collected the latest data available for factors discussed in Section II. This additional data was publicly available on the Internet and was mapped to 159 countries: population [46], corruption perception index [47], compliance with the Anti-Money Laundering and Countering Terrorism Financing International Standard (AML) [48], economic inequality (Gini) index [49], [50], percentage of population living in urban areas (urbanization) [51], education index [52], GDP [53], unemployment percentage [54], number of patent grants for direct applications [55], number of relay Tor users [56], number of bridge Tor users [57], number of Bitcoin downloads [58], and number of Bitnodes [59]. After removing entries with missing values from the dataset, we ended up with 95 observations. A description of these variables is available in Table I.

IV. ANALYSIS

In order to investigate the relationship between Darknet offers and the different country-specific factors, we applied the following methods of analysis.

Regression Analysis (using *R* [60]): Regression analysis aimed to explore if there are regional, socio-economic or technological factors, which are related to Darknet offerings. We performed two regression techniques independently. Thus, we first applied *multivariate regression* to determine the existence of a relationship between certain factors and Darknet offerings. Rather than quantifying the exact effect that each factor has on Darknet offerings, we observed the significance of the factors. Second, we applied a *regression tree analysis* to test the results from the former one and to note the similarities. Ultimately, we aimed to find the most important variables related to Darknet offerings with the regression analyses.

Qualitative Comparative Analysis (using *fsQCA* [61]): In addition to the regression analysis, we performed a qualitative comparative analysis (QCA) to support our findings from the regression analysis. By applying a different analysis technique, we aimed to test if the same variables show a similar significant correlation. QCA is a method that indicates whether a variable is a minor or major contributor in a given set of combinations of variables that are jointly related to the outcome [62]. Therefore, we aimed at obtaining a set of factors that relate to a high number of items on Darknet markets.

Given that our dataset included 95 countries (159 exist in total), we assumed it to be a representative dataset to derive global implications. Nevertheless, applying independent methods would strengthen our results and make the outcome more robust. As a data pre-processing step, to enable a fair comparison between countries, we divided all count variables by the population. This way, we could perform a per capita analysis.

A. Regression Analysis

1) Multivariate Regression: The regression analysis had the goal to fit a model that would explain the response variable, i.e., number of items on the Darknet per capita, by the other variables in the dataset. Given the non-linear relationship between the response and the predictor variables, an option to restore linearity was to log-transform the response and to use a multivariate regression model. We tested the null hypothesis (1) that there is no predictor variable influencing the number of Darknet items, against our exploratory hypothesis (2) that there is at least one variable influencing our response. We performed the testing with a significance level of 0.05 (the b_i's are the corresponding coefficients of the 12 predictors):

$$H_0 : b_i = 0 \tag{1}$$

$$H_1 : \text{at least one } b_i \neq 0 \quad (2)$$

We used the R built-in function lm to build the model. The fitted multivariate regression model followed the linearity assumption; the residuals are equally scattered around zero and show no pattern, the sample quantities lie on a straight line, and the influence plot and Cook's distance plot show no over-dominant observation. After fitting the model with all predictors, we used the AIC step-wise selection criterion in both directions to find the subset including the best predictor variables.

The final model summary is shown in Table II, indicating the predictors' significance. To test our hypotheses, we used a simple F-test. Given that $F_0 = 45.16 \geq F_{5,89} = 2.32$, we rejected the null hypothesis H_0. The adjusted R-squared (0.7) shows a fair linear effect on the log-transformed response.

2) Regression Tree: In order to evaluate the results from the multivariate model, we used an additional regression method called regression trees. This method partitions the dataset into smaller groups and fits a simple model to each sub-group. We used the same dataset as before, but this time performing no log-transformation of the response, because regression trees do not rely on any assumptions about the data. First, we split our dataset into training (85%) and testing (15%), and then used grid search to find the max depth of the tree as well as the min observation split. To build the tree, we used the R $rpart$ package. Second, we performed bagging, i.e., combining and averaging multiple models, to reduce variance. Thus, we were able to assess the predictors' importance on the response across bagged trees. The root mean squared error (RMSE) on the testing data was 0.0003122384, which is reasonably small. Table III shows all predictor variables and their importance on a scale from 0 (low) to 100 (high).

B. QCA

To extend our results from the regression analysis, we conducted a qualitative comparative analysis (QCA). We performed the QCA according to the methodology provided in the literature [61], [63]. The results of QCA should indicate a set of combinations (i.e., sets of country-specific characteristics), which are jointly related with a high number of item offers on Darknet platforms. Given the regression results, we assumed that the number of Bitcoin downloads per capita, the number of Tor relay users, GDP per capita, and the education index are related to a high number of items per capita sold on the Darknet. Furthermore, we included corruption and AML as explanatory variables in our analysis, given their conflicting significance in the two regression models. Hence, our sample contained 95 cases and we used 6 causal conditions. We assumed the appropriate number of conditions in the model [64], and obtained a dataset with a satisfactory variability across sample countries [61].

Each country represented an individual set of characteristics, which resulted from specific explanatory variables. After specifying our research model, we conducted a calibration process. For each of the aforementioned variables, we used a median to specify a middle threshold of outcome and causal conditions. For upper and lower thresholds, we used a percentile at the point of 0.75 and 0.25, respectively. Additionally, we performed a truth table analysis. The truth table presented a list of all combinations of explanatory variables for a given dataset. The truth table showed that cases were distributed among several possible combinations, which indicated that no more conditions had to be added to the model [63]. We eliminated configurations by setting frequency and consistency thresholds. After optimizing the configurations with respect to the sample size, we set the minimum frequency threshold to 1 and the minimum consistency threshold to 0.80.

V. Results

A. Regression Results

The regression analysis using the multivariate model with a log-transformed response, suggested a positive relationship between the number of items per capita on Darknet markets and the following variables: number of Bitcoin downloads per capita, education index, AML, number of Tor relay users per capita, and GDP per capita. Therefore, our results show that there may be socio-economic and technological factors influencing Darknet market activity. Given that our model is an ordinary least squares regression including only continuous data, we interpret the regression coefficient of a predictor variable as the expected change in log of the response with respect to a one-unit increase in the predictor, holding all other variables fixed. The most significant predictor was the number of Bitcoin downloads per capita variable (having the smallest p-value). Thus, a one-unit increase in the number of Bitcoin downloads per capita increases the log of the number of items per capita by $4.079e+02$. The relationship between the coefficients of the other predictors and the response variable can be interpreted accordingly (Table II).

The analysis using regression trees suggested that all variables except AML influence to some extent the number of items per capita on Darknet markets (see Table III). However, the most influential variable was by far GDP per capita, having the maximum importance. Other important variables were: corruption index, number of bitnodes per capita, number of Bitcoin downloads per capita, education index and Tor relay users per capita. Given that we applied bagging to the regression trees, which combines multiple trees into a single procedure to reduce variance and improve accuracy, the statistical interpretation of this method was poor. Therefore, the resulting tree and the split could not be shown. Nevertheless, given the nature of our exploratory study, having a rank of the predictors with a small RMSE was sufficient. Although, the two regression methods did not produce the exact same results, they did have a few similarities. Both methods indicated that GDP per capita, the education index, Bitcoin downloads, and Tor relay users seem to have a significant effect on Darknet market activity.

TABLE II
SUMMARY OF THE MULTIVARIATE REGRESSION MODEL WITH THE LOG-TRANSFORMED RESPONSE VARIABLE

	Estimate	Std. Error	t-value	Pr($<\|t\|$)
(Intercept)	-1.782e+01	9.692e-01	-18.383	$<$ 2e-16***
AML	5.179e-02	2.575e-02	2.011	0.04732**
Education index	4.011e+00	1.762e+00	2.277	0.02521**
GDP (per capita)	2.046e-05	1.125e-05	1.819	0.07232*
Number of Bitcoin downloads (per capita)	4.079e+02	1.227e+02	3.323	0.00129***
Number of Tor relay users (per capita)	2.805e-01	1.399e-01	2.004	0.04807**
Observations	95			
R^2	0.717			
Adjusted R^2	0.701			
Residual Std. Error	1.591 (df = 89)			
F-Statistic	45.162*** (df = 5; 89)			
Note:	*p<0.1; **p<0.05; ***p<0.01			

TABLE III
VARIABLE IMPORTANCE OF BAGGED REGRESSION TREE MODEL

GDP (per capita)	100.000
Corruption index	89.572
Number of bitnodes (per capita)	75.115
Number of Bitcoin downloads (per capita)	73.086
Education index	51.953
Number of Tor relay users (per capita)	51.075
Number of Tor bridge users (per capita)	19.205
Gini index	8.684
Number of patents (per capita)	6.146
Urbanization rate	5.339
Unemployment rate	2.222
AML	0.000

B. QCA Results

Standard analysis with the QCA method showed two configurations of results. The intermediate solution indicated three different factors' configurations which explain 75% of the cases that led 88% of the time to a high number of items. Based on the set consistency threshold (0.80), the model expressed results distributed among 22 combinations. In the end, the model enables us to explain 75% of the cases with 3 different combinations:

1) Number of Bitcoin downloads per capita * Number of Tor relay users per capita * ∼Corruption index * ∼AML
2) Number of Bitcoin downloads per capita * Number of Tor relay users per capita * ∼Corruption index * Education index
3) Number of Bitcoin downloads per capita * Number of Tor relay users per capita * GDP per capita * Education index

The notation used above corresponds with standard mathematical convention. The star "*" indicates Boolean multiplication and the operator "∼" indicates negation (meaning an absence of a condition) [65]. Table IV gives an overview of the QCA results.

The results were compared with the parsimonious solution, as the intermediate solution provided only simple counterfactuals [63]. The parsimonious solution suggested that the number of Bitcoin downloads and Tor relay users should contribute to a high number of items sold on Darknet. It means that both of these factors are more robust, i.e. they are more likely to remain unchanged in case of a model adjustment.

The results of standard analysis indicated several countries that had a major contribution to the set including the per capita variables of number of Bitcoin downloads and number of Tor relay users: Sweden, Lithuania, Finland, Netherlands, Luxembourg, Switzerland, Estonia, Ireland, Latvia, Germany, Austria, Malta, Norway, Bulgaria, Slovenia, United Kingdom, Czech Republic, United States and Denmark. As those countries belong to countries of rather high GDP (higher than the median GDP for the 95 countries in our dataset), this result suggests that highly developed countries are more likely associated with Darknet activity.

VI. DISCUSSION

For our analysis, we merged different Darknet market data sources found on the Internet Archive [43]. The data comprised 38 markets and included 402.093 item offerings. We grouped the offerings per country and further included regional, socio-economic, and technological indicators. We assessed the effect of these indicators on the number of item offerings on the Darknet. We used two different methods of analysis using two different kinds of software. First, we performed a multivariate regression with a log transformation as well as a bagged regression tree analysis using R [60]. Second, we used qualitative comparative analysis using fsQCA [61] to support our results from the former analyses. We summarize our results in Table V.

Literature research shows that both personal characteristics of an individual as well as environmental factors may lead to crime [18]. Nevertheless, we are not accounting for the sensitivity of certain individuals to the environment in our study. Rather, we show that a general social situation is related to crime, as suggested by Canter and Youngs [20]. Our regression analysis shows that there are various factors that influence Darknet market activity. The analysis indicates a relationship between GDP per capita, the education index,

TABLE IV
CONFIGURATIONS FOR HIGH NUMBERS OF ITEMS ON DARKNET PLATFORMS; SOURCE: OWN REPRESENTATION BY ADAPTING CONFIGURATION CHART USED BY FISS [62]

	Solution 1	Solution 2	Solution 3
Number of Tor relay users (per capita)	◯	◯	◯
Number of Bitcoin downloads (per capita)	◯	◯	◯
AML	⊗		
Corruption index	⊗	⊗	
GDP (per capita)			○
Education index		○	○
Consistency	0.82	0.81	0.90
Raw Coverage	0.14	0.18	0.69
Unique Coverage	0.02	0.00	0.55
Overall Solution Consistency	0.88		
Overall Solution Coverage	0.75		

Note: White circle - presence of a condition. Circle with "x" - absence of a condition. Large white circle - core conditions. Small white circle - peripheral conditions.

TABLE V
SUMMARY OF RESULTS

	Multivariate Regression	Regression Tree	QCA
Number of Tor relay users (per capita)	significant	significant	significant
Number of Bitcoin downloads (per capita)	significant	significant	significant
GDP (per capita)	significant	significant	
Education index	significant	significant	

and the number of Bitcoin downloads and Tor relay users with the number of items on the Darknet (per shipping country).

A. Socio-economic dimension

Darknet market activity is higher in countries that have a high GDP per capita. It might indicate that developed countries are associated with more sophisticated types of crime. As a consequence, wealthy nations are more likely to get involved or be exposed to Darknet activities. A study showed that Darknet drug vendors are primarily located in a small number of consumer countries. Therefore, given that GDP shows the level of spending and general consumption of a nation, it could be argued that countries with a high GDP are attractive for Darknet vendors due to highly active marketplaces and a high demand for goods and services available online. Hence, GDP and cybercrime are related [27]. Although research shows that schooling significantly reduces criminal activity [35], we found that the education index is positively related to the number of items sold on Darknet markets. The QCA results suggest a certain interaction between the technological variables and education. Our findings imply that better educated individuals usually have a better understanding of technologies in general, hence, might be more familiar with Darknet-enabling tools. Our results do not show any significance when it comes to the relationship between economic inequality and unemployment with Darknet market activity. Although the AML variable shows importance in the linear regression model, this could neither be confirmed by the regression tree nor by the QCA. Thus, the relationship of a country's compliance with the AML/CFT International Standard and Darknet market activity remains questionable and a subject for future research.

B. Technological dimension

Our results imply that cybercrime and certain technologies might co-evolve [40]. Although the number of patent grants, used as a variable for a general technological development of a country, does not hold a high significance in our study, there are technologies that are particularly important for Darknet activities. The indicator of Bitcoin downloads is significant in both of our analysis methods. With the advent of Bitcoin technology and the growing popularity and adoption of cryptocurrencies, cyber-criminals obtained tools, which eased their payment transactions and enabled them to trade anonymously on the Darknet. Furthermore, QCA results show that a combination of Bitcoin downloads and Tor relay users jointly lead to a high number of items sold on the Darknet. Tor usage is strongly associated with Darknet activity. Although many services and products offered on the Darknet, the Tor hidden services, are illegal [4], most individuals do not use Tor for illicit purposes. Rather, individuals use Tor to protect their data privacy from government censorship and surveillance systems [66]. Therefore, both technologies do not always coexist, but in case they do, they are associated with a high number of items sold on the Darknet. Additionally, research suggests a strong relationship between GDP per capita and the adoption of the Bitcoin blockchain by country [67]. This indicates a likelihood of an interaction between GDP, general Bitcoin usage and Darknet market activity.

C. Regional dimension

The bagged regression tree shows that the corruption perception index is an important variable in explaining the number of Darknet items. Similarly, the QCA specifies one case of factor combinations, which indicates that low levels of corruption are related to a high response outcome. The corruption perception index shows how corrupt the public sectors of a certain country are, where a low index indicates high corruption and vice versa [47]. The QCA results show the presence of a low corruption perception index, meaning that the activity of vendors on the Darknet is greater in more corrupted countries. This suggests that the presence of corruption relates to online crime and may encourage illegal cyber-activity [18].

The data indicates that the top ten countries account for 90% of all items offered on the Darknet. These top countries include: United States, United Kingdom, Germany, Netherlands, Australia, Canada, China, Belgium, France, and India. These countries were also found to be representative in the Darknet drug trade study by Dittus et al. [17]. Furthermore, 4 countries out of the 10 top countries (United States, United Kingdom, Germany and Netherlands) were indicated also in the QCA results. Hence, the appearance of the same group of countries in separate studies suggests that the Darknet trade has a nonuniform geographical distribution [17]. If we consider the common characteristics of these countries, we note that all of them have a high GDP. Moreover, according to the literature, areas with a high urbanization rate correlate with high crime rates [31]. In our analysis, we could not observe a general significant effect of the urbanization rate on Darknet market activity. However, we note that the urbanization rate of the top ten countries is above 75% (except India and China). Furthermore, the corruption perception index for the abovementioned countries is also rather high (except for India and China), which means that most of the top ten countries are less corrupt.

VII. Conclusion

In this study, we aimed to explore the various factors, which might influence Darknet trade. Specifically, we studied what impacts the number of items offered on the Darknet across countries. We based our exploratory quantitative research on the literature that aimed to explain cybercrime as a sociological and economic phenomenon. We further explored regional and technological drivers to explain Darknet market activity. For our analysis, we collected data from 38 Darknet markets from pre-existing datasets, which included data for 159 countries. Finally, we added per-country data for regional, socio-economic, and technological indicators.

To evaluate the influence of country-related variables on the number of items sold on the Darknet, we used two methods: regression analysis and qualitative comparative analysis (QCA). The results showed that there are specific factors that may influence Darknet trade and there are groups of countries that hold similar characteristics with respect to their activity on the Darknet.

Regression analysis implied a relationship between the GDP per capita, the education index, the number of Bitcoin downloads and the number of Tor relay users and the number of items offered on the Darknet per shipping country per capita. The influence of those variables was further explored in the QCA. The latter showed that Bitcoin downloads and Tor relay users were jointly present in the combination of factors that lead to high number of items on the Darknet.

The top ten shipping countries were characterized by a comparatively high GDP. This may imply that these countries represent attractive marketplaces for Darknet vendors due to the higher buying power of their citizens. Furthermore, we found that cybercrime activity on the Darknet co-evolves with certain technologies. Particularly, the relationship between the number of Bitcoin downloads and Tor relay users with Darknet market activity indicates that Darknet vendors and users have high capabilities with respect to novel technologies.

To the best of our knowledge, this is the first study to research the relationship between regional, socio-economic, and technological factors and Darknet item offers. However, given the limited availability of country-level data, our assumptions cannot provide a full understanding of global Darknet trade. Researchers should channel efforts to find information on more countries that have users on the Darknet. Moreover, having complete datasets for economic indicators across countries would be beneficial for further research. International institutions with dedicated programs against cybercrime as well as national authorities should cooperate to map the supply and demand chain of illegal trade. A profound understanding of individuals' incentives to engage in cybercrime as well as knowledge about the distribution of illegal items on the Darknet can enable a successful battle against the darker corners of the Internet.

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