MASTER

# Differences in cocaine quality sourced from cryptomarkets and traditional drug markets

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# Differences in Cocaine Quality Sourced from Cryptomarkets and Traditional Drug Markets

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***Abstract*—Cryptomarkets tap into the very large and profitable market of illegal drugs, estimated to be in the billions of EUR. Some of the hazards (and societal costs) of illegal drug consumption are derived from the lack of quality control of these substances (adulteration and purity imbalances). This study analyzes the effect of cryptomarkets in the quality of cocaine, comparing worldwide results of analyzed samples sourced from cryptomarkets versus traditional markets. Our findings show that cryptomarkets do not offer a significant higher quality of cocaine with respect to traditional drug markets and we observe a lack of correlation between price per gram and quality. For both cryptomarkets and traditional markets, the geographical factor was the decisive factor in quality of cocaine. We also show the inter and intra-country cocaine trade in cryptomarkets and we analyze and quantify the effect of the harm reduction possibilities enabled by cryptomarkets, showing that making an informed purchase has clear benefits in expected drug quality.**

## I. Introduction

Technological advancements tend to pile up until someone sweeps in and combines them into something greater than the sum of its parts. Phones, cameras, and computers gave us smartphones; anonymous networks, cryptography, and cryptocurrencies, cryptomarkets.

Cryptomarkets enable anonymous trading over the Internet, which makes them a safe haven for illegal goods. The most traded category of products in cryptomarkets is drugs [1]. This opens cryptomarkets to a huge market: the global market of drugs was calculated to be between 426 and 652 billion USD in 2014 [2]. In the EU, the market of illegal drugs was calculated to be around 30 billion EUR in 2017 [3].

In the illegal drug market, the most sought out drug is cannabis, both in the EU [3], and in cryptomarkets [1]. However, cannabis is not an illegal drug in The Netherlands and has been legalized in 11 out of 50 states in the US [4]; further, whereas still debated, the adverse health effects of cannabis and other light drugs are relatively small when compared to the oftentimes life-threatening effects of (adulterated) heavy drugs such as cocaine.

Cocaine accounts for the second largest market for illegal drugs in the EU, closely following cannabis. Cocaine covers 31% of the EU drug market and is calculated that 4 million people have consumed cocaine in the last year [3].

A significant threat to cocaine user health is *adulteration*, the process of mixing the drug's active principle with other substances to enhance the drug's effects, and/or increase the revenue for the seller by effectively diminishing the drug amount per sold gram of product [5], [6]. At the same time, there is substantial difficulty in assessing the quality of a purchased drug, as users of drugs have been shown to not being capable of discerning 'high quality' drugs from 'low quality' drugs, even after use [7]. This problem is worsened by the way in which drug cartels work: drug vendors are often only distributors (as opposed to producers) of the product, meaning that it is hard for them too to know the exact composition of the product they distribute to its final users. This greatly complicate the dosage and adulteration issues, whereby additional modifications of the drug from the producer to the consumer are hard to track and assess at any point in the distribution chain. As an effect of this 'quality measurement' problem, drug users often rely on a small circle of trusted vendors they know for the provision of the substance.

The introduction of cryptomarkets for drug distribution further exacerbated this problem, as the limits of the 'circle of trust' in which drug users and vendors operate became fuzzier. Previous studies showed that one of the reasons customers resort to cryptomarkets, instead of traditional street markets, is a perceived higher quality of the product [8], [9]. Similarly, product quality is not only important for users but also for vendors, who claim quality is important to survive and maintain good reviews and a stable business [10]. To address this interest in quality, apart from the reputation systems included in the cryptomarkets and their associated forums, specialized websites started to emerge to provide *harm reduction* services, publishing substance analysis, discussing dosages, and exchanging experiences about vendors and substances. These websites oftentimes make available to drug users real laboratory facilities where they can send samples of the acquired drug; the laboratories perform the analysis (purity and adulterating agents) and publish the results back on the platform. This serves the purpose of both informing the user, as well as providing a history of drug quality measurements from specific cryptomarkets, or vendors operating therein.

Some studies have analyzed quality of drugs sold in cryptomarkets: van der Gouwe et al. [11] compared quality and price of drugs bought online versus offline in The Netherlands between 2013 and 2016 and found that quality was very similar in both markets; Caudevilla et al. [12] analyzed the results of their international drug checking service between 2014 and 2015 and compared cocaine quailty with samples from the traditional market in Spain, finding that samples from cryptomarkets had a higher purity and lower rates of adulteration. The difference in these findings suggests that cryptomarkets and geographical factors play an important role in the quality of drugs.

In this study, we will use data, available through both public and private sources, on cryptomarkets and traditional markets to compare purity and adulteration of cocaine samples across different countries and type of markets. This will allow us to analyze the differences between cryptomarkets and traditional markets when it comes to the illegal drug market, and the factors that cause these differences.

This study addresses the following main research goal: **Identify differences in cocaine quality obtained through cryptomarkets and traditional drug markets**.

To guide this study and to do a comprehensive analysis of these differences, we divide the main goal in three research questions.

First we analyze general differences between cryptomarkets and traditional drug markets and see what is the effect of the market in the quality of the sample:

**RQ1:** *Are there differences between the quality of cocaine samples traded in traditional markets and those available through cryptomarkets?*

Then, as cryptomarkets enable a global market for drugs, we analyze how geographical factors affect the quality of samples and if this effect is different between cryptomarkets and traditional drug markets:

**RQ2:** *Does the quality of cocaine samples depend on its geographical provenance?*

Finally, it is very easy for a user to compare different vendors in cryptomarkets before making a purchase—much like everyone does with any other (legal) purchase—, but the benefits of a informed purchase are not clear in the case of cryptomarkets, we want to analyze and quantify this:

**RQ3:** *How quality of cocaine samples sourced from cryptomarkets vary across vendors?*

This document is structured as follows: Section II provides some background about drug consumption—defines purity and adulteration and describes the most common adulterant and its effects on the health of consumers—, it also introduces harm reduction strategies and drug checking services. Section III presents the relevant literature, Section IV details the methodology followed in this study, including the identification of data sources and the data collection and its preparation. Section V contains the results of the analysis of the data. In Section VI we discuss the analysis of the data and present the implications of our results, as well as the limitations of the study and future work. Section VII concludes the paper with a brief highlight of the findings.

## II. Background

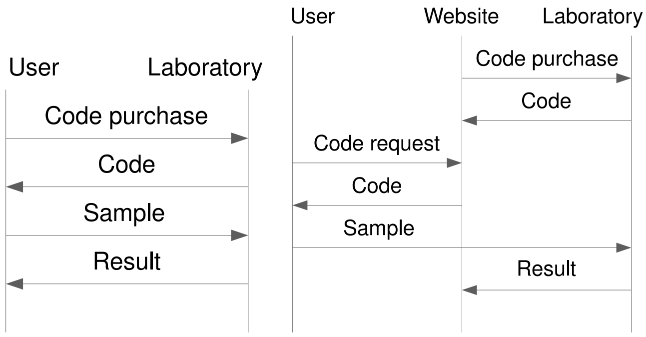
Drug (ab)use is a global public health problem with huge economic and human costs [13]: from law enforcement operations (e.g., the 'War on Drugs'), medical interventions to help people with drug related problems, and violence related to drug crimes.

As putting drug trade and consumption to a halt is not a feasible goal in the short term, much attention has been spent, by voluntary and independent organizations, on *quality control* of the traded substances [14]: the illegal nature of drug trade and consumption favours the adoption of *adulteration* substances that modify the chemical properties of the drug, often with increased adverse effects on the health of the final user [15], [16], [6]. In this study, we will use the definition of adulteration from [12], as: "*the addition of a component not ordinarily part of that substance*". Hence, adulteration occurs when drugs are mixed with other substances, either to enhance or change their effects or just to increase revenue for the seller by being able to generate a greater trade volume per gram of active drug principle. These adulterants can in some cases be more dangerous than the actual drug, as exemplified with the current problem regarding heroin mixed with fentanyl (an opiod 50 times as potent as heroin), that is reportedly causing an increment in overdose-related deaths in the US [6]. The most common adulterant in cocaine is levamisole [17], [18], an antihelminthic (deworming) substance used in veterinary medicine [19], it was also used in humans to treat pediatric nephritic syndrome, rheumatoid arthritis, and as adyuvant in cancer treatment of the colon until it showed a significant toxicity [18], [20]. The main adverse effect of levamisole is agranulocytosis, an acute condition characterized by lowered white blood cell count. People suffering from agranulocytosis are immunodepressed and are at a very high risk of serious infections from things that will usually not cause infections [21]. Adverse effects of levamisole are dose and duration dependent, daily users as well as weekend users with high consumption are the main groups that can suffer these effects [19].

A different but related issue is that of *purity*, which [12] defines as "*the proportion of the active principle present in a sample compared to those of synthesis impurities, residual solvents or diluents*". Purity is therefore generally reported as the percentage of the active principle in the sample. Whereas *adulteration* may induce the absorption of dangerous chemicals through ingestion or inhalation, uncertainty on the purity of a drug may lead to severe dosage problems: as the user's organism adapts to tolerate a certain intake of the active principle per application, a drastic increase in the absorbed amount of the active principle in a single application may lead to severe health issues, and death. For example, a person used to consume a certain dosage of low purity cocaine (say, 1 gram of 40%-purity cocaine) might overdose when consuming the same dosage of high purity cocaine (e.g., 1 gram of 90% purity cocaine). Aggravating this problem, drug users are reported to *not* being able to distinguish a high-purity sample from a low-purity one, even after its use (that being oral, or through inhalation or injection). This issue boils down again to the illegality of the product: as it is not possible to 'certify' the properties of the product to inform its users *before* application (e.g., similarly to how reporting alcohol content is mandated by law on all alcoholic beverages), it is not possible for a drug user to adjust the intake of drug products to always tolerable levels. By comparison, most people would drink a pint of 4.6% Vol. beer, but not a pint of 55% Vol. whiskey.

To address this problem, drug checking services arose at the end of the '90s. These services analyze drug samples anonymously delivered by users who want to know the chemical composition and properties of the drug they purchased; the analyses usually provide composition analysis and purity as well as an explanation of the risks of the adulterants found in the submitted sample. There are currently drug checking services in most countries of the EU [5]. Even though these services cannot be the only weapon to fight drug deaths and harm reduction through public policy, previous studies provide evidence of their usefulness: for example, drug safety testing pilots at two UK festivals in 2016 saw almost one in five users (18%) dispose of their drugs once aware of their content [22].

As a (small) part the global drug market progressively moves to online platforms, one of these laboratories (Energy Control [23]) started providing their service through platforms and forums in the so-called 'darkweb' or 'hidden web'. "DNMA" (acronym for DarkNet Market Avengers) currently is the most prominent and active platform where users can ask for the analysis of samples acquired through hidden web cryptomarkets. In the DNMA forum, the administrators offer 'codes' that any user of the forum could request and send their substances to a laboratory to get them tested; Figure 1 provides an overview of this mechanism.




a: Direct. b: Using DNMA/DNStars.

The administrators of the websites (DNMA and DNStars) purchase codes in bulk from the laboratory. When users request a code, the administrators gives them one, which they will use when sending the sample to the analysis laboratory. The analysis laboratory then sends the result of the analysis to the administrators of the websites who publish them.

Figure 1: Flow diagram of the analysis process.

## III. Related work

The European Monitoring Center for Drugs and Drug Addiction (EMCDDA) [24] publishes a yearly report about the EU Drug Markets. In their 2019 report [3], they emphasize that the drug market is "increasingly digitally enabled", mentioning explicitly cryptomarkets ("darknet hidden markets"). However, they do not analyze the differences between the digital and non-digital markets. This study complements their work by providing a comprehensive analysis and quantification of the differences between cryptomarkets and traditional markets in terms of the quality of the substances.

The purity and adulteration of cocaine has been studied in different locations and time periods: Galicia, Spain, between 2007 and 2014 [25]; Modena and Regio Emilia, Italy, between 2008 and 2017 [26]; the south metropolitan area of Rome, Italy, over the course of a year [18]; Queensland, Australia, in 2015 and 2016 [17]; France, in 2006 [7]; The Netherlands, between 2013 and 2016 [11]; the United States, between 1984 and 1997 [27].

The Trans European Drug Information (TEDI) project published a report about drug testing in Europe, including data from 6 countries, using data from the drug checking services of each country [5]. This study, however, does not take into account where the substances were acquired (regular markets or cryptomarkets).

The findings in these studies are linked to the locations in which the sample was taken; cryptomarkets, on the other hand, enable a global drug market in which a user can purchase a substance from a vendor in a different country or even continent. For this reason, in this study, we analyze international data.

Studies about cryptomarkets have been mainly focused in users [8], [9], vendors [10], and amount of business [28], [29]. Quality of illegal drugs in cryptomarkets has been studied in [12], [11], and specific adulteration problems in [16], [30].

The studies that have compared cryptomarkets and traditional markets have done so with some geographical limitations: [11] did it only for users in The Netherlands, [12] used worldwide results for cryptomarkets, but the comparison was done with the traditional market in Spain.

Several studies [8], [9] mention that cryptomarket users research the markets, drugs, and vendors prior to making a purchase, much like any other buyer of legal goods in the internet. Our work is the first that is able to quantify the effect of this informed choices by using data from harm reduction websites to compare drug checking results from different vendors.

## IV. Methodology

### A. Identification of analysis laboratories

We started researching drug quality in cryptomarkets in the DNMA forum, a forum in the hidden web focused in drug discussion, including harm reduction. Reading the forums, we discovered that the analysis were performed by a Spanish NGO working in harm reduction: *Energy Control* [23].

After an additional investigation on previous research conducted by *Energy Control* [5] and through Internet searches, we discovered three further harm reduction organizations that offer these kind of analysis: *Ai Laket!* also in Spain, *WEDINOS* in Wales (UK), and *DIMS* in The Netherlands. Whereas *Ai Laket!* and *WEDINOS* have a dataset available online (ref Sec. IV-C), *DIMS* does not. Furthermore, we suspected that the data published on DNMA was only a small subset of all the analyses conducted by *Energy Control*. We therefore proceeded to contact both *Energy Control* and *DIMS* to request access to their data. We report on this activity in Section IV-C below.

### B. Identification of data sources

Referring to these laboratories as sources for data on drug quality analysis, we identified the following datasets:

- *Energy Control*: the DNMA forum reports analysis results performed by *Energy Control*. We were able to contact Energy Control and schedule an interview with Dr. Caudevilla, one of the professionals behind Energy

Table I: Dataset description.

| Laboratories | Dataset | Samples | Market | Type |
|---|---|---|---|---|
| | DNMA | 68 | Cryptomarkets | Public |
| | DNStars | 66 | Cryptomarkets | Public |
| *Energy Control* | EC | 381 | Cryptomarkets | Private |
| | EC | 286 | No cryptomarkets | Private |
| | EC | 106 | No information | Private |
| *WEDINOS* | DNStars | 30 | Cryptomarkets | Public |
| *Ai Laket!* | AiLaket | 132 | No information | Public |

Control. Dr. Caudevilla is a Doctor of Medicine that was known as Dr. X in the forums of early cryptomarkets, were he answered drug related questions. In our interview, he pointed to another website that performed a similar role as DNMA: DNStars, that resulted in another dataset. He also kindly shared with us the anonymized results from their international drug checking service. To keep track of data provenance, we report separately analyses performed by Energy Control across these three platforms and identify three respective datasets split by the provenance of the data: `DNMA`, `DNStars`, `EC`.

- The website of *Ai Laket!* publishes the results of their drug checking service. This information will be our `AiLaket` dataset.

Finally, we got in touch with DIMS, but they declined our request to access their analysis data as they are unfortunately unable to share it with third parties.

The difficulties that arise from comparing analysis performed by different laboratories will be dicussed in Section IV-D.

### C. Data collection

We used 4 datasets in the analysis. The datasets `DNMA`, `DNStars`, and `AiLaket` consist in public data that we gathered from the respective websites and parsed into a format that can be analyzed. The dataset `EC` consists in data from Energy Control that was shared with us in anonymized form. Table I provides a summary of the datasets, grouped by the laboratories that performed the testing.

1) `DNMA`. We crawled the DNMA forum from October 2018 to December 2018 using Scrapy for the scraping and Privoxy to route the traffic through Tor. During this period, we visited the website twice a week with the crawler configured to add any new results to our database. We gathered 68 results from October 2017 to November 2018.
2) `DNStars`. DNStars has a separate results page in which they publish results from drug checking services. This page allows filtering by substance, which enabled us to copy the data into a spreadsheet. We gathered 96 results from March 2018 to October 2019.
3) `EC`. Energy Control shared with us data from their International Drug Checking Service. The data contained 773 results from which approximately a half (381) were from cryptomarkets, from January 2017 to July 2019.
4) `AiLaket`. Ai Laket! publishes their drug checking results online, however there is no possibility of filtering them by substance. We used Beautiful Soup to extract the data and parse it into an appropiate form, We gathered 249 results from August 2014 to November 2018.

Details about how the substance analysis was performed are out of the scope of this study but can be found in the websites of the laboratories (*Energy Control* [23], *WEDINOS* [31] and *Ai Laket!* [32]).

### D. Data preparation

Most of our data falls into the period 2017-2019, where we have data from both cryptomarkets and no cryptomarkets. The only data we have outside this time frame is from the `AiLaket!` dataset. This dataset is heavily localized in a region of Spain and lacks information about the market in which the drug was purchased. For these reasons, we will only consider results between 2017 and 2019 for the analysis.

DNMA and DNStars provide a proxy between the users and the labs analyzing the samples. Due to this, the results in the datasets `DNMA` and `DNStars` that list Energy Control as the laboratory in which the sample was analyzed, should be a subset of the `EC` dataset. To check this, and to analyze the reliability of these websites, we tried to match each of the records analyzed by Energy Control in `DNMA` and `DNStars` with entries in `EC` that come from cryptomarkets. First, we performed an inner join between the `EC` dataset and `DNMA` and `DNStars` by Purity, Adulterated, Levamisole, and Levamisole concentration. Then, we filtered the results adding the constrain that the date in `EC` must be in the 30 days before the publication date in `DNMA` or `DNStars`. With these constraints, we found matches for 41 results out of 66 in `DNStars` and for 34 out of 68 in `DNMA`. This is less than we would expect, as we would expect to find a match for each result in `DNStars` and `DNMA`. As some of the data in `DNMA` and `DNStars` also appear in the `EC` dataset, we will use both datasets separately: we will use the `EC` dataset in most comparisons between cryptomarkets and no cryptomarkets—as `DNMA` and `DNStars` only contain data from cryptomarkets—, and we will use `DNMA` and `DNStars` in analysis that could benefit from the extra variables that these datasets contain.

Finally, as mentioned in Section II, *Energy Control* defines purity as "*the proportion of the active principle present in a sample compared to those of synthesis impurities, residual solvents or diluents*", whereas adulteration is "*the addition of a component not ordinarily part of that substance*" [12]. Ai Laket!, on the other hand, uses a different purity definition, measuring the ratio between substance and adulterants. Levels of purity reported in `Ai Laket!` dataset are therefore not comparable to those of other datasets; for this reason, analysis of purity in this paper does not include data from `Ai Laket!`.

## V. Results

In this section, we first describe the data and give some aggregate statistics, then we continue the analysis guided by the research goals.

Table II: Summary of collected data.

| Variable | Dataset | Unit | Description | Lvls | Min | Mean | Max | sd |
|---|---|---|---|---|---|---|---|---|
| market | All | Cat. | Type of market from which the sample comes. | 3 | | | | |
| lab | All | Cat. | Laboratory that performed the analysis. | 3 | | | | |
| date | All | Date | Date in wich the result was published. | | 2017-01-02 | 2018-04-23 | 2019-10-24 | 263 |
| purity | All[1] | [0,1] | Concentration of the main substance. | | 0 | 0.65 | 1 | 0.27 |
| adulterated | All | Bool | Is the sample adulterated. | 2 | 0 | 0.31 | 1 | 0.46 |
| levamisole[2] | All | Bool | Contains levamisole. | 2 | 0 | 0.23 | 1 | 0.42 |
| leva_conc[3] | All[1] | [0,1] | Concentration of levamisole. | | 0 | 0.06 | 0.9 | 0.17 |
| vendor | DNMA, DNStars | Cat. | Vendor who sold the sample. | 73 | | | | |
| vendor_country | DNMA | Cat. | Vendor country. | 7 | | | | |
| price | DNMA | EUR | Price per gram. | | 39 | 56 | 75 | 11 |
| country_origin | AiLaket, EC | Cat. | Country of the sample. | 32 | | | | |

*Unit* indicates the type of data field. *Levels* indicates the number of factors in categorical variables (including blank value). Summary statistics are provided for numerical variables and boolean variables, where 0 is considered FALSE and 1 TRUE.
[1] Results in the DNStars dataset analyzed by *WEDINOS* do not contain percentage purity of main substance or adulterants.
[2] Levamisole is the main adulterant in cocaine. See Section II for a description.
[3] Levamisole concentration is defined as the percentage of levamisole present in the sample.

Table III: Variables available in each dataset.

| Dataset | Market | Vendor | Price | Sample country | Vendor country |
|---|---|---|---|---|---|
| AiLaket | - | - | - | ✓ | - |
| DNMA | ✓ | ✓ | Some | - | Some |
| DNStars | ✓ | ✓ | - | - | - |
| EC | ✓ | - | - | ✓ | - |

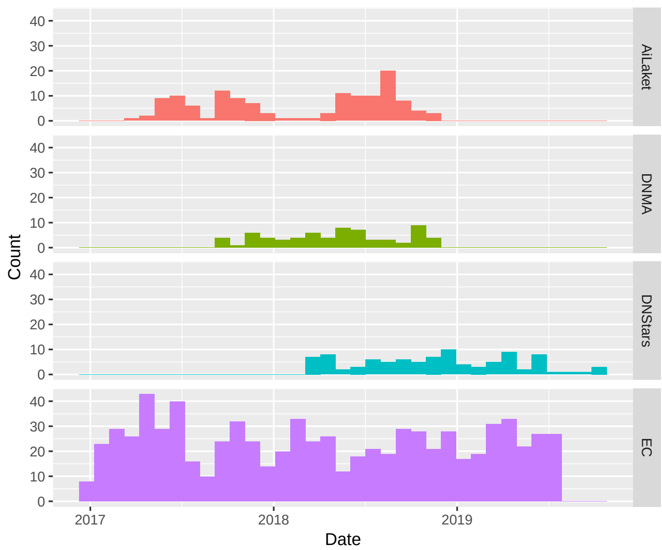



Figure 2: Number of results per month for each dataset.

Table II contains a summary of the collected variables. Due to their provenance, not all datasets contain the same variables. While some of them are shared between all (purity and adulteration), we only know the price of some samples in the DNMA dataset. In a similar way, we only have vendor information in the datasets that were gathered from harm reduction websites: DNMA and DNStars. Table III details the variables that each dataset contains.

### *A. Descriptive statistics*

Table II reports a summary of the collected variables with their description.

As mentioned in Section IV-D, we limit our data to the period 2017-2019, with the earliest recorded sample sitting at the beginning of 2017 and the last one in October 2019. The EC dataset is the one that spans more time: from January 2017 to July 2019; it is also the one with more samples: 773. The other datasets contain less number of samples and also the time frame is smaller; DNMA contains 68 samples from October 2017 to November 2018, DNStars starts in March 2018 and contains 96 samples until October 2019, and AiLaket 132 from March 2017 to November 2018. Figure 2 shows a time histogram of the samples for each dataset, each bar corresponding to a month. The distribution of samples across time is more or less uniform, the EC dataset presents less results in the summer months, when they focus more on on-site testing in events.

The purity of the samples varies substantially between datasets (Table IV). The datasets DNMA and DNStars have the highest purity (around 70%) and the lowest adulteration rate (around 25%). These datasets contain only samples sourced from cryptomarkets and, as mentioned in Section IV-D, should be a subset of the EC dataset. Purity of the EC dataset is lower than that of DNMA and DNStars (58%), and has also higher standard deviation (30% in EC and around 15% in DNMA/DNStars). Purity of the AiLaket dataset cannot be compared with the rest as explained in Section IV-D. Regarding adulteration ratio, the AiLaket dataset contains the highest adulteration ratio of all analyzed datasets (55%).

Levamisole is the most common adulterant of cocaine (see Section II), appearing in more than half of the adulterated samples, however with low concentration (Table V). There are big differences in the percentage of adulterated samples that contain levamisole between the datasets: AiLaket, DNStars, and EC show similar percentages (53% to 61%); however in the DNMA dataset almost all adulterated samples contain levamisole (94%).

Table IV: Purity and adulteration rate per dataset.

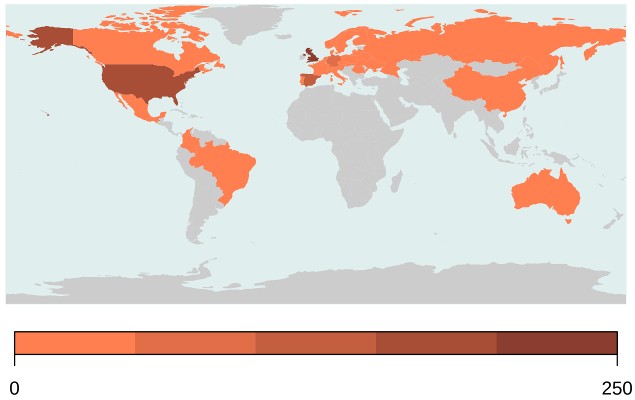
| Dataset | Mean purity ± SD | Adulteration rate |
|---|---|---|
| AiLaket | - | 55% (73/132) |
| DNMA | 71 ± 17% | 24% (16/68) |
| DNStars | 73 ± 14% | 26% (25/96) |
| EC | 58 ± 30% | 38% (290/773) |

Table V: Percentage of adulterated samples that contain levamisole and its concentration.

| Dataset | Levamisole | Mean concentration ± SD |
|---|---|---|
| AiLaket | 53% (39/73) | - |
| DNMA | 94% (15/16) | 2 ± 6% |
| DNStars | 56% (14/25) | 1 ± 3% |
| EC | 61% (178/290) | 7 ± 19% |

The datasets DNMA and DNStars contain the name of the vendor who sold the substance. This is public information that a prospective buyer can research. Most of the vendors appear only once, however there is a small group of vendors with more than 2 analyzed samples that account for more than half of the total analyzed samples (25% of the vendors account for 56% of the samples). In terms of pricing, there are 25 samples from the DNMA dataset with price per gram information. The price distribution is uniformly distributed between the minimum of 39 EUR per gram and the maximum of 75.

The country with more vendors is the US (12), followed by The Netherlands (6), and Germany (3). The rest of the represented countries are France, Norway, and the UK; with one vendor. The geographical analysis of the data (Figure 3) shows that most of the analyzed samples come from countries in the western hemisphere, with a majority coming from Europe and North America. Africa, the Middle East, and Southeast Asia have no data. Even though the total number of countries represented in the data is high (31), their representation is not uniform: United Kingdom with 213 and the United States with 170 are the countries with more results, but the median number of results per country is only 5.




Dataset: AiLaket, EC.

Figure 3: Number of samples per country of origin.

Table VI: Purity and adulteration per market.

| Market | Mean purity ± SD | Adulteration rate |
|---|---|---|
| Cryptomarkets | 59 ± 29% | 34% (131/381) |
| No cryptomarkets | 58 ± 30% | 39% (111/286) |

Dataset: EC.

### *B. Are there differences between the quality of cocaine samples traded in traditional markets and those available through cryptomarkets?*

A first look at the aggregate statistics of cryptomarkets and non-cryptomarkets data shows that there is no significant difference in purity between cryptomarkets and no cryptomarkets, and a minimal difference of only 5% in case of adulteration rates (Table VI). The purity distribution also shows a similar pattern in both cryptomarkets and no cryptomarkets (Figure 4).

These similarities also occur in adulteration: the percentage of adulterated samples sourced from cryptomarkets that contain levamisole is almost the same as in samples sourced from traditional drug markets. The concentration of levamisole in the samples is also very similar (Table VII). The distribution of levamisole concentration shows that most of the samples containing levamisole do so in a low concentration. There is however another (smaller) peak in the distribution of levamisole concentration both in cryptomarkets and traditional drug markets with levamisole concentrations higher than 50% (Figure 5).

We do not have price per gram data for cocaine sourced from traditional markets. However, in cryptomarkets, price per gram is not an indicator of quality, as shown in Figure 6.

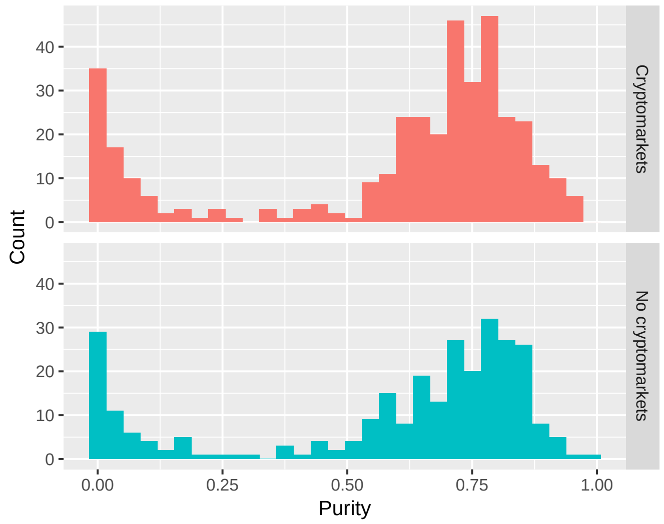
### *C. Does the quality of cocaine samples depend on its geographical provenance?*

As cryptomarkets offer a global drug market, we would expect to see a decrease in the importance of geographical factors in the quality of cocaine sourced from cryptomarkets.

Analyzing samples from different countries, we can see that in 3 of the top 4 countries with more analyzed samples, the purity is very similar between all of them, be it sourced from cryptomarkets or traditional markets (Figure 7, Table XII for the complete data). In the US however, cocaine sourced from cryptomarkets is of significant higher purity.

The percentage of adulterated samples stays at a similar level in Canada, Germany and UK, with differences inside each country of at most 6% between cryptomarkets and traditional markets (Figure 8). There are however, significant differences between countries: in Canada the percentage of adulterated samples is just 24%, while in Germany is around 40%. In the US, the percentage of adulteration in cryptomarkets is 20 points lower than in traditional markets. The percentage of adulterated samples that contain levamisole is much higher in the US than in the other countries, both in cryptomarkets and no cryptomarkets, as well as its concentration (Table VIII).

A possible reason for these results is that users in cryptomarkets buy from vendors in their own country. Using the results




Dataset: EC.

Figure 4: Purity distribution for cryptomarkets and no cryptomarkets.

Table VII: Percentage of adulterated samples that contain levamisole and its concentration.

| Market | Levamisole | Mean concentration ± SD |
|---|---|---|
| Cryptomarkets | 61% (80/131) | 7 ± 19% |
| No cryptomarkets | 59% (66/111) | 6 ± 18% |

Dataset: EC.

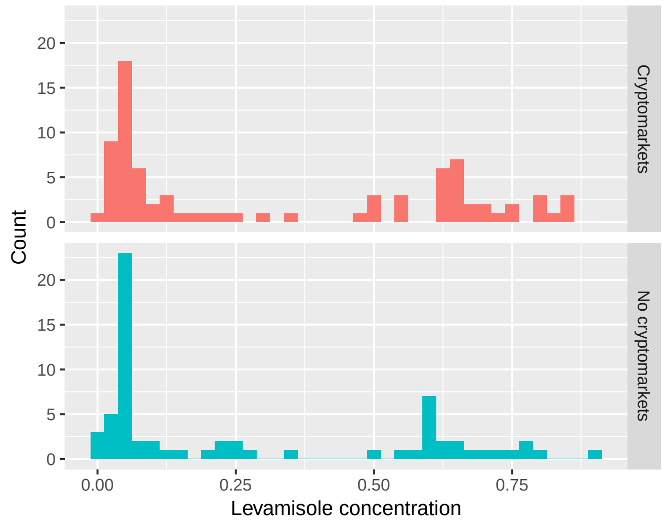
from DNMA that we were able to match to samples in EC, we can see the links between users and vendors in cryptomarkets. Figure 9 shows the origin countries—the ones with colors—, in which the vendor is located, and the country of destination, the country of the user. The width of the link is proportional to the amount of samples that follow the same route. We can see that the more represented countries are also those with more vendors (US and The Netherlands). Most of the trade of US-based vendors is to users also in the US except for some overseas trade with the UK. Vendors in The Netherlands have trades with Germany, Austria, and the UK, as well as overseas with the US and Canada.

The price information in the DNMA dataset shows a difference of 30 EUR in price per gram between the cheapest country (France) and the most expensive (UK), as shown in Table IX.

### D. *How quality of cocaine samples sourced from cryptomarkets vary across vendors?*

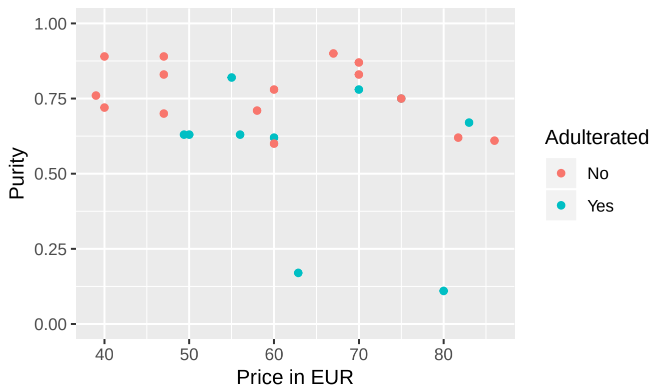
One reason for using cryptomarkets cited by users [9] is the possibility of researching vendors and make an informed purchase. This research may involve checking the reputation of the vendor in the cryptomarket's reputation system, read the reviews of the past purchases, and see test results of substances sold by the same vendor in the past in harm reduction websites.

As mentioned in Section V-A, regarding the number of analyzed samples per vendor, there is a group of around 25%




Dataset: EC.

Figure 5: Levamisole concentration of samples that contain levamisole.




Dataset: DNMA.

Figure 6: Purity and price of samples from cryptomarkets

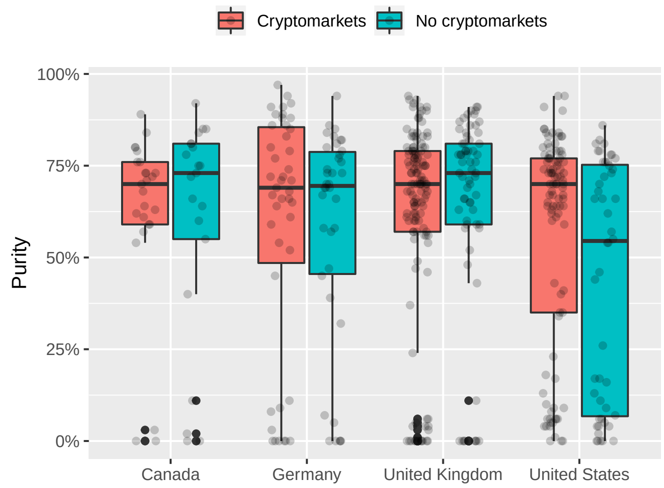
of vendors with more than 2 analyzed samples that account for 50% of all analyzed samples.

The results from the group of vendors with more analyzed samples show slightly higher purity than the other group (Table X). However, the difference in purity is very significant: the samples from the more analyzed vendors are characterized by an adulteration rate 25 points lower than samples from vendors with fewer analyzed samples.

Regarding the adulterants present, in the group of more analyzed vendors the percentage of adulterated samples that contained levamisole is almost 20 points higher than for the other group of vendors Table XI. The levamisole concentration, however, is lower (Figure 10).

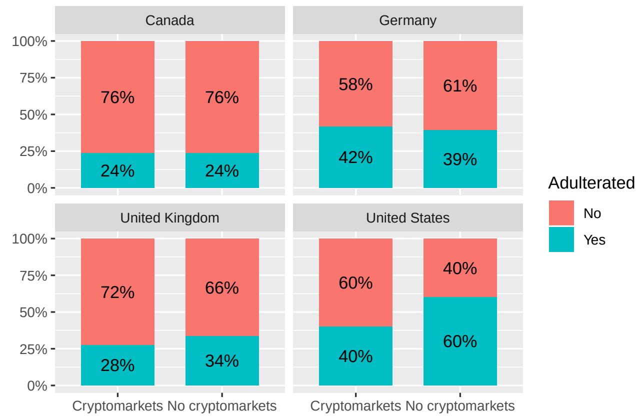
## VI. Discussion

*1) Are there differences between the quality of cocaine samples traded in traditional markets and those available through cryptomarkets?:* We found that cryptomarkets by themselves do not offer a significant difference in terms of quality with




Dataset: EC.

Figure 7: Difference in purity between samples from different countries.



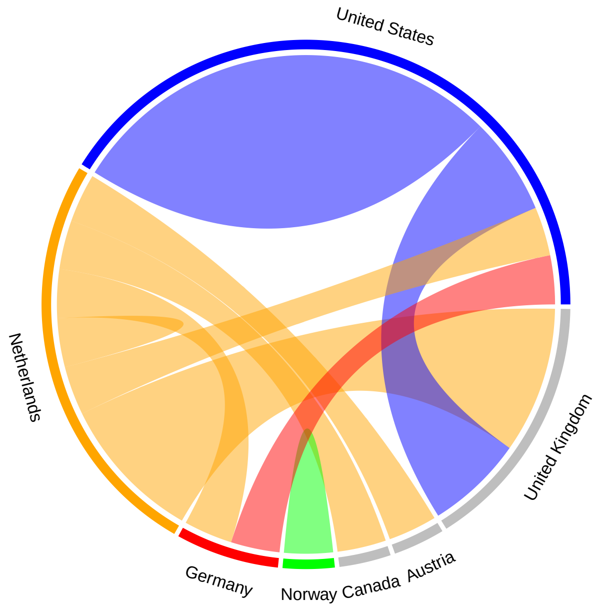

Dataset: EC.

Figure 8: Difference in adulteration between samples from different countries.

Table VIII: Percentage of adulterated samples that contain levamisole and its concentration per vendor country.

| Country | Market | Levamisole | Mean concentration ± SD |
|---|---|---|---|
| Canada | Cryptomarkets | 50% (3/6) | 5 ± 18% |
| Canada | No cryptomarkets | 40% (2/5) | 6 ± 17% |
| Germany | Cryptomarkets | 56% (10/18) | 7 ± 20% |
| Germany | No cryptomarkets | 47% (7/15) | 4 ± 11% |
| United Kingdom | Cryptomarkets | 61% (22/36) | 5 ± 17% |
| United Kingdom | No cryptomarkets | 55% (12/22) | 2 ± 8% |
| United States | Cryptomarkets | 82% (32/39) | 12 ± 24% |
| United States | No cryptomarkets | 83% (24/29) | 20 ± 29% |

Dataset: EC.




Dataset: DNMA, EC.

Figure 9: Countries of origin and destination of the analyzed samples ($n = 25$).

respect to traditional markets. The mean purity and adulteration rate are comparable, with a marginal difference of 5% in adulteration that favors cryptomarkets. The distribution of purity is also very similar for both cryptomarkets and traditional markets.

*2) Does the quality of cocaine samples depend on its geographical provenance?:* Yes, furthermore the important variation of quality between countries seems to suggests that most users tend to buy from vendors in their own country—likely due to security reasons, as packages within the same country will go over less controls. Reduced delivery times may also play a large role in this effect, as drug users may be particularly sensitive to short delivery times both in terms of reduced risk, as well as a consequence of addiction to the drug. This means that cryptomarkets do not tend to work as the "global market" that they look like, but rather a digital way of contacting dealers in the same country. These findings suggest that cryptomarkets appear in the "last mile" of the supply route, as suggested by other studies [33], replacing street dealers but not modifying the existing global supply routes.[1]

Levamisole is also closely tied to the country of origin of the sample, the differences in percentage of adulterated samples that contain levamisole between cryptomarkets and no cryptomarkets in the same country are at most 10%, while the differences between countries go as high as the 40 points difference between Canada and the US (Table VIII). This suggests that adulteration may be a heavily geographical-dependent phenomenon in cryptomarkets, with relatively stable adulteration rates within the same country, and high

[1]Most of the data used in the analysis come from countries in Europe and North America. The language barrier–most cryptomarkets are in English—may be one of the reasons why countries in the Eastern hemisphere are underrepresented in the data.

Table IX: Price per gram per vendor country (cryptomarkets).

| Vendor country | Mean price ± SD (EUR) |
|---|---|
| France | 39 ± 0 |
| Germany | 66 ± 14 |
| Netherlands | 49 ± 8 |
| Norway | 68 ± 0 |
| United Kingdom | 70 ± 0 |
| United States | 57 ± 9 |

Dataset: DNMA.

Table X: Difference in purity and adulteration by number of analyzed samples per vendor.

| Vendor analysis | Mean purity ± SD | Adulteration rate |
|---|---|---|
| 1 or 2 | 69 ± 18% | 39% (28/72) |
| More than 2 | 75 ± 12% | 14% (13/92) |

Dataset: DNMA, DNStars.

across-country variance. Matching this results to our previous observation on drug provenance being often the same as user location, further stresses the low relative importance of drug quality when making a purchase decision, even when testing facilities are readily available [27]: if the opposite were true, users from high-adulteration countries should tend to purchase more from vendors located at low-adulteration countries. Nonetheless, we observe trades happening between users and vendors of different countries, as seen in Figure 9, but their relative frequency is too low to 'normalize' an otherwise very wide difference in adulteration rate across countries.

A direct comparison with the other studies that have analyzed purity and adulteration in cryptomarkets is difficult to make, as the periods of analysis are different and drug quality presents important variation over time [25].

However, our findings are similar as those of [11], in that we did not find significant differences in quality between samples from cryptomarkets and traditional markets, and contrast with those of [12], where they did find that samples from cryptomarkets had higher purity and lower adulteration rates.

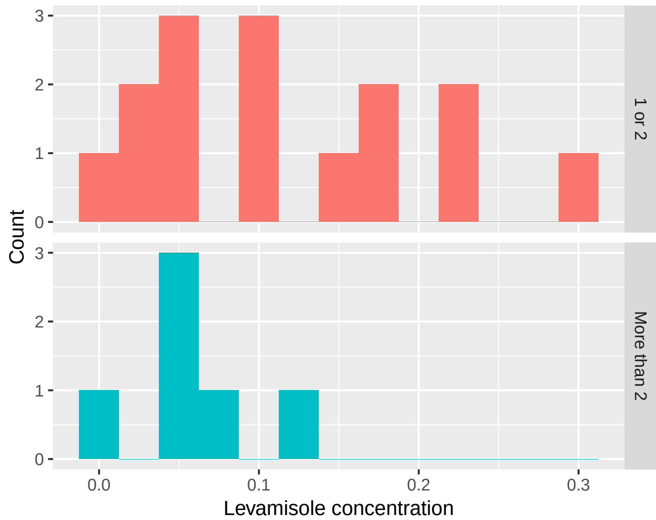
Regarding the purity results, our aggregated results from cryptomarkets look similar to those in [11] (collected in The Netherlands from 2013 to 2016) with a mean purity between 50% and 60%, and are lower than the ones in [12] (international data from 2014-2015) with 71%. Adulteration rates however, are more consistent with the findings in [12] with an adulteration rate of around 50% and much lower than those reported in [11] between 70% and 82%. This differences in purity and adulteration rates highlight the variation of quality with time and location.

*3) How quality of cocaine samples sourced from cryptomarkets vary across vendors?:* In our interview, Dr. Caudevilla painted an interesting landscape for drug markets where cryptomarkets account for a small number of the overall transactions but have an incredible potential. He also reported a clear interest in harm reduction from users, who were informed customers that did their research and compared between vendors and reviews prior to buying the drugs, and from administrators, who reacted promptly to alerts raised

Table XI: Percentage of adulterated samples that contain levamisole and its concentration per vendor group.

| Vendor analysis | Levamisole | Mean concentration ± SD |
|---|---|---|
| 1 or 2 | 64% (18/28) | 10 ± 9% |
| More than 2 | 85% (11/13) | 6 ± 4% |

Dataset: DNMA, DNStars.




Dataset: DNMA, DNStars.

Figure 10: Levamisole histogram per vendor group for samples that contain levamisole.

upon finding dangerous substances in samples analyzed from the market.

We found that informed customers that check harm reduction websites and compare vendors may get a substantial benefit from doing so, as adulteration rate across the more analyzed vendors was only 14%, substantially lower than the 39% average in cryptomarkets. This is a clear benefit of cryptomarkets, as this comparison would be much more difficult in traditional markets. This highlights the potential of harm-reduction services in incentivizing trade of less harmful drugs in the cryptomarkets, as users become empowered with authoritative evaluations of drug quality ahead of consumption and, importantly, purchase. In turn, this may push drug vendors in the cryptomarkets toward higher-quality products to avoid being pushed out of the market due to the quality controls.

However, harm reduction websites collecting information about drug testing are usually short-lived and have downtime issues. At the time of writing (December 2019), DNStars has closed and there has been no new results posted in DNMA in the last few months. This limits the opportunities for users to check past analysis of vendors and make an informed choice. These websites act as a proxy between final users and analysis laboratories and cover the fees of the analysis; the reliability of these services however is unclear, as we have been unable to match all of their data to the corresponding laboratory records. This may pose operative limitations to the 'normalizing' effects of harm-reduction services in the underground, as low availability and fragmentation across multiple platforms may reduce overall impact on market dynamics.

### A. Limitations

Our study focuses in cocaine, other drugs may behave differently in cryptomarkets and traditional markets.

In their website, Energy Control remarks that their service cannot be used to endorse the quality of any vendor and that it is only offered as a service for final users. Apart from legal reasons, this is because they cannot be sure that the sample they analyzed and other samples sold afterwards by the same vendor are part of the same batch and have been through the same treatment. Similar limitations apply to this study, as we cannot be certain that the vendor that a certain user listed in their request is actually the vendor who sold them the substance and the quality of samples from the same vendor could vary, as often the vendors are not producers and have little knowledge about the quality of the product themselves (see Section II). Moreover, these services could be used by vendors to improve their reputation by posing as users and sending samples that they know are higher quality than they usually sell. Likewise, they could send an adulterated sample and say that they bought it from a rival vendor. Despite this, nothing in the forums of DNMA or the DNStars website seemed to suggest that such behaviors were occurring.

### B. Future work

It would be possible to extend the findings in this study to include the reputation systems of cryptomarkets, linking the reputation of vendors and the analysis of their products. Unfortunately, the instability of cryptomarkets made this data collection impossible for this work.

## VII. Conclusion

This study highlights the difficulty of analyzing the quality of illegal drugs in different markets (traditional and cryptomarkets). Harm reduction organizations that offer drug checking service are currently the only source of information on this topic for users.

We extend the literature of cryptomarkets and drug analysis and quantify the effect in expected drug quality of the new factors enabled by cryptomarkets: the benefit of making an informed purchase from a vendor that is analyzed often accounts for a decrease of 25% in the adulteration ratio and an increase of 6% in purity.

We also find that cocaine purchased in cryptomarkets is not of higher quality than cocaine purchased in traditional markets, and that there is a stronger correlation between the quality and the country of origin of the sample than there is between the quality and the market in which the drug was purchased.

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## Appendix

Table XII: Purity and adulteration of cocaine by market and country.

| Country | Market | Mean purity ± SD | Adulteration rate | Levamisole | Mean concentration ± SD |
|---|---|---|---|---|---|
| Australia | Cryptomarkets | 21 ± 28% | 67% (2/3) | 0% (0/2) | 0 ± 0% |
| Australia | No cryptomarkets | 50 ± 32% | 17% (1/6) | 100% (1/1) | 10 ± 24% |
| Austria | Cryptomarkets | 88 ± 1% | 0% (0/2) | 0% (0/0) | 0 ± 0% |
| Austria | No cryptomarkets | 91 ± 0% | 0% (0/1) | 0% (0/0) | 0 ± 0% |
| Belarus | No cryptomarkets | 85 ± 0% | 0% (0/1) | 0% (0/0) | 0 ± 0% |
| Belgium | Cryptomarkets | 45 ± 40% | 33% (1/3) | 0% (0/1) | 0 ± 0% |
| Brazil | Cryptomarkets | 73 ± 0% | 0% (0/1) | 0% (0/0) | 0 ± 0% |
| Brazil | No cryptomarkets | 5 ± 0% | 100% (1/1) | 0% (0/1) | 0 ± 0% |
| Canada | Cryptomarkets | 62 ± 25% | 24% (6/25) | 50% (3/6) | 5 ± 18% |
| Canada | No cryptomarkets | 60 ± 31% | 24% (5/21) | 40% (2/5) | 6 ± 17% |
| China | No cryptomarkets | 65 ± 0% | 0% (0/1) | 0% (0/0) | 0 ± 0% |
| Colombia | No cryptomarkets | 40 ± 36% | 100% (2/2) | 0% (0/2) | 0 ± 0% |
| Czech Republic | Cryptomarkets | 79 ± 0% | 0% (0/1) | 0% (0/0) | 0 ± 0% |
| Czech Republic | No cryptomarkets | 82 ± 0% | 0% (0/1) | 0% (0/0) | 0 ± 0% |
| Denmark | Cryptomarkets | 80 ± 3% | 0% (0/3) | 0% (0/0) | 0 ± 0% |
| Denmark | No cryptomarkets | 72 ± 24% | 40% (2/5) | 100% (2/2) | 4 ± 7% |
| Finland | Cryptomarkets | 57 ± 40% | 40% (2/5) | 0% (0/2) | 0 ± 0% |
| Finland | No cryptomarkets | 46 ± 34% | 67% (4/6) | 50% (2/4) | 14 ± 33% |
| France | Cryptomarkets | 53 ± 36% | 50% (5/10) | 80% (4/5) | 16 ± 29% |
| France | No cryptomarkets | 65 ± 26% | 35% (8/23) | 88% (7/8) | 8 ± 22% |
| Germany | Cryptomarkets | 59 ± 33% | 42% (18/43) | 56% (10/18) | 7 ± 20% |
| Germany | No cryptomarkets | 58 ± 30% | 39% (15/38) | 47% (7/15) | 4 ± 11% |
| Italy | Cryptomarkets | 82 ± 2% | 0% (0/2) | 0% (0/0) | 0 ± 0% |
| Italy | No cryptomarkets | 53 ± 0% | 0% (0/1) | 0% (0/0) | 0 ± 0% |
| Latvia | No cryptomarkets | 65 ± 0% | 0% (0/1) | 0% (0/0) | 0 ± 0% |
| Lithuania | No cryptomarkets | 75 ± 10% | 14% (1/7) | 100% (1/1) | 3 ± 9% |
| Mexico | Cryptomarkets | 61 ± 0% | 0% (0/1) | 0% (0/0) | 0 ± 0% |
| Netherlands | Cryptomarkets | 54 ± 37% | 33% (3/9) | 33% (1/3) | 9 ± 27% |
| Netherlands | No cryptomarkets | 59 ± 30% | 43% (3/7) | 67% (2/3) | 1 ± 2% |
| Norway | Cryptomarkets | 54 ± 38% | 33% (1/3) | 0% (0/1) | 0 ± 0% |
| Norway | No cryptomarkets | 85 ± 1% | 0% (0/2) | 0% (0/0) | 0 ± 0% |
| Poland | Cryptomarkets | 53 ± 33% | 38% (3/8) | 33% (1/3) | 2 ± 5% |
| Poland | No cryptomarkets | 52 ± 31% | 40% (4/10) | 25% (1/4) | 8 ± 24% |
| Portugal | Cryptomarkets | 32 ± 18% | 100% (2/2) | 0% (0/2) | 0 ± 0% |
| Portugal | No cryptomarkets | 52 ± 45% | 67% (2/3) | 50% (1/2) | 0 ± 1% |
| Romania | Cryptomarkets | 34 ± 37% | 50% (2/4) | 50% (1/2) | 16 ± 32% |
| Romania | No cryptomarkets | 50 ± 0% | 100% (1/1) | 100% (1/1) | 6 ± 0% |
| Russia | Cryptomarkets | 78 ± 9% | 25% (1/4) | 100% (1/1) | 1 ± 2% |
| Russia | No cryptomarkets | 52 ± 0% | 0% (0/1) | 0% (0/0) | 0 ± 0% |
| Slovakia | No cryptomarkets | 77 ± 0% | 0% (0/1) | 0% (0/0) | 0 ± 0% |
| Slovenia | No cryptomarkets | 60 ± 40% | 25% (1/4) | 0% (0/1) | 0 ± 0% |
| Spain | Cryptomarkets | 77 ± 1% | 0% (0/2) | 0% (0/0) | 0 ± 0% |
| Spain | No cryptomarkets | 53 ± 36% | 29% (2/7) | 0% (0/2) | 0 ± 0% |
| Sweden | Cryptomarkets | 70 ± 17% | 33% (5/15) | 60% (3/5) | 1 ± 2% |
| Sweden | No cryptomarkets | 73 ± 19% | 29% (4/14) | 0% (0/4) | 0 ± 0% |
| Switzerland | Cryptomarkets | 46 ± 42% | 100% (2/2) | 100% (2/2) | 16 ± 18% |
| Switzerland | No cryptomarkets | 59 ± 24% | 67% (4/6) | 75% (3/4) | 1 ± 2% |
| Ukraine | Cryptomarkets | 78 ± 7% | 0% (0/2) | 0% (0/0) | 0 ± 0% |
| United Kingdom | Cryptomarkets | 61 ± 28% | 28% (36/130) | 61% (22/36) | 5 ± 17% |
| United Kingdom | No cryptomarkets | 63 ± 29% | 34% (22/65) | 55% (12/22) | 2 ± 8% |
| United States | Cryptomarkets | 57 ± 29% | 40% (39/97) | 82% (32/39) | 12 ± 24% |
| United States | No cryptomarkets | 44 ± 33% | 60% (29/48) | 83% (24/29) | 20 ± 29% |

Dataset: `EC`.