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The Economic Functioning of Online Drugs Markets

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Abstract

The economic functioning of online drug markets using data scraped from online platforms is studied. Analysis of over 1.5 million online drugs sales shows online drugs markets tend to function without the significant moral hazard problems that, a priori, one might think would plague them. Only a small proportion of online drugs deals receive bad ratings from buyers, and online markets suffer less from problems of adulteration and low quality that are a common feature of street sales of illegal drugs. Furthermore, as with legal online markets, the market penalizes bad ratings, which subsequently lead to significant sales reductions and to market exit. The impact of the well-known seizure by law enforcement of the original Silk Road and the shutdown of Silk Road 2.0 are also studied, together with the exit scam of the market leader at the time, Evolution. There is no evidence that these exits deterred buyers or sellers from online drugs trading, as new platforms rapidly replaced those taken down, with the online market for drugs continuing to grow.

1. Introduction

Trade in illegal drugs has been moving online in recent years. This has been facilitated by the opening of platforms located on the Dark Web that have grown rapidly since 2011. In the 2017 Global Drug Survey, over one in ten respondents in the online drugs part of the survey report having ever bought drugs online. In some countries, this has been rising fast: in the UK, one of the biggest online drug purchasing countries, the percentage buying drugs from the Dark Web in the twelve months preceding the survey date rose from 12.3 percent in 2014 up to 25.3 percent by 2017; in the US it doubled between 2014 and 2017 to reach 13.2 percent; in the 2017 survey in six English speaking countries (Australia, Canada, Ireland, New Zealand, the UK and US) the percent buying drugs online was 11.9 percent.[1]

The online market for drugs is an infant industry, but it is a rapidly growing one. Its origins as an important economic activity date back to early 2011, with Silk Road, the first major online anonymous drugs platform (see Christin, 2012).[2] Silk Road was located on the Dark Web, a part of the Internet that can only be reached through anonymisation software (like the Tor network[3] described below), utilising encryption programs and conducting transactions with the anonymous cryptocurrency, Bitcoin.[4] The technology used on Silk

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[1] The Global Drug Survey is an annual voluntary online survey of drug users. 119846 people from over 50 countries participated in the most recent 2017 survey, 115523 having their data used in the survey reports, available at https://www.globaldrugsurvey.com/wp-content/themes/globaldrugsurvey/results/GDS2017_key-findings-report_final.pdf. For a write up of findings of the 2016 survey see Barratt et al. (2016).

[2] See Bartlett (2014) for discussion of Dark Web activities more broadly, including a Chapter on Silk Road. Ormsby (2014) provides a fascinating and informative narrative on Silk Road.

[3] Tor stands for 'the onion router'. Tor hidden network services were first developed by mathematicians and computer scientists in the early 1990s in the US Naval Research Laboratories for ensuring anonymity of US intelligence communication services online. The onion analogy is because Tor nodes are encrypted in a layered protocol as it bounces users across different relays and nodes with high levels of encryption making it almost impossible to trace the location of the site and its activities.

[4] For a discussion of the economics and technology of Bitcoins see Bohme et al. (2015).

Road represented a major advance on previous small scale attempts to sell drugs online.[5]

Indeed, the technological advances and innovation first used on Silk Road have proven

instrumental in transforming the way in which drugs are traded.

Silk Road and the other online drugs platforms that have subsequently opened have

received hardly any attention from economists and have only been studied to a limited extent

by researchers from other disciplines.[6] Yet they are highly relevant to the economics of crime

and the economics of online markets.[7] Unlike other black markets, detailed time series data

covering the items on sale, together with their prices and rated transactions, is readily

available from scraping the websites of the online platforms. This gives a unique insight into

the functioning of these illicit markets.

The empirical analysis implemented in this paper utilises over 1.5 million drugs

transactions, using data scraped from several of the largest online drugs platforms between

2013 and 2016, to present evidence on the economic functioning of online drugs markets.

Some of the reported evidence comes from analysing these data in ways similar to other

research on (legal) online markets, like eBay or Amazon, where a focus has been placed upon

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[5] Buying and selling drugs online was not new. For example, at times there have been some drugs listings on regular Internet sites like Craigslist in the US and Gumtree in the UK. Just prior to Silk Road's launch, there were two sites (the Open Vendor Database and Farmer's Market) whose main activity was to sell drugs online, but with little or no attempt to facilitate anonymity (e.g. using PayPal for transactions payment).

[6] Examples include research in computer science by Christin (2012) and Soska and Christin (2015), who, like us scraped Dark Web platforms to obtain data, and the papers by crime and drugs researchers like Aldridge and Decary-Hutu (2014), Martin (2104) or Van Hout and Bingham (2013a, 2013b). Other up to date studies feature in the special issue on Drug Cryptomarkets of the International Journal of Drug Policy, published in 2016. In economics, at the time of writing there are only a handful of unpublished draft papers including, for example, those by Armona (2017), Armona and Stackman (2014) and Janetos and Tilly (2017).

[7] Of course, in the economics of crime literature, the market for illicit drugs has been a significant research area. The orthodox demand-supply framework used by economists to model the drug market dates back to Becker (1968), with many contributions since, including formal economic modelling of addiction (see, for example, Becker and Murphy, 1988) . There is also work that tries to estimate the market size for particular drugs (a recent example being Parey and Rasul, 2016) and a large body of research on the questions of drug legalisation (see, inter alia, the review of Donohue et al., 2011).

whether online activity alters the way in which trust between market participants operates and whether it impacts on efficiency of outcomes. A particular emphasis has been placed upon whether online activity enhances or diminishes seller reputations so that moral hazard problems either improve or deteriorate in the context of online commerce (see Cabral and Hortacsu, 2010).

This study considers three aspects of the economics of Dark Web drugs activity. First, it offers an appraisal and empirical analysis of the buyer ratings of online drug purchases that the platforms collect. Second, it looks at whether these ratings act to generate a reputation mechanism for sellers in the illegal online market setting as other authors have proposed that legal online markets do. Third, the dynamics of the market are analysed, as seller turnover and platform turnover are observed to be high in the online drugs markets.

The key findings are as follows. Reputation mechanisms appear to work relatively well -- analysis of over 1.5 million online drugs transactions reveals that the online drugs markets function, for the most part, without the significant moral hazard problems that *a priori* one might think would plague them. First of all, there is evidence that only a small minority of online drugs deals receive bad ratings from buyers. Second, as with legal online markets, bad ratings subsequently lead to significant sales reductions and to market exit. Furthermore, the quality of drugs supplied seems to be relatively high, so that online markets do not suffer from the problems of adulteration and low quality that are known to commonly feature in street sales of illegal drugs. This is likely to be because the presence of feedback means more information is available to buyers relative to street sales.

Finally, as the online drugs markets have appeared and rapidly grown, they have simultaneously become a source of media focus and attention from law enforcement. Some

platforms have been seized and shut down by law enforcement. Other platforms have undertaken exit scams and run off with the money they were holding. Thus the market has become characterised by platform (and seller) entry and exit. The paper therefore looks at what happens to the online drugs market when large platforms exit, in particular by studying three specific cases, the well-known seizure of the original Silk Road, the shutdown of Silk Road 2.0 by law enforcement agencies and the exit scam by the market leader at the time, Evolution. There is no evidence that these large scale exits deterred buyers or sellers from continuing to engage in online drug sales and purchases, with new platforms rapidly arising to replace those taken down. As such, the market seems to reconstitute itself rapidly and so continues to rapidly grow, despite the uncertainty that platform moral hazard problems generate for both sellers and buyers.[8]

The remainder of the paper is structured as follows. Section 2 explains how the data, which was mostly scraped from various Dark Web platforms over time, were collected and processed. It also shows how these data can be used to document the rise of the online drugs market over time. In Section 3, findings are reported from the reputations analysis which studies the ratings of drugs transactions that buyers provide, how they compare with street 'ripoffs'. It also presents statistical evidence on the impact of bad ratings on seller sales performance and on seller exit. Section 4 considers what happened to the online drugs market after law enforcement agency shutdowns and exit scams caused the exit of market leaders. Finally, Section 5 offers some conclusions.

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[8] See also the recent analysis for the Silk Road 2.0 shutdown under Operation Onymous that reaches the same conclusion by Decary-Hutu and Giommoni (2016).

2. Dark Web Drugs Markets

The data comes from scraping the websites of online illegal drugs markets.[9] We ourselves have scraped data from late 2013, but also have access to some other data and information from before that time.

Dark Web Drugs Platforms

Silk Road and its successors function as two-sided markets or platforms (see Rochet and Tirole, 2003), serving as intermediaries for transactions between buyers and sellers. The drugs platforms operate on the Tor hidden network services that were first developed by mathematicians and computer scientists in the early 1990s in the US Naval Research Laboratories for ensuring anonymity of US intelligence online communication services. Tor bounces users across different relays and nodes, with high levels of encryption making it almost impossible to trace the location of the site and its activities. This feature is highly attractive to potential buyers and sellers, as well as the platform organizers.

Transactions on these platforms are made using the cryptocurrency Bitcoin, so that payments can be made with neither buyer nor seller revealing any information about their offline identity.[10] The anonymity permitted by Tor and Bitcoin was the technological breakthrough that facilitated the emergence and rapid growth of the first big online drugs market, Silk Road. It distinguished itself from the small scale black markets that had been

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[9] Economic research based on Big Data from scraping internet sides is relatively rare, but there are some recent examples beginning to emerge: see, for example, work comparing on online and physical store (offline) prices using scraped online data from large retailers by Cavallo (2017).

[10] Where a physical product such as drugs is bought, the buyer has to provide a shipping address, so the transaction cannot be completely anonymous. Various mechanisms are used to attempt to obfuscate the buyer's identity, such as using false names, or using so-called 'drop' addresses.

operating on the Dark Web before by its highly professional website and its ability to ensure anonymity.

Silk Road also recommended that buyers and sellers use an escrow system, where the funds deposited by the buyer are withheld from the seller, and held by the platform until receipt of the goods is verified by the buyer. The platform owners make money from collecting a commission from the sales made on the website.[11] In principle the escrow system mitigates seller moral hazard, since a seller cannot just make away with the funds without sending the good, a real possibility when the transaction is illegal. However, it raises the problem of platform moral hazard – i.e. the platform stealing the funds held in escrow.

Although the original Silk Road and many other platforms recommended transaction via escrow, it has not always been used. In some situations – particularly where sellers have accumulated good reputations – sales were made on a 'finalise early' basis, which means that payment is made immediately, before the goods are received. One concern that buyer and seller may have with the escrow system is *platform moral hazard*, where the platform shuts down and takes the money. This can be avoided by a 'multi signature' escrow, whereby funds can be released only if two of three parties (the platform, the seller and the buyer) agree. Although this would mitigate if not eliminate both types of moral hazard (seller and platform), it appears to have been hardly used, possibly due to the increased transaction costs involved.

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[11] The commission on Silk Road was initially a flat rate of 6.23% of the sales price. However, as the platform's lifetime progressed this was altered to a tiered schedule (rather like on eBay), with a tapered rate with higher commissions for lower value transactions which then reduced as the sales value rose (see Christin, 2012).

Figure 1 shows a screenshot of Silk Road. It looks rather like other legal E-Commerce sites, only the merchandise on offer is evidently different.[12] The other key features are that the drugs on offer for sale are priced in Bitcoins and that the principal activity is to sell drugs, although some other (mostly) illegal items are on sale. The left hand bar shows the number of listings which, for the selected screenshot, shows 8859 drugs listings, which is by far and away the main activity on the platform.

Christin (2012) was the first to systematically scrape large amounts of data on listings from the original Silk Road and he collected data from the site from February 3, 2012 to July 24, 2012. One can find earlier information on Silk Road, with the first dating back to May 5, 2011, from various screenshots of the site's navigation page which features a count of the total number of drug listings. In what has become a highly publicised law enforcement intervention on cybercrime, the website was shut down by the FBI on 2 October 2013.[13]

From Silk Road's inception in January 2011, it ran for two and three quarter years. From the first data point from the screenshot of May 5 2011, where the site had 343 drugs listings, to just before the shutdown the number of drugs listing rose by a rose by a phenomenal nearly 3700 percent, reaching 13000 on October 1 2013 (Digital Citizen's Alliance, 2014).

Silk Road was the pioneer of online drugs trading. When shutting the platform down, the FBI referred to it as: "the most sophisticated and extensive criminal marketplace on the

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[12] Barratt (2012) and Van Hout and Bingham (2013b) remark that "'Silk Road' operates similarly to 'eBay' " and the Economist wrote on November 1 2014 about 'The Amazons of the dark net'. Aldridge and Decary-Hutu (2014), on the other hand, prefer to highlight the differences with legal online markets referring to Silk Road as 'not an eBay for drugs'.

[13] This occurred with the well-publicised arrest of Ross Ulbricht, the 29 year old libertarian American, who went to trial in January 2015 and was sentenced to life imprisonment for running Silk Road in May 2015.

internet". Many more online platforms have followed as the market has continued to grow very rapidly. Table 1 shows the lifetimes of 88 Dark Web drugs platforms that operated following the Silk Road shut down by law enforcement in the time period up to the start of 2016.[14] Maybe not surprisingly there have been a lot of new setups, many of whom did not operate for very long as the Days Open column in the Table shows. Thus platform turnover is high in this online market. But some of the bigger platforms – notably Silk Road 2, the direct descendent of the original Silk Road, Agora, Evolution and Nucleus – operated for quite some time. This is shown in Figure 2, which plots a histogram of Days Open for the Dark Web platforms listed in Table 1. It is evident that a large number of platforms enter and exit rapidly, some voluntarily and some in exit scams involving stealing the money held in the escrow service account most platforms operated. It is also interesting that, up to 2016, it is the original Silk Road that had lasted the longest, being up and running for 976 days until it was shut down.

The Post Silk Road Market

After the shutdown of the first Silk Road, it is clear that some of the sellers based there migrated to alternative Dark Web platforms. Two existing platforms (Sheep Marketplace and Black Market Reloaded), that were relatively small scale whilst Silk Road was in operation, straightaway experienced very rapid growth as is shown in Figure 3.[15] The experiences of buyers and sellers on these two platforms simply could not be more different. The number of sales listings for drugs on Sheep Marketplace was 4358 on October 17 2013

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[14] These are English language based platforms taken from Branwen (2016).

[15] There were also some smaller markets, but none took off to the extent that these two did after the demise of Silk Road.

and rose hugely to 8457 by October 30 2013. It seems the owners of the platform could not believe their luck and the market disappeared, along with money that was held in escrow and in sellers' and buyers' accounts on the site.[16] Black Market Reloaded also shut down, but this time because it seemed it could not handle the increased traffic. In a striking and almost inexplicable display of "honour among thieves", the closure was announced in advance and the platform gave users time to withdraw their funds before it disappeared. These are two early examples of the transient, and short time horizon, nature of Dark Web drugs platforms and, in the case of Sheep Marketplace, of the issues of platform moral hazard to which we have already alluded.

After this, and only 34 days after the closure of Silk Road, a new Silk Road 2.0 platform opened up. The exponential growth of the online drugs markets resumed. We ourselves began to scrape weekly listings data from Silk Road 2.0 on December 8 2013, when there were 1450 drugs listings. By the end of the year (30 December 2013), this almost doubled to 2700. By January 2014 it had reached 10228. Maybe somewhat perversely, the international media coverage that accompanied the closure of the original Silk Road may have been one factor driving the rapid growth of markets at this time.

Two highly professional platforms also entered the market soon after. These are Agora (in December 2013) and Evolution (in January 2014). We also collected data from these two platforms as they and Silk Road 2.0 became the big three players in the online drugs market in 2014. Figure 2 also plots their drugs listings through time. It shows a very big increase in the size of the market in 2014, with massive growth initially from Silk Road

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[16] Although figures are difficult to verify due to the anonymity built into the Bitcoin, various reports suggest the total amount stolen was in the millions or tens of millions of dollars.

2.0 followed by a plateauing out, and rapid trend increases for Agora and Evolution.[17] By the start of November, there were almost 40000 drugs listings on the three markets combined, reflecting a huge increase in market size.

On November 5 2014, a joint law enforcement operation (named Operation Onymous) carried out by the US Federal Bureau of Investigation (FBI), the Immigration and Customs Enforcement (ICE) Homeland Security Investigations and European law enforcement agencies managed to successfully shut down Silk Road 2.0. This took place after an FBI agent infiltrated the platform, managing to gain enough trust to be granted administrator rights. At the same time, some of the other smaller online markets were shutdown (Pandora, Cloud 9, Hydra, Blue Sky) thus causing a sizable shock to the online drugs market. The two biggest, Agora and Evolution, however, remained in place, both having a larger market share owing to the demise of Silk Road 2.0. The fact they remained unaffected by the law enforcement action may suggest that their platforms were comparatively secure, and could not be taken down by a purely technical approach.[18]

In fact, after the closure of Silk Road 2.0, these two grew rapidly, although Agora's operations became affected by the increased flow of buying and selling activity, sometimes being offline because of the increased pressures. So it was Evolution that really took off, as

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[17] Silk Road 2.0 withdrew its escrow service when it was subject to a major hack on February 13 2014. There are varying reports, but at least 4400 bitcoins (worth $2.6 million at the time) were stolen. The site's reputation may well have suffered from this, and likely contributed to the slowdown in its growth.
[18] That said, as already noted, Silk Road 2 was infiltrated by FBI agents not through any sophisticated technological means, but by more 'traditional' undercover agent activity. Indeed the head of European police cybercrimes division said Evolution was not part of Operation Onymous it was "because there's only so much we can do on one day". See http://www.dw.com/en/raids-on-underground-darknet-websites/a-18048251.

the trends shown Figure 3 make clear, and became the market leader.[19] Evolution exited the market in March 2016, in an exit scam where the platform owners reputedly ran off with more than $12 million.[20] Agora continued to grow, but finally its operating troubles took their toll, and it left the market in August 2016.[21] Yet again, these exits resulted in very rapid growth of a new platform, Nucleus, which in turn became the market leader, until it too left the market in March 2016 in another exit scam.

Web Scrapes

Unlike other black markets, detailed time series data covering the items on sale, prices, and rated transactions, is readily available from scraping the websites of these online platforms. We began scraping data from the original Silk Road in August 2013, obtaining some full scrapes of its listings (although not actual transactions) prior to its market exit in October 2013. When Silk Road 2.0 opened, we began to scrape its site from December 2013. We also started scraping the Agora website in December 2013, Evolution in January 2014 and Nucleus when it opened in November 2014. Thus we have data on drugs listings and purchases for essentially the full lifetimes of four of the largest Dark Web drugs platforms. This permits an empirical analysis that focuses in detail on the way in which these online platforms function, with data on actual drug prices and sales, for a wide range of different drugs, which allow a unique and large-scale insight into the functioning of illicit markets.

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[19] This greater increase in market share comes in part from the fact that Evolution was more available (i.e. had better uptime) than Agora. Agora regularly went offline due to traffic surges, and people were worried (and stated so in the online forums) they were going to disappear with all the escrow funds.
[20] https://www.theguardian.com/technology/2015/mar/18/bitcoin-deep-web-evolution-exit-scam-12-million-dollars
[21] Agora was taken off line and closed voluntarily with administrators claiming problems of server issues with security and suspicious activity. They let all customers and vendors take out all of their money first. At the time, they stated that had plans on improving security, after which they would return. This never materialised.

3. Reputations Analysis

We first study reputation mechanisms and their economic impact. This is feasible because, as with many legal online markets, there is a rating system where buyers rate sellers.

The starting point is an empirical analysis that, in some respects, resembles studies of online legal markets. There are a number of empirical papers on eBay and Amazon, mostly cross-sectional in nature (see, for example, Houser and Wooders, 2006, or Resnick and Zeckhauser, 2002, for eBay and Mudambi and Scuff, 2010, for Amazon). A panel data paper on the dynamics of seller reputation by Cabral and Hortacsu (2010) is closer in spirit to what we study here. They analyse a sample of very specific products sold on eBay (IBM Thinkpads, Collectible coins, and 1998 Holiday Teddy Beanie Babies), and find that only 0.3 percent of sales are negatively rated, and a further 0.4 percent rated neutral. Cabral and Hortacsu provide evidence that, on receiving negative feedback ratings, the subsequent growth rate of sales declines and this also triggers a faster rate of arrival of negative feedbacks.

Descriptive Statistics

The existence of a rating system for buyers on most of the online Dark Web drugs markets means an analogous exercise can be conducted for the case of illegal drugs. Table 2 shows descriptive information on the numbers of rated sales, both from Christin's (2012) original Silk Road scraped data and from our own scraped data from Silk Road 2.0, Agora, Evolution and Nucleus.[22] Summary statistics are presented separately by site and, in the final column of the Table, are aggregated over the five platforms.

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[22] Example screenshots for Silk Road 2.0, Agora, Evolution and Nucleus are given in the Appendix.

The Table shows information on over 1.5 million rated sales of drugs. It also confirms that drug selling is the main, though not exclusive, activity on the websites. The vast majority of rated sales on Silk Road 2.0 (92 percent), Agora (92 percent) and Nucleus (88 percent) were drugs sales. The percentages in the original Silk Road (79 percent) and Evolution (73 percent) were lower, reflecting that these platforms did sell other illicit goods, most notably counterfeit goods, money and documents, and other fraud-related listings. Weapons sales were banned on Silk Road and Silk Road 2.0 and, whilst weapons listings were present on Agora, Evolution and Nucleus over the period of study, rated sales were extremely uncommon. The smallest share of drug sales for Evolution – with a higher proportion of sales in fraud-related categories - is probably a result of the site's origins, which reportedly trace back to an online 'carding' forum known as Tor Carding Forum.[23]

Table 2 also breaks down the number of drugs sales (and the percent of all drugs sales in square parentheses) into the broad classifications the websites use, namely cannabis, dissociatives, ecstasy, opioids, prescription, psychedelics, stimulants and a catch-all 'other' category. All of the markets sold drugs in each of these broad categories. The Table also makes it quite clear that the transactions were typically relatively small, with the median price across markets being in the range of 36 to 45 pounds.[24] That the 'typical' demographic of buyers on these markets is of consumers purchasing relatively small amounts of drugs for their own consumption is confirmed in the qualitative study of Silk Road consumers by Van Hout and Bingham (2013a).

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[23] In this context 'carding' refers to fraudulent use of credit cards.
[24] Prices were converted to pounds using the bitcoin exchange rate prevailing on the date that the listing was observed.

Ratings Analysis

Table 3 shows the descriptive results from the analysis of ratings. It shows the percentage of ratings that are positive, neutral or negative by website, and by drug classification. The overall impression the Table gives is very much one of positive ratings of product quality. There are some negative feedbacks, but the overall percentage is small. For all drugs transactions on the four platforms around 1.2 to 2.9 percent of ratings are negative. A further 1.8 to 3.7 are neutral, meaning that between 94.5 to 96.9 percent receive positive ratings. So there are slightly more negative ratings than the case of eBay noted earlier. These relatively small percentages of unsatisfactory ratings are noteworthy when one considers that these are illegal transactions in market where lack of trust is likely to be widespread.

How are good service and product quality maintained? Buyers not only rate the transaction, but also provide feedback comments. An investigation of the comments given for negative feedbacks only acts to reinforce the impression that these markets function well, with few deals involving products of poor quality. The majority of the negative feedback comments pertain to problems linked to shipping, rather than the quality of the product. One feature of the online drugs markets is the presence of various forums on the Dark Web where buyers and users of the sites have a very active discussion about what happens on these platforms, including frequent discussion of sellers who do not offer good deals and who renege on transactions ('scammers' is a frequently used name both in the feedback comment and on the forums; not surprisingly, more derogatory terms are used as well).

Looking across drug types and platforms reveals a degree of heterogeneity. Some platforms seem to do better, and this is likely due to some events and the perceptions of security and risk on the different platforms contributing to the observed differences in ratings

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performance. In particular, over their whole lifetimes in operation Evolution, the only site claiming to offer multi-signature escrow, and the original Silk Road have the fewest negative ratings, with respectively an overall 1.3 percent (Evolution) and 1.2 percent (Silk Road). The ratings of Silk Road 2.0 were initially similar to the original Silk Road, but some events occurred that seem to damage the platform's reputation. In particular, the hack of the website that took place in February 2014 (referred to in footnote 16) seemed to damage the ratings and sales of the platform. [25] Finally, the highest percent of negative ratings are for Agora (at 2.6 percent) and Nucleus (at 2.9 percent). For Agora, this seems to be because Agora has had periods where they faced difficulties processing financial transactions in a timely manner, with one particular set of problems occurring due to large trading volumes after the Silk Road 2.0 shutdown as buyers and sellers migrated to the site. This particular event can be seen clearly in Figure 4 which shows the weekly drugs revenues by platform, where Agora's sales revenue dips sharply in a week of late November 2014. Nucleus also seemed to face more volatility in the time leading up to their ultimate exit in March 2016 (see the revenue dip in Figure 4).

In terms of ratings for different drug types, the numbers in the Table seem to show a coherent pattern, with some platform specific differences. The latter may well be tied to particular sellers on the sites. Overall, there seem to be fewer bad ratings of prescription drugs and the biggest selling drug, cannabis, also seems to be well rated across sites. The same is mostly true for stimulants (the main drug here is cocaine) and psychedelics (like LSD and acid). The worst rated seems to be Dissociatives (which are mostly hallucinogenic drugs),

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[25] For example, at the start of 2014, before they encountered some difficulties, Silk Road 2.0 ratings were better. In January 2014, for example, only 0.9 percent were rated negative. By July 2014, this had risen to 2.1 percent.

although this varies by site. Evolution seems to have easily its worst ratings here, after being largely the best across the other drug types. Closer inspection reveals this is dominated by one quite big seller with a large share of negative ratings.[26] Similarly Ecstasy is well rated on the sites, except for Nucleus. Thus the ratings are, for the most part, good. Buyers are very active on the online forums and willing to widely share information regarding their bad experiences with specific vendors. Moreover, the majority of the negative ratings are probably not for receipt of low quality drugs, but to reflect scams or delivery problems.

To further demonstrate this, a text analysis of the 32574 negative ratings on the four platforms was undertaken. An initial word search was implemented to identify text listings that raised issues of product quality, scams and delivery problems, and from this it proved possible to classify 24750, or 76 percent, of the text listings to these three broad groups. We then went through the remaining 7824 trying to classify them. Some of this was necessarily ad hoc and, at the end of the day, some could not be coherently classified, but the end result gave the following distribution of reasons for negative ratings: product quality = 6.6 percent; scams = 28.7 percent; delivery problems = 60.2 percent; not classifiable = 4.4 percent.

Of course, this text analysis has limitations, but it is suggestive that the percentages of negative ratings in many cases are not so much to do with poor quality drugs, but rather to do with the scams and delivery problems that are a feature of the online transactions. This issue will be returned to shortly, when the relatively low number of negative ratings as compared to drug ripoffs on street markets are considered. Before moving on to that, the

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[26] The one seller alone accounts for 31 percent of the 231 negative ratings for Dissociatives on Evolution.

results from the statistical analysis examining whether acquisition of a negative reputation impacts seller economic performance, and by how much, are reported.

Reputations and Seller Performance

Does seller reputation harm seller performance? This hypothesis is examined by looking at individual seller performance over time on each of the platforms, examining whether, and to what extent, receipt of negative ratings damages sales. This is investigated by putting together a panel of seller transaction histories over the lifetimes of each of the four platforms from which data were scraped. We put together a monthly panel of sales, where we can exploit the longitudinal nature of the data to look at the impact of receipt of negative rating on sales within sellers over time.

Specifically, consider the following equation for sales (S) made by seller s in time period t (where t is month by year) on a given platform:

$$\log(S_{st}) = \alpha_s + \gamma \text{Neg}_{s,t-1} + \alpha_t + v_{st} \tag{1}$$

where $\text{Neg}_{s,t-1}$ is the proportion of negative ratings received in the previous month, α_s and α_t are respectively seller and time (month-year) fixed effects and v is an error term. This empirical model includes controls for seller and time fixed effects and therefore investigates within-seller/drug variations that control for unobserved seller time invariant factors

Table 4 shows the results emerging from estimating equation (1), first for all four platforms pooled together (in column (1)) and then separately for sellers on Silk Road 2.0, Agora, Evolution and Nucleus (respectively in columns (2) to (5)). Considering first the pooled specification in column (1), it is evident that there is a significant sales penalty associated with acquiring a bad reputation through negative ratings. On average, if 10

percent of sales receive a bad rating in a given month, sales are about 20 percent lower in the following month.

Columns (2) to (5) show this negative effect on sales effect following receipt of negative ratings is present, and of similar magnitude, across all four sites. If anything, the penalty is slightly less negative on the platforms that were shown to have better overall ratings in Table 3. But overall it is a clear feature of these four sites that if a seller obtains higher percentages of negative ratings than the average that would lead to big reductions in subsequent sales.

These panel estimates could understate the overall scale of punishment for negative ratings, as they are estimated for sellers continuously in the market. It is likely that continually bad ratings increase the probability of seller exit from the market. We consider this in an analysis of the exit probability of sellers that, the results of which are reported in Table 5. Given that all four platforms do shut down in the periods we look at, the results show estimates of the probability that a seller exits (before the month in which the platform shuts down) as a function of the previous rating history. Sellers with poor rating histories are significantly more likely to exit. This is the case across all the platforms that are studied.

Thus in a way analogous to studies of legal online markets, the economic performance of Dark Web drugs sellers is significantly harmed by receipt of negative ratings from buyers. The online illegal markets function in a similar way to legal markets - consumers react to a decline in seller reputation by reducing purchases.

Comparison of Ratings with Street Drug Markets

The overall picture of drugs sales on the Dark Web sites is one of good quality and service, with issues of moral hazard less prevalent than one might initially surmise. Moral

hazard problems with drugs trades on the street are well known. The face-to-face nature of these trades (usually between dealer and buyer) means that quality typically cannot be verified before purchase, and so it is easy to get duped into buying drugs of low or no purity. Moreover, relative to the anonymous online trades, there is a real possibility of violence, especially in the settings where street trades occur.[27]

It seems natural to compare problems of product quality between the online and street markets. Galenianos, Pacula and Persico (2012) have calculated the percent of ripoffs from purchase of drugs on the street when US undercover police have actually bought drugs and then tested their quality, as part of the data they compile under the System to Retrieve Information from Drug Evidence (STRIDE).[28] Table 6 compares the percent of negative ratings for heroin and cocaine for the five online platforms with the percent of street ripoffs from the Galenianos, Pacula and Persico analysis. The online negative rating percent is much lower than the STRIDE ripoffs percent. For heroin, the negative ratings percent ranges from 0.9 to 3.2 percent, and for cocaine from 1.4 to 3.8 percent. The STRIDE percent ripoffs are 8.2 percent for heroin and 7.2 percent for cocaine. Thus product quality is substantially higher online as compared to street transactions. This is striking; moreover, the gap between the two is likely understated because not all the negative ratings come about because of poor product quality, as many are to do with communications/delivery problems.

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[27] This is backed up by numbers from the Global Drug Survey of 2015, a voluntary online survey of more than 100,000 drug users. In the survey, 3.3 percent of online drugs buyers reported threats to personal safety as compared to a much higher 17.9 percent of non-online drug buyers; 1.3 percent of online buyers reported experiencing physical violence as compared to 7.3 percent of non-online drug buyers.

[28] Galenianos and Gavazza (2017) argue, based on the same data, that legalization would substantially reduce the adulteration of drugs sold on the street.

4. Market Dynamics

As the analysis to date has made clear, the online market for drugs is a volatile one; platform entry and exit has been frequent. Nonetheless, the service is of surprisingly high quality. Moreover, platform exits of both major players in the market and of the smaller, shorter lived platforms, have taken different forms. These have included the high profile shut downs by law enforcement, exit scams where platform owners have run off with the money being held by the site (in escrow and/or in buyers' and sellers' accounts), and voluntary exit. In this section, we look at how the overall market has evolved in response to some of the major exits. We focus in particular on what happened to the market before and after three major exits, where the market leader at the time exited. These are the law enforcement shuts downs of the original Silk Road and Silk Road 2.0 that occurred in October 2013 and November 2014 respectively, and the exit scam of Evolution of March 2015.

From an economics of crime perspective, it is interesting to study whether the shutdown of sites has a deterrence effect on buyers, sellers or potential new platforms that may enter the market. For buyers, shutdown does not result in a financial loss, unless they have a transaction in escrow or funds deposited in order to make a purchase. However, the probability of a shutdown affecting any individual transaction is so small that this is unlikely to have a major deterrent effect. Thus the only way in which a shutdown might affect buyers is by suggesting that their identities may be compromised and found by law enforcement. For sellers, the financial consequences of a shutdown are somewhat larger, but still very small. Finally, since the platform is a direct target, there is some chance that a shutdown might deter individuals from starting new platforms. To explore these issues, empirical evidence on the effects of shut downs is considered next.

For all three episodes, it is hard to find any evidence of deterrence; in each case the overall market rebounds quickly after shutdown. Indeed, in each case, the overall market is at least as big or bigger three months after the market leader exit than it was before. This suggests the online drugs market is responding flexibly to shocks as demand does not seem to be affected by the loss of the market leader. Indeed, the publicity accompanying the shutdowns may well have attracted new buyers to online markets, so increasing the size of the market. We now consider each of the three major market exits in turn.

1). Shutdown of Silk Road

Table 7 shows the number of drugs listings on Dark Web drugs platforms before and after the closure of the original Silk Road. At the time of closure, Silk Road was the major player in the online drugs market and had just under 9000 drugs listings. Black Market Reloaded, Sheep Marketplace and Deepbay were smaller platforms with a total of 5174 listings between them, so that the overall market size in terms of listings was just over 14000.

As was described in Section 3 and is shown in Figure 2, after Silk Road was closed, the market first became volatile as sellers migrated to Sheep Marketplace, Black Market Reloaded and Silk Road 2.0, a new site that was opened 34 days after the closure of the original Silk Road. But the growth of the overall market rapidly got back on trend and subsequently grew even faster. By January 2014 Silk Road 2.0 itself had 10228 listings and new online drugs platforms entered, most notably Agora and Evolution as the start of the 'big three' began, but also some small markets. By April 2014, as Table 7 shows, there were around 32000 drugs listings on these sites, 128 percent higher than at the time the original Silk Road was shut down. Thus, there is no evidence whatsoever of deterrence effects. In fact, it seems much more likely that the media coverage of the shutdown probably alerted

potential buyers and sellers, who may not have known about the existence of these online markets before. Thus the shutdown of Silk Road may well have contributed to the rapid growth in the online drugs market.

2). Shutdown of Silk Road 2.0

The second significant shutdown by law enforcement was when Silk Road 2.0 was closed on November 5 2014. Table 8 shows the number of drugs listings and total sales revenue in each month of 2014 and in the first two months of 2015 for the big three platforms. It is evident from the Table that the rapid growth of the online drugs market continued right up to the Silk Road 2.0 shutdown. For example, just before that event in October 2014, there were over 36,000 drugs listings on all three sites and revenues reached a total of around $26 million a month.

The numbers in the Table also show what happened after the Silk Road 2.0 shutdown. There are a few things to note. The first is that Evolution grew very rapidly and became the clear market leader by February 2015. Its drugs listings rose from 9226 in October 2014 up to 14767 by December 2014, a rise of 60 percent in just two months. It continued to grow in 2015, reaching 18554 drugs listings in February 2015. Sales revenues on Evolution rose very rapidly, going from $5.0 million in October 2014 to $12.8 million in February 2015, a rise of 156 percent.

The second point of note is that Agora also first experienced a post-shutdown boom, with sales revenues rising up to $13.9 million in November and further rising to $14.3 million in December. But it also had some trouble coping with the influx of new demands to buy and sell on the website at the time, the result of which was a dip down in sales revenues in the first two months of 2015.

Thirdly, these patterns of change mean that the overall market size did take a hit following the Silk Road 2.0 closure. However, when the market reconstituted to have two main players rather than three, their sales performance went up compared to before the shutdown. Indeed, by December, sales revenues had bounced back to the pre-shutdown levels, at around $26 million. Therefore Operation Onymous, and its successful seizure of the Silk Road 2.0 site, seemed to have had an impact on the market, but only as a short-term transitory shock, rather than permanently reducing drug sales on the Dark Web.

3). Exit Scam of Evolution

When it was market leader in March 2015, with nearly 20000 listings and with weekly sales revenues of over $4 million, the operators of Evolution shut down the site in an exit scam, taking the escrow funds. Table 9 shows online drugs listings the day before the shutdown (on March 17 2015) and then just over a month later on April 21. There were a total of nearly 42000 listings on March 17, of which almost half were on Evolution (comprising 19902 listings).

The highly resilient nature and rapid dynamics of the online drug markets are very clearly illustrated by what happened after the Evolution exit scam. First of all, there were already more listings only a month following the scam, at 43622 by April 21. Thus the overall market rebounded very rapidly and continued to grow after the scam. Second, this arose because of modest growth in traffic on Agora, which at the time of the scam was, by some distance, the second biggest online platform. Third, very rapid growth occurred at Nucleus and Black Bank Bitcoin, with each increasing their listings by around 5000 following the scam. As noted above, and shown in Figure 2, Nucleus would itself become the market leader

in due course. There is also the emergence of Alphabay which goes from less than 300 listings in March to over 2500 by April 21.[29]

Summary

Overall, it is not possible to find evidence of deterrent effects associated with either the two law enforcement shutdowns or the exit scam. In the case of the original Silk Road, the overall market grew very rapidly indeed as new players entered the online drugs trade and buyers and sellers quickly gravitated towards them. The publicity surrounding the shutdown of Silk Road seems likely to have attracted new traffic. In the case of Operation Onymous, and its take down of Silk Road 2.0 and some smaller sites, the big players in the Dark Web drugs trade (Agora and Evolution) were unable to be infiltrated and shut down by law enforcement. After this, they grew rapidly in terms of listings suggesting that new sellers were using these platforms. This was most likely driven by the pattern of migration of sellers that we have shown. The faster growth in sales revenue than listings also implies consumers switched to them after the Silk Road 2.0 shutdown, overall implying little evidence of deterrence effects on sellers and buyers from the law enforcement success of shutting down the Silk Road 2.0 platform. Finally, the market reconstituted itself rapidly after the Evolution exit scam, with the total number of drugs listings being higher a month later, as Agora became the new market leader and Nucleus grew very rapidly.

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[29] After the demise of Agora and Nucleus, Alphabay became the biggest online market and, at December 2016, was the market leader in online drugs sales.

5. Conclusions

In this paper data scraped from online drug platforms on the Dark Web is studied, with an aim of better understanding their economic functioning and the extent to which problems of moral hazard impact on them. Analysis of over 1.5 million drugs sales reveals that the online drugs markets function, for the most part, without the significant moral hazard problems that *a priori* one might think would constrain their operation. Only a small minority of online drugs deals receive bad ratings from buyers and, as with legal online markets, these bad ratings subsequently lead to significant sales reductions. Moreover, poor product quality, and the likelihood of being 'ripped off' in purchasing drugs, seems to be less of a problem for drug consumers than in street purchases.

The market also seems resilient, despite high turnover of the platforms that host the buyers and sellers of drugs. Indeed, following the well-known seizure of the original Silk Road, the shutdown of Silk Road 2.0 by law enforcement and an exit scam by Evolution (the market leader at the time of exit), there is little evidence that these closures – and the publicity surrounding them - deterred buyers or sellers from continuing to engage in the online drugs trade. As with legal online markets, illegal online markets are substituting for offline economic activity (for drugs, street transactions) as drugs buyers and sellers increasingly ply their trade online, a trend that seems likely to continue to increase in the future.

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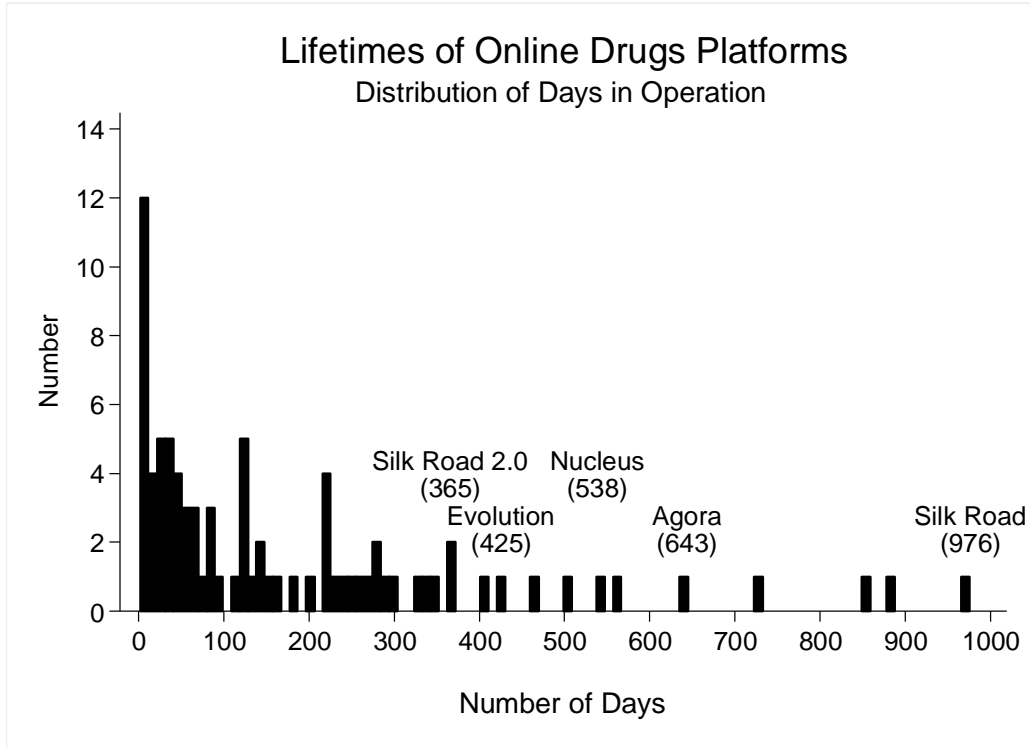
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Figure 1: Silk Road Example Screenshot

Figure 2: Lifetimes of Online Drugs Platforms

Lifetimes of Online Drugs Platforms
Distribution of Days in Operation

Notes: Calculated for the 83 platforms with complete lifetimes listed in Table 1.

Figure 3: Online Drugs Listings By Platform, 2011-2016
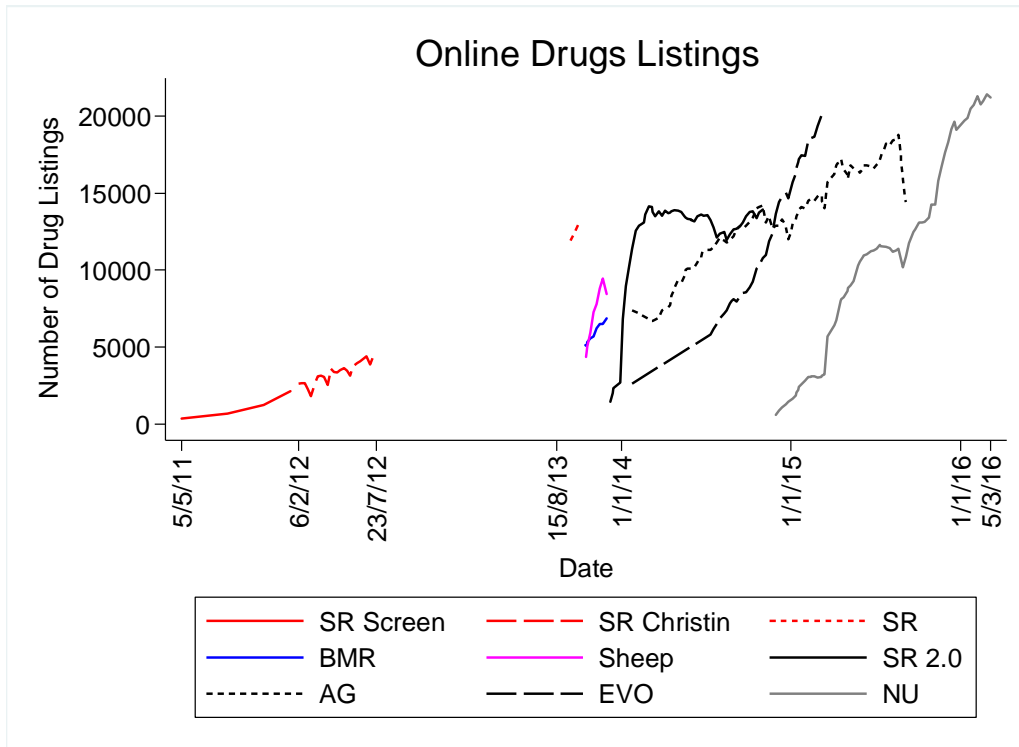
Notes: SR Screen - Silk Road screenshots; SR Christin - Silk Road numbers from Christin's (2012) data; SR – Silk Road from Aldridge and Decary-Hutu (2014) and Digital Citizen's Alliance (2014); SR 2.0 - Silk Road 2.0, own scrapes; BMR – Black Market Reloaded, own scrapes; Sheep – Sheep Marketplace, own scrapes; AG - Agora, own scrapes; EVO – Evolution, own scrapes; NU – Nucleus, own scrapes.

Figure 4: Weekly Drugs Revenues By Platform, 2013-2016
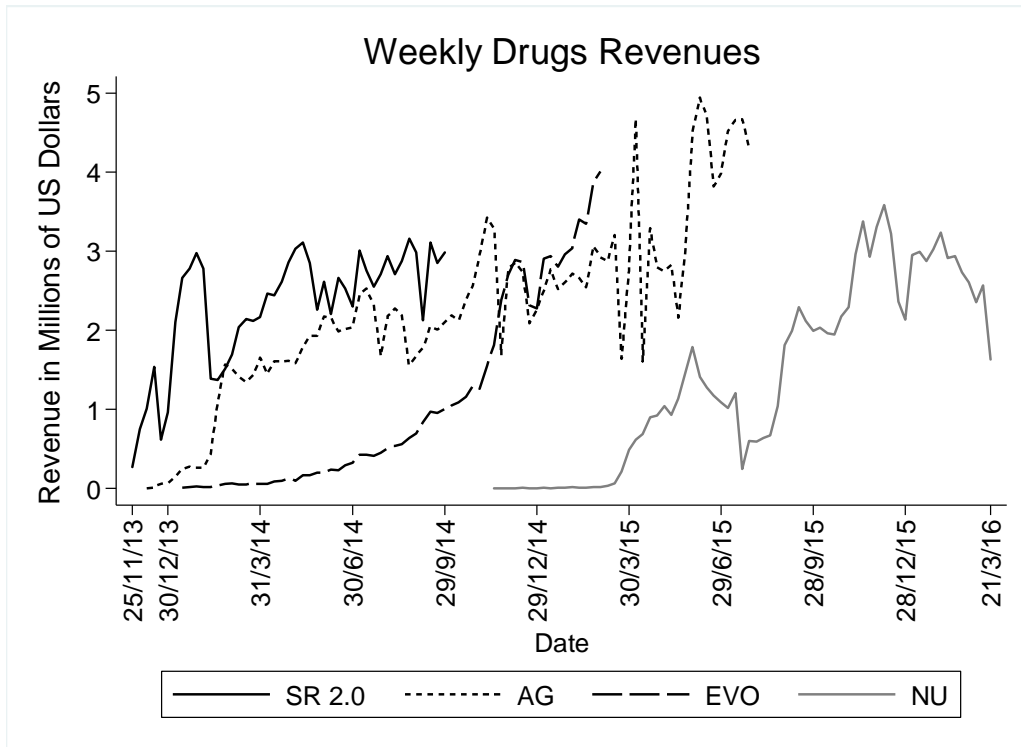
Notes: SR 2.0 – Silk Road 2.0, own scrapes; AG - Agora, own scrapes; EVO – Evolution, own scrapes; NU – Nucleus, own scrapes. Own calculations. See Appendix for issues calculating revenues.

Table 1: Chronology of Online Drugs Platforms

Market	Opened	Closed	Days Open	Reason for Closure
Silk Road	31 January 2011	2 October 2013	976	Shut down
Black Market Reloaded	30 June 2011	2 December 2013	887	Hacked
Sheep Marketplace	28 February 2013	29 November 2013	275	Scam
Atlantis	26 March 2013	20 September 2013	179	Scam
BuyItNow	30 April 2013	17 February 2014	294	Voluntary
Deepbay	30 June 2013	4 November 2013	128	Scam
Budster	10 October 2013	20 October 2013	11	Scam
Project Black Flag	14 October 2013	28 October 2013	15	Scam
Pandora	21 October 2013	19 August 2014	303	Scam
Silk Road 2	6 November 2013	5 November 2014	365	Shut Down
TorMarket	7 November 2013	22 December 2013	46	Scam
BlackBox Market	12 November 2013	1 February 2014	82	Voluntary
Dream Market	15 November 2013			
The Marketplace	28 November 2013	9 November 2014	347	Voluntary
Pirate Market	29 November 2013	15 August 2014	260	Scam
FloMarket	1 December 2013	1 January 2014	32	Hacked
Black Services Market	2 December 2013	1 February 2014	62	Scam
FreeBay	2 December 2013	28 February 2014	89	Voluntary
Blue Sky	3 December 2013	5 November 2014	338	Shut Down
Agora	3 December 2013	6 September 2015	643	Voluntary
Tortuga	16 December 2013	5 January 2014	21	Voluntary
TorBay	18 December 2013	20 April 2014	124	Voluntary
White Rabbit	23 December 2013	1 February 2014	41	Scam
Outlaw Market	29 December 2013			
GreyRoad	4 January 2014	1 February 2014	29	Voluntary
drugslist	8 January 2014	28 February 2014	52	Scam
Evolution	14 January 2014	14 March 2015	425	Scam
Doge Road	18 January 2014	13 March 2014	55	Scam
Cantina	20 January 2014	7 February 2014	19	Hacked
TorBazaar	26 January 2014	5 November 2014	284	Shut Down
DarkBay	30 January 2014	1 May 2014	92	Voluntary
Breaking Bad	1 February 2014	6 February 2014	6	Voluntary
TorEscrow	2 February 2014	19 April 2014	77	Scam
Black Goblin Market	3 February 2014	4 February 2014	2	Hacked
Cannabis Road	3 February 2014	7 February 2014	5	Hacked
Utopia	3 February 2014	11 February 2014	9	Shut Down
BlackBank Market	5 February 2014	18 May 2015	468	Scam
Armory Vendor Market	6 February 2014	7 April 2014	61	Scam
Cloud Nine	11 February 2014	5 November 2014	268	Shut Down
Darknet Nation	19 February 2014	1 March 2014	11	Hacked
Sanitarium Market	20 February 2014	28 March 2014	37	Voluntary
Hansa	9 March 2014	20 March 2014	12	Voluntary
Red Sun Marketplace	20 March 2014	23 March 2014	4	Hacked
EXXTACY	23 March 2014	24 March 2014	2	Hacked
Topix 2	25 March 2014	5 November 2014	226	Voluntary
Hydra	27 March 2014	5 November 2014	224	Shut Down
Cannabis Road 2	28 March 2014	25 August 2014	151	Scam
Mr Nice Guy	29 March 2014	20 April 2014	23	Voluntary

Andromeda	5 April 2014	18 November 2015	228	Scam
Silk Street	8 April 2014	4 August 2014	119	Scam
Underground Market	9 April 2014	26 August 2014	140	Voluntary
Pigeon Market	14 April 2014	7 May 2014	24	Voluntary
1776	19 April 2014	2 October 2014	167	Voluntary
Alpaca Marketplace	20 April 2014	5 November 2014	200	Scam
Tortuga 2	23 April 2014	17 June 2014	56	Voluntary
TOM	10 May 2014	18 December 2014	223	Scam
Deepzone	14 May 2014	13 July 2014	61	Voluntary
Onionshop	18 May 2014	17 September 2014	123	Hacked
Area51	20 June 2014	24 January 2015	219	Scam
Middle Earth Marketplace	22 June 2014	4 November 2015	501	Scam
Freedom Market	16 September 2014	25 September 2014	10	Voluntary
Cannabis Road 3	6 October 2014	5 November 2014	31	Scam
Diabolus/SR3	13 October 2014	12 February 2017	854	????
Nucleus Marketplace	24 October 2014	13 April 2016	538	Scam
Panacea	27 October 2014	13 February 2015	110	Voluntary
Abraxas	13 December 2014	5 November 2015	328	Scam
Alphabay	22 December 2014			
Silk Road Reloaded	13 January 2015	27 February 2016	411	????
Free Market	14 January 2015	26 February 2015	44	Voluntary
Tochka	30 January 2015			
Crypto Market	14 February 2015	12 February 2017	730	Scam
Kiss	19 February 2015	16 May 2015	87	Scam
Mr Nice Guy 2	21 February 2015	14 October 2015	236	Scam
Ironclad	17 March 2015	25 March 2015	9	Scam
TheRealDeal	9 April 2015	22 October 2016	563	????
Havana/Absolem	13 April 2015	22 May 2015	40	Hacked
Oxygen	16 April 2015	27 August 2015	134	Scam
East India Company	28 April 2015	1 January 2016	249	Scam
Haven	5 May 2015	6 June 2015	33	Scam
Anarchia	7 May 2015	9 May 2016	369	????
Zanzibar Spice	7 May 2015	14 June 2015	39	Voluntary
Tornado	12 May 2015	20 May 2015	9	????
Horizon Market	23 May 2015	8 July 2015	47	Scam
Darknet Heroes League	27 May 2015			
Agape	29 May 2015	4 June 2015	7	Voluntary
Poseidon	2 June 2015	29 June 2015	28	Scam
Amazon Dark	8 June 2015	25 October 2015	140	Scam
Simply Bear	20 June 2015	21 October 2015	124	Scam

Notes: Amended from the Branwen (2016) dataset of English language online drugs markets, https://www.gwern.net/Black-market%20survival. Days open calculated inclusive of start and end date.

Table 2: Descriptive Statistics on Numbers of Rated Sales on Dark Web Drugs Markets

Platform	Silk Road	Silk Road 2.0	Agora	Evolution	Nucleus	Total
Time Coverage	May 2011 to July 2012	November 2013 to October 2014	December 2013 to August 2015	January 2014 to March 2015	November 2014 to March 2016	
Total	184796	335832	597745	346961	358788	1824122
Of which:						
Drugs	145485 [79]	309493 [92]	550627 [92]	253869 [73]	314674 [88]	1574148 [87]
Of which:						
Cannabis	42373 [29]	79600 [26]	167193 [30]	83228 [33]	99490 [32]	471884 [30]
Dissociatives	4082 [3]	9024 [3]	16520 [3]	5393 [2]	7838 [2]	42857 [3]
Ecstasy	26656 [18]	50987 [16]	79815 [14]	34605 [14]	42109 [13]	234172 [15]
Opioids	8472 [6]	11214 [4]	53015 [10]	22889 [9]	28561 [9]	124151 [8]
Prescription	11828 [6]	47372 [15]	32846 [6]	18029 [7]	19462 [6]	129537 [8]
Psychedelics	23937 [16]	47527 [15]	69371 [13]	25703 [10]	24438 [8]	190976 [12]
Stimulants	19772 [14]	57553 [19]	128686 [23]	62357 [25]	91480 [29]	359848 [23]
Other	8365 [6]	6216 [2]	3181 [1]	1665 [1]	1296 [0]	20723 [1]
Number of Drugs Sellers	902	796	2604	1754	1836	
Median Drugs Price in Bitcoins	9.22	0.13	0.22	0.18	0.20	
Median Drugs Price in GB Pounds	35.53	42.43	44.54	37.48	41.30	

Notes: Silk Road numbers from Christin's (2012) data. Silk Road 2.0, Agora, Evolution and Nucleus numbers from downloads of each Dark Web platform. Percent shares (rounded to the nearest full integer) shown in square parentheses.

Table 3: Ratings Analysis

	Silk Road				Silk Road 2.0				Agora			
	Number	Percent of Ratings			Number	Percent of Ratings			Number	Percent of Ratings		
		Positive	Neutral	Negative		Positive	Neutral	Negative		Positive	Neutral	Negative
All Drugs	145485	96.1	2.7	1.2	189628	94.8	3.3	1.9	550627	95.3	2.1	2.6
Cannabis	42373	96.4	2.6	1.0	48882	94.0	4.0	2.0	167193	95.0	2.3	2.7
Dissociatives	4082	96.8	2.4	0.8	5548	95.4	3.0	1.6	16520	93.8	2.5	3.7
Ecstasy	26656	96.0	2.7	1.3	30215	95.6	2.7	1.7	79815	95.3	1.9	2.8
Opioids	8472	96.5	2.3	1.2	7071	93.6	3.4	3.0	53015	94.9	1.8	3.3
Prescription	11828	97.0	2.0	1.0	29366	96.0	3.2	1.8	32846	96.5	1.7	1.8
Psychedelics	23937	97.1	2.1	0.8	28435	96.6	2.2	1.2	69371	96.9	1.6	1.5
Stimulants	19772	93.3	4.7	2.0	35939	92.8	4.9	2.3	128686	94.6	2.5	2.9

	Evolution				Nucleus			
	Number	Positive	Neutral	Negative	Number	Positive	Neutral	Negative
All Drugs	253689	96.9	1.8	1.3	314674	94.5	2.6	2.9
Cannabis	83228	96.7	2.0	1.3	99490	94.7	2.8	2.5
Dissociatives	5393	93.4	2.3	4.3	7838	92.8	3.5	3.7
Ecstasy	34605	96.8	1.8	1.4	42109	93.1	2.3	4.6
Opioids	22889	98.0	1.1	0.9	28561	95.2	2.2	2.6
Prescription	18029	97.8	1.3	0.9	19462	96.6	1.2	2.2
Psychedelics	25703	97.5	1.4	1.1	24438	95.0	2.5	2.5
Stimulants	62537	96.8	1.9	1.3	91480	94.2	3.5	2.3

Notes: As for Table 2. The Silk Road 2.0 numbers are different from those in Table 2 because the platform stopped the ratings system when redesigning the website in July 2015 and did not reinstate it subsequently.

Table 4: Monthly Sales and Negative Ratings

	Log of Monthly Sales				
	All Four Platforms	Silk Road 2.0	Agora	Evolution	Nucleus
	(1)	(2)	(3)	(4)	(5)
Proportion of Sales Rated Negative [t-1]	-2.011 (0.091)	-1.712 (0.253)	-2.207 (0.182)	-1.759 (0.299)	-2.014 (0.117)
Seller Fixed Effects	Yes	Yes	Yes	Yes	Yes
Time Fixed Effects	Yes	Yes	Yes	Yes	Yes
R-Squared	0.68	0.76	0.64	0.72	0.70
Sample Size	31393	4086	13190	5849	8268
Number of Sellers	5094	626	1853	1259	1356

Notes: The dependent variable is the log of monthly sales by seller. Sample consists of sellers with at least three contiguous monthly observations. Standard errors clustered by seller in parentheses.

Table 5: Probability of Exit and Negative Ratings

	Probability of Exit Before Shutdown				
	All Platforms	Silk Road 2.0	Agora	Evolution	Nucleus
	(1)	(2)	(3)	(4)	(5)
Mean Proportion of Sales Rated Negative [t-1]	1.658 (0.120)	6.510 (1.156)	2.397 (0.282)	1.959 (0.371)	1.214 (0.138)
Control For Number of Months	Yes	Yes	Yes	Yes	Yes
Platform Fixed Effects	Yes	No	No	No	No
Number of Sellers	5094	626	1853	1259	1356

Notes: The dependent variable is a dummy variable for whether the seller exits the platform before the shutdown month. Sample consists of sellers with at least three contiguous monthly observations. Probit marginal effects reported, with standard errors in parentheses. Specifications include control for number of months observed.

Table 6: Online Ratings of Heroin and Cocaine as Compared to Street Market Ripoffs

	Rated Sales From Online Drugs Markets					Street Purchases
	Silk Road	Silk Road 2.0	Agora	Evolution	Nucleus	DEA STRIDE
Dates	May 2011 to July 2012	November 2013 to October 2014	December 2013 to August 2015	February 2014 to March 2015	November 2014 to April 2016	1981 to 2003
Heroin						
Percent Negative Rated Sales/ Street Ripoffs	1.3	3.0	3.2	0.9	2.6	8.2
Number of Rated Sales/Street Purchases	6021	4579	22144	16312	19339	12721
Cocaine						
Percent Negative Rated Sales/ Street Ripoffs	1.4	2.5	3.8	1.6	2.8	7.2
Number of Rated Sales/Street Purchases	10726	15004	44310	23009	36146	21564

Notes: The numbers from STRIDE (System to Retrieve Information from Drug Evidence) database of drug exhibits sent to Drug Enforcement Administration (DEA) laboratories for analysis come from Galenianos, Pacula and Persico (2012). The cocaine percent of street ripoffs of 7.2 from STRIDE is a sample size weighted average of 5.3 percent ripoffs for powder cocaine (from 5362 street purchases) and 7.9 percent street ripoffs for crack cocaine (from 16202 street purchases).

Table 7: Silk Road Shutdown - Drugs Listings

	Silk Road Shutdown, 2 October 2013	
	Time of Shutdown	April 2014
Total Number of Drug Listings	18174	32029
Silk Road	13000	
Black Market Reloaded	3567	
Sheep Marketplace	1407	
Deepbay	200	
Silk Road 2.0		13648
Agora		7400
Pandora		5249
Evolution		2623
Blue Sky		1740
6 Small Markets (<1000 Listings)		1369

Notes: From Digital Citizen's Alliance (2014).

Table 8: Silk Road 2.0 Shutdown - Drugs Listings and Revenues

	Number of Drugs Listings				Revenues (million $)			
	Silk Road 2.0	Agora	Evolution	Total	Silk Road 2.0	Agora	Evolution	Total
January 2014	10228	1700	74	12002	10.8	1.1	0.1	12.0
February 2014	13104	3200	436	16740	7.4	3.4	0.1	10.9
March 2014	13477	6800	1917	22194	8.5	7.5	0.3	16.3
April 2014	13672	7700	2850	24222	10.7	8.4	0.4	19.5
May 2014	13508	9200	4658	27366	12.5	9.9	0.7	23.1
June 2014	13505	10500	5016	29021	10.6	10.7	1.1	22.4
July 2014	13265	11300	5828	30393	12.1	12.3	1.8	26.2
August 2014	11961	11800	7376	31137	12.6	11.4	2.5	26.5
September 2014	13095	12900	8312	34307	12.0	10.0	3.7	25.7
October 2014	13796	13400	9226	36422	incomplete	12.4	5.0	incomplete
			Silk Road 2.0 Shutdown, 5 November 2014					
November 2014		13500	11864	25364		13.9	7.0	20.9
December 2014		13300	14767	28067		14.3	11.5	25.8
January 2015		13500	16993	30493		13.5	11.9	25.4
February 2015		14600	18554	33154		12.2	12.8	25

Notes: Own calculations. See Appendix for issues calculating sales revenue numbers. The Silk Road 2.0 October 2014 numbers on revenues are incomplete as our last pre-shutdown scrape of the website was on 9 October 2014.

Table 9: Evolution Shutdown - Drugs Listings

	Evolution Exit Scam, 18 March 2015	
	Time of Exit	21 April 2015
Total Number of Drug Listings	41934	43622
Evolution	19902	
Agora	14618	16751
Nucleus	3220	8187
Middle Earth	1228	3342
Abraxas	773	2531
Black Bank Bitcoin	601	5635
Silkittien Dutch	407	652
Outlaw Market	396	692
Dream Market	337	986
Alphabay	286	2559
Crypto Market	85	1734
Mr Nice Guy	41	389
Babylon	32	56
Swiss Shop	8	
The Real Deal		42
Kiss Marketplace		36
Tochka Free Market		30

Notes: Own calculations supplemented with information from Digital Citizen's Alliance (2015).

Appendix

<u>Revenue Calculations</u>

Our data contains an almost-comprehensive record of the feedback that has been left on Silk Road 2, Agora, Evolution and Nucleus. This can be used to estimate site revenues.

Feedback records typically contain information about the date of sale, the vendor, and the product sold. These data can be linked to the weekly data that we collect on the price of listings and the bitcoin exchange rate. This results in a ledger of sales through time. A basic estimate of dollar revenues would therefore involve conversion of prices to dollars, and summing across all items of feedback.

In practice, this would be an underestimate for three main reasons.

First, feedback is not mandatory, so there will be sales for which feedback is not recorded. Second, due to omissions in the data that is made available by the markets, some items of feedback cannot be associated with a specific product, and so their price is unknown. Third, some purchases may be of multiple units of a given product, but this is not recorded in the feedback data. In our revenue estimates we attempt to correct for the first two of these issues, but are unable to correct for the third. There are differences in methodology between the sites due to differences in the information that is available.

To correct for the fact that feedback is not mandatory, a multiplier is used which represents an estimate of the ratio of sales to feedback. This multiplier is calculated from statistics available on sellers' pages on Evolution, which is the site with the best information to calculate a multiplier. For each seller, statistics are available on the number of items of feedback received, and the number of sales made. On Evolution, this multiplier can be used for each seller to multiply up sales observed in their feedback. This information is not available on the other sites, but the overall average multiplier of 1.86 observed on Evolution has been used to multiply up revenues on Agora and Silk Road 2. An additional adjustment was made on a per-seller basis for sellers on Agora, because the site provided information on the number of rated transactions, so it was possible to identify cases where the scraper had not picked up every piece of feedback.

To correct for the second issue – the missing product data in some items of feedback – we backfill the missing data with estimates of the likely revenue from the sale. The estimates are generated by computing the average revenue per sale for each seller, using only complete records.

Adjustments were also made for some sales where revenues appeared to be implausibly high. There seems to be a practice amongst some sellers of inserting an implausibly high price on a listing when the item goes out of stock, as a signal to buyers that they should not buy the item. This 'signal' price is usually very high - $100000 or more. This practice is sometimes picked up in our data because our price data is collected weekly, and therefore cannot be exactly synced with the price that prevailed at the time of sale. To correct for this issue, a simple ceiling of $5000 per sale was used, above which it was assumed product data was missing. This ceiling was chosen because inspection

of the data found that sales of $1000 to $5000 tended to be valid sales of large quantities. Sensitivity testing showed that varying the $5000 ceiling made little difference to the overall revenue estimates.

Finally, it should be noted that the statement that feedback is not mandatory is at odds with some other work in the area.[30] This is something that has been difficult to verify given that we have not made any purchases, and the sites no longer exist. However, as part of the work to create revenue estimates, we researched this area in some depth and all the evidence we collected and saved from this research pointed to feedback being non-mandatory. Specifically, we searched the forums of the different sites for evidence, and asked questions to the forum users. The responses to our questions – from multiple forum users - were that feedback was non-mandatory. We also have direct evidence from Evolution that feedback was non mandatory in that some sellers were able to attain 'seller ranks' that were impossible given the amount of feedback they had received. To gain a given seller rank, one criterion was that the seller must have made a certain minimum number of sales. We were able to find examples where the seller had fewer feedbacks than the sales threshold for a given rank, yet was still placed in this rank. For these sellers, their 'experience level' – which the site's wiki defined as "the total number of sales that an individual vendor has made" – was higher than the number of feedbacks and qualified them for the higher seller rank.

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[30] In particular, see Soska and Christin (2015), section 4.1, which says that 'In many marketplaces (e.g., Silk Road, Silk Road 2.0, Agora, Evolution among others) customers are required to leave feedback for a vendor whenever they receive their order of one of the vendor's items.'

Figure A1: Screenshots

Silk Road 2.0

Agora

Figure A1: Screenshots (Continued)

Evolution

Nucleus

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