# An analysis of a Heisenbot uncertainty problem: a large anonymous online marketplace.


## Abstract

Performing a comprehensive measurement analysis of Silk Road, an anonymous, international on-line marketplace that operates as a Tor hidden service and uses Bitcoin as its exchange currency, one may gather and analyze data, including daily crawls of the marketplace. Obtaining a detailed picture of the type of goods being sold, and of the revenues made both by sellers and operators is useful. Anonymous online marketplace is overwhelmingly used as a market for controlled substances and narcotics. A relatively small core of about several tens of sellers has been present throughout measurement interval, while the majority of sellers leaves or goes under-ground within a couple of weeks of their first appearance. Evaluation of the total revenue made by all sellers to approximately USD some million per month; this corresponds to about USD several hundred thousand per month in commissions perceived by the operators. Marketplace has been operating steadily, with daily sales and number of sellers overall increasing over the past few months. Economic and policy implications of the analysis and ethical considerations are discussed.



Keywords: Online crime, web frauds, electronic commerce.


Some site offers a number of licit and illicit items, with a marked focus on narcotics [1]. More brazen than anything else by light-years characterized an online anonymous marketplace [2]. This sentiment is characteristic of the certain nervousness among political leaders when it comes to anonymous networks. The relatively recent development of usable interfaces to anonymous networks, such as the Tor browser bundle, has in-deed made it extremely easy for anybody to browse the Internet anonymously, regardless of their technical background. In turn, anonymous online markets have emerged, making it quite difficult for law enforcement to identify buyers and sellers. As a result, these anonymous online markets very often specialize in black market goods, such as pornography, weapons or narcotics. Such anonymous online market is not the only one. Others are offering similar services, but it gained fame after an article, which resulted in it being noticed by congressional leaders, who demanded prompt action being taken. It is also reportedly very large, with estimates mentioned in the online forum ranging between tens of thousands and several hundred thousand customers. A scientific characterization of the marketplace, by gathering a set of controlled measurements over roughly some months, and analyzing then have

been making [2]. An online anonymous marketplace provides infrastructure for sellers and buyers to conduct transactions in an online environment. In this respect, an online anonymous marketplace is more similar to Craigslist, eBay or the Amazon Marketplace than to Amazon.com. The major difference between an online anonymous marketplace and these other marketplaces is that an online anonymous marketplace focuses on ensuring, as much as possible, anonymity of both sellers and buyers. A typical transaction involved in accessing, making a purchase, and getting the goods delivered. Accessing suppose that Bob (B) is a prospective buyer, wants to access the marketplace (M). Bob will first need to install a Tor client on his machine, or use a web proxy to the Tor network (http://tor2web.org) as Silk Road runs only as a Tor hidden service [3]. That is, instead of having a DNS name mapping to a known IP address, Silk Road uses a URL based on the pseudo-top level domain onion that can only be resolved through Tor. At a high level, when Bob's client attempts to contact the Silk Road server URL (http://silkroadvb5piz3r.onion)at the time of this writing), Tor nodes set up a rendez-vous point inside the Tor network so that the client and server can communicate with each other while maintaining their IP addresses unknown from observers and from each other. Once connected to the Silk Road website, Bob will need to create an account. The process is simple and merely involves registering a user name, password, withdrawal PIN, and answering a CAPTCHA. After this registration, Bob can access all of Silk Road's public listings. Silk Road places relatively few restrictions on the types of goods sellers can offer. From the Silk Road sellers' guide [4], "Do not list anything who's (sic) purpose is to harm or defraud, such as stolen items or info, stolen credit cards, counterfeit currency, personal info, assassinations, and weapons of any kind. Do not list anything related to pedophilia." Conspicuously absent from the list of prohibited items are prescription drugs and narcotics, as well as pornography and fake identification documents (e.g., counterfeit driver's licenses). Weapons and ammunition used to be allowed until March 4, 2012, but have since then been re-listed on a sister site called the Armory [5], which operates with an infrastructure similar to that of Silk Road. Not all of the Silk Road listings are public. Silk Road supports stealth listings, which are not linked from the rest of Silk Road, and are thus only accessible by buyers who have been given their URL. Stealth listings are frequently used for custom listings directed at specific customers, and established through out-of-band mechanisms (e.g., private messaging between seller and buyer). Sellers may further operate in stealth mode, meaning that their seller page and all the pages of the items they have for sale are not linked from other Silk Road pages. While Silk Road is open to anybody, stealth mode

allows sellers with an established customer base to operate their business as invitation-only. After having perused the items available for sale on Silk Road, Bob decides to make a purchase from Sarah (S). While Tor ensures communication anonymity, Silk Road needs to also preserve payment anonymity. To that effect, Silk Road only supports Bitcoin (BTC, [6]) as a trading currency. Bitcoin is a peer-to-peer, distributed payment system that allows anonymous transactions between different parties. Bob thus needs to first procure Bitcoins, which he can do from the many online trading places such as Mt. Gox [7]. At the time Bob purchases the item from Sarah, instead of paying Sarah directly, Bob places the corresponding amount in escrow with the site operator. Effectively, B pays M, who will subsequently pay S. The escrow mechanism allows the market operator to accurately compute their commission fees, and to resolve disputes between sellers and buyers. Silk Road mandates all sellers and buyers use the escrow system. Failure to do so is punishable by expulsion from the marketplace [8]. Once the purchase has been made, Sarah must ship it to Bob. Thus, Sarah needs a physical address where to send the item. To preserve anonymity, Silk Road recommends use delivery addresses that are distinct from the buyer's residence. For instance, Bob could have the item delivered at Patsy's house. Once Sarah has marked the item as shipped, Bob's delivery address is erased from all records. Once the item reaches its destination, Bob finalizes the purchase, that is, he releases the funds held in escrow to Sarah, and leaves feedback about Sarah. Finalizing is mandatory – if Bob forgets to do so, the site will automatically finalize pending orders after a set amount of time. Established sellers with more than 35 successful transactions and who have been active for over a month are allowed to ask their buyers to finalize early; that is, to release payment and leave feedback before they actually receive the item. Due to the potential for abuse, Silk Road discourages finalizing early in general, and prohibits it for new sellers. Finally, Silk Road enhances transaction anonymity by providing tumbler services that consist of inserting several dummy, single-use intermediaries between a payer and a payee. That is, instead of having a payment correspond to a single transaction $B \rightarrow S$, the payment goes through a transaction chain are one-time-use intermediaries. One can register an account on Silk Road. One may start with a few test crawls. Silk Road relies on authentication cookies that can be reused for up to a week without having to re-authenticate through the login prompt of the website. Provided you can manually refresh the authentication cookie at least once per week, this allows us to bypass the CAPTCHA mechanism and automate our crawls. One conducted a near-comprehensive crawl of the site using HTTrack [9]. All item, user (seller, buyer) and

category web pages were crawled. Silk Road had moved to inlining images as base64 tags in each webpage. This considerably slowed down crawls. Using an incremental mode, that is, ignoring pages that had not changed from one crawl to the next, each of these crawls ran about some hours. The fastest crawl completed in slightly over some hours; the slowest took almost several tens of hours, which resulted in the following daily crawl to be canceled. To avoid confusion between the time a crawl started, and the time a specific page was visited, one recorded separate timestamps upon each visit to a given page. Kanich et al. [10] emphasize the importance of ensuring that the target of a measurement experiment is not aware of the measurement being conducted. Otherwise, the measurement target could modify their behavior, which would taint the measurements. They thus waited for a few days after the November crawl to see if the full crawl had been noticed. Perusing the Silk Road forums [11] one may found no mention of the operators noticing us; our account was still valid and no one contacted us to inquire about our browsing activities. One concluded that we either had not been detected, or that the operators did not view our activities as threatening. One spent some additional effort making our measurements as difficult to detect as possible. Since all Silk Road traffic is anonymized over Tor, there is no risk that our IP address could be blacklisted. However, an identical Tor circuit could be repeatedly used for crawling if the application (HTTrack in this case) keeps the same socket open; this in turn could reveal that they are crawling the entire site. They addressed this potential issue by ensuring that all circuits (including active circuits) are periodically discarded and new circuits are built. To further slightly obfuscate activities, instead of always starting at the same time, one started each crawl at a random time. A number of changes were implemented to Silk Road to prevent profiling of the site [11]. Whether this was due to Silk Road operators noticing our crawls or to other activity is unclear. URL structure changed: item and users, instead of being referenced by a linearly increasing numeric identifier, became unique hashes. Fortunately, these hashes simply consist of a substring of the MD5 hash of the numeric identifier, making it easy to map them to the original identifiers. More annoyingly, feedback data, which is crucial to estimating the volume of sales became aggregated and feedback timestamps disappeared. Feedback data became completely useless. Thankfully, due to all dates and times are expressed in Universal Time Coordinates (UTC). Each item page of the reference book hacking for beginners contains seller, price, and shipping information, as well as buyer feedback on the item. It’s very strong pushback from buyers who argued that per-item feedback was necessary to have confidence in purchases [11]. Silk Road operators reverted to time

stamped, per-item feedback. In several instances, Silk Road went down for maintenance, or authentication was unsuccessful leading to a few sporadic days of missing data. Each item page describing the goods being sold on Silk Road is bound to a unique item identifier as part of it and contains the name of the item hacking for beginners, the category in which the item fit, seller information, price, shipping information, item description, and buyer feedback. Each piece of feedback consists of three fields: a rating between, a textual description of the feedback, and the age of the feedback. Feedback age is expressed in minutes, hours, days or months, depending on how old the feedback is. Hence, one can timestamp much more accurately feedback recently given at the time of the crawl, than older feedback. This is one of the reasons for crawling Silk Road daily: the age of feedback less than a day old can be quite precisely pinpointed. Furthermore, timestamps of feedback given long before t may be very approximate. The time at which feedback is entered does not, in general, correspond to the time the item was purchased, but to the time the item was delivered. Hence, feedback data is an imperfect proxy for accurately estimating daily sales volume. Over a collection interval of a couple of months, however, feedback data is a good indicator of the overall volume of sales. Marketplace characteristics describe the Silk Road as a marketplace. That is providing an overview of the types of goods being sold in Silk Road, before discussing seller characteristics. Items offered on Silk Road are grouped by categories. There are approximately some hundred distinct categories, ranging from digital goods to pornographic materials, to various kinds of narcotics or prescription medicine. Categories ordered by decreasing popularity. It was founded tens of thousands of items being sold over that period. While a few categories seem to hold the most items, Silk Road, like other online marketplaces, exhibits a long-tail behavior, where a large number of items appear to be unique. Categories ranked by popularity. The number of items in each category was ordered by decreasing popularity and the cumulative distribution of all items over all categories. The 20 most popular categories represent over 2/3 of all items available. The cumulative distribution of items as a function of the number of categories considered. They take a closer look at the top 20 categories per number of item offered. Weed is the most popular item on Silk Road, followed by drugs, which encompass any sort of narcotics or prescription medicine the seller did not want to further classified. Prescription drugs, and benzos, colloquial term for benzodiazepines, which include prescription medicines like Valium and other drugs used for insomnia and anxiety treatment, are also highly popular. The four most popular categories are all linked to drugs; nine of the top ten, and sixteen out of the top twenty are drug-related. In other words, Silk

Road is mostly a drug store, even though it also caters some other products. Finally, among narcotics, even though such a classification is somewhat arbitrary, Silk Road appears to have more inventories in soft drugs than hard drugs; this presumably simply reflects market demand. Items are long available on Silk Road. Items may have been listed and de-listed several times in the meantime. Most items are only available for short periods of time, with a vast majority of items disappearing within a few days from the listings. Very long-lived items have been essentially present for the entire collection interval. There may be two different explanations for the relatively short lifespan of each item: vendors may run out of stock quickly and de-list their items, possibly re-listing them later under a slightly different name resulting in a different item page, or they may elect to make them stealth listings as soon as they have established a customer base. Finally, public custom listings are relatively rare. Products sold on Silk Road are mostly listed as narcotics or controlled substances. Most items are only available for limited periods of time. Evolution of the number of sellers is a point of comparison. Due to the anonymous nature of Silk Road, it is impossible to discern whether certain sellers use multiple seller pages. Likewise, several sellers in the physical world may offer their goods through a unique seller page on Silk Road, although this would certainly be a clear indication of a business partnership. The evolution of the number of sellers on Silk Road over time between start until last daily crawl may be plotted. One can found several hundred distinct sellers with at least one item listed for sale on Silk Road. It appears that a number of sellers entered the marketplace in the week or two prior to this operation; and a non-negligible number left immediately afterwards. It is unclear whether this played a role in the marked increase of the number of sellers since that time – i.e., whether newcomers attempted to fill the void. The main lesson from this data is that the number of active sellers has been continuously increasing. The increase in the number of sellers appears linear. However, simple regression analysis does not accurately reflect the fact that many sellers actually leave the marketplace. There are two interesting trends. There is a core of number of a seller lifetime. Most sellers leave the site fairly quickly; at the same time a core of all sellers have been on the site for the entire duration of investigation. Second, and perhaps more interestingly, a majority of sellers are only on the site for less than two months; and in particular a lot of sellers are present only for a couple of weeks at most. This may be because they leave the site as soon as they are done selling their products; or because they move into stealth mode as soon as they have established a large enough customer base. The top geographic locations for both origin and destinations may be shows. Some items

ship to multiple destinations. Most items ship from the United States, with the United Kingdom a distant second. The Netherlands are also strongly represented, which is not necessarily surprising given the relatively permissive narcotics laws in the country. A clear bias toward English-speaking countries which represent almost two-thirds of all listed origins may be notes. This can easily be explained by the fact that all communications on Silk Road are in English. More surprisingly, one note that a majority of items ship worldwide, in spite of the nature of the items, as discussed above. One would think that sellers may be reluctant to ship narcotics across borders. It turns out not to be the case, for a couple of reasons. First, sellers with an established reputation may often demand that buyers pay upon purchase, and before delivery of the item. If the item is not delivered, the buyer may have very little recourse, particularly if they have not established a strong reputation in the marketplace. While Silk Road offers an escrow service, disputes arising after early finalization are considerably harder to mediate by the marketplace operators. Second, the quantities being sold are generally rather small, and tracing the senders may be a very difficult task as they can use private couriers to ship the items. Third, most sellers use techniques to make package inspection unlikely for example vacuum sealing, professional-looking envelopes with typed destination addresses [11]. Sellers can expand their customer base at a relatively low risk for them. Economic incentives justify worldwide shipping, especially since sellers can factor in their selling price the risk of package seizure, and accordingly offer loyal customers at least partial refund guarantees. There have been several thousand sellers on Silk Road. While it does not appear like a given seller (or group of sellers) sells a significant proportion of items overall, it could be the case that a few selected items sell in large quantities. One may use the amount of feedback collected as a proxy for the number of sales made. For instance, the seller with the largest volume of sales received approximately some thousand feedback messages over the six month. However, the market is quite spread out between sellers. There are a number of sellers that do not appear to stay very long on the site, but amass a large number of transactions, while on the other hand, some of the old timers appear to relatively rarely engage in transactions. These results may be due to the sellers electing to go in stealth mode after having built up a fraction of all items in the market. The top 100 sellers are responsible for approximately 60% of all feedback gathered, which is a strong indicator of the number of sales made. A vast majority of transactions seems to proceed to the satisfaction of the buyers. On a site like Silk Road most of the goods sold are illicit, one would expect a certain amount of deception to occur. Indeed, a buyer choosing, for instance, to purchase heroin from an

anonymous seller would have very little recourse if the goods promised are not delivered. Surprisingly, though, most transactions on Silk Road seem to generate excellent feedback from buyers. Thus, it appears at first glance that Silk Road sellers are highly reliable. Internet users in general disproportionately use positive feedback when rating online experiences. Not all transactions have feedback reported. Indeed, a number of transactions are made out of escrow directly between a seller and a buyer. There is no feedback mechanism, not any oversight possible from the Silk Road operators. There does not appear to be significantly more problems reported with feedback including strings. This seems to show that established sellers that are offered the option of requesting early finalization from their customers do not abuse that privilege. All transactions on Silk Road are using Bitcoins (BTC). Bitcoin has been a notoriously volatile currency. Evolution of the exchange rate of the Bitcoin against the three major currencies, using sellers in their countries as can be seen has remained relatively stable oscillating. The evolution of the normalized price of the five most sold items on Silk Road in BTC closely mirrors the evolution of the Bitcoin exchange rates, suggesting little inflation for these items over the time interval considered. Normalized prices of these five items quite closely mirror the fluctuations of the Bitcoin exchange rate: as the Bitcoin appreciates, the prices drop; conversely, a drop in the Bitcoin value results in a price increase. Silk Road provides automatic pegging of prices to existing currencies. It appears that all five items use this system, and there does not seem to be considerable variations in prices beyond those due to the exchange rate. An estimation of the total amount of daily sales realized in Silk Road is a very approximate. The total volume of sales has been increasing quite significantly. The decrease is, however, an artifact of the Bitcoin sharply appreciating against all major currencies, rather than an indication of a drop in sales. The commission was at a flat 6.23% rate. Converting to US dollars, using the Bitcoin exchange rate give a total sales volume of some USD millions per month, which corresponds to a projected annual revenue of over some tens million USD for the entire marketplace. Silk Road operators perceive a commission on all sales realized on the website. The commission schedule was originally set at 6.23% of the sales price. In January 2012, a tiered commission schedule was established, using a model similar to that proposed by eBay. Even though the volume in Bitcoins may have decreased due to the Bitcoin rising against the US dollar, the transaction volume in US dollars and the corresponding commissions have significantly increased. Silk Road operators perceive, an average, roughly some hundred thousand USD per month in commissions. In other words, over a year, Silk Road operators' revenue is probably

around some million US dollars. This research may bring up a number of discussions, and hopefully even start a public policy debate on the effectiveness of current intervention or prevention strategies for controlled substance abuse, we. An overview of the ethical considerations and associated conclusions were come to during the design of this study. Conducting this research yielded some ethical quandaries. Registration is open to anybody who connects to the site. Perhaps, bypassing the authentication mechanism and associated CAPTCHA by reusing an authentication cookie could be construed as a hack. However, this is nothing more than using a convenient feature that the site operators have willingly offered their visitors. Indeed, nothing would prevent the site operators from setting authentication cookies with very short expiry dates. Considering that the data one obtained is available to anybody, one does not think this work adds any additional risk for the Silk Road operators, their customers or their sellers. In fact, Silk Road operators seem to espouse crypto-anarchist ideals and to that end, willingly make their website – and, as a result, its data – publicly available. Another ethical consideration is linked to the design of the study itself. The scientific value of this study, and its potential public policy impact justified the use of the network one have been made. Given the nature of the goods sold on Silk Road, it is quite clear that various law enforcement agencies may have a strong interest in trying to disrupt Silk Road operations. Four possible intervention strategies that could be considered: disrupting the network, disrupting the financial infrastructure, disrupting the delivery model, and laissez-faire. The first possible intervention policy is to disrupt the Tor network. Indeed, without Tor, Silk Road cannot operate. This strategy is very likely to be difficult to put in place. First, Tor has many uses beneficial to society – Silk Road and other anonymous online marketplaces are far from representing the majority of Tor traffic, even though this work argues that their importance is growing. Tor is routinely used by oppressed individuals to communicate without fear of reprisal. Thus, disrupting the entire Tor network for the purpose of taking down Silk Road would come at a potentially high collateral cost. Furthermore, Tor has shown to be resilient to a large number of attacks, due to its open design and to the large amount of academic research it fosters. In particular, Tor hidden services, like Silk Road, have been the subject of considerable scrutiny [22, 23], where showed that timing and intersection attacks could be used to reveal the location of hidden services. Most of these concerns have been addressed in recent versions of Tor, e.g., through the use of entry guards. Murdoch described how covert channels (specifically, clock skew) could leak information allowing to pinpoint the location of a hidden service. Another possible disruption strategy is to attack the

financial infrastructure supporting Silk Road. Bitcoin has shown, in the past, to be a very volatile currency. Theft of a large number of Bitcoins from the Mt.Gox exchange [7] actually caused an abrupt collapse of the currency. Certain users have been complaining in forums of the uncertainty on the prices they end up paying due to the instability of Bitcoin and the various commissions they have to pay to purchase Bitcoins, and then to purchase items on Silk Road[11]. Disrupting the Bitcoin network appears, compared to attacking the Tor network, to be a more actionable possibility. In fact, in the aforementioned [24] one of the Bitcoin developers argued that Bitcoin was not providing the level of security Silk Road and other anonymous marketplace operators would desire. More precisely, recent research [25] has shown that Bitcoin transactions are partially vulnerable to traffic analysis. Indeed, the history of all transactions is publicly available and network analysis can allow map sets of public keys to individual users and transactions. Since currency exchanges like Mt.Gox where users redeem Bitcoins for cash bind public keys to actual identities, Bitcoin anonymity guarantees are weaker than most Silk Road users seem to assume, even though additional intermediaries (tumblers) are in place. In particular, large Silk Road sellers withdrawing massive amounts of Bitcoins at once may be relatively easily identified. Another possible angle of action is to attack the delivery model. That is, to reinforce controls at the post office and/or at customs to prevent illicit items from being delivered to their destination. One interesting finding from this work is the apparent lack of worries a large number of sellers have: Most items are marked as shipping internationally, which means that the risk of package loss or destruction is viewed as minimal by the sellers. This is certainly an area that warrants further investigation. Yet, very often, packages that are seized are simply destroyed, or returned to the sender. Finally, a last possible intervention strategy is actually not to intervene. Politically, this is a questionable proposition, as it may sound as an admission of weakness. There are however studies that show that drug abuse prevention is considerably more cost-efficient than enforcing drug prohibition [26]. The relatively rapidly expanding business of online anonymous markets such as Silk Road and the logistic difficulties in shutting down such markets may further tilt the economic balance toward prevention and cure. As a result, laissez-faire, however untenable it might currently appear from a policy standpoint, might become even more attractive in light of budget constraints. Although there is no public statement about it, this could be the strategy currently adopted by law enforcement, seeing that the marketplace has not met any significant disruption to its operations, other than transient technical issues, in the past nine months, while at the same time sales

volumes have doubled. From a technical standpoint, the work is closely related to rapidly growing literature on measuring cybercrime [12-21]. The techniques used in the paper (periodic crawls, use of anonymous networks) to collect measurements indeed are relatively common to most work in this field. Instead of trying to characterize a security attack or the behavior of an attacker one may trying to describe as precisely as possible an online marketplace. In that respect, work shares some similarities with works that have tried to model transactions on eBay [27, 28] or Amazon [29]. McCoy et al. provided a characterization of traffic using the Tor network by monitoring a Tor exit node [15]. Motoyama et al. [20] performed related measurements to evidence the existence of online mule recruitment schemes in crowdsourcing marketplaces. A more recent paper [16] uses leaked transaction databases to precisely estimate the revenues and profits of three major illicit online pharmacy affiliate networks. Contrary to Silk Road, these networks heavily resort to spam [14] and search-engine manipulation [13] for advertising. Mc. Coy et al. find that, between 2007 and 2011 the gross revenues of each of these illicit affiliate networks range from USD 12.8 million/year to USD 67.7 million/year. Without any advertising other than word-of-mouth, Silk Road, with its USD 22 million/year transaction volume, appears to be comparable in size with these illicit online pharmacy networks. At the same time, Silk Road caters to a priori more technically sophisticated users, and proposes an inventory that far exceeds prescription drugs; as such, it seems to occupy a market niche different from that of traditional illicit online pharmacies. The work is also close in spirit to a number of studies in the drug policy realm. Work performing an econometric analysis of drug markets to discuss their structure is the [30]. Molnar et al. [31] noted that a number of techniques used to perform analysis of controlled substance markets could be applied to online crime as well. There may be a convergence between the two fields. Analysis of one of the largest anonymous online marketplaces was performed. Silk Road indeed mostly caters to drug users. Other items are also available. It consists of a relatively international community, and that a large number of sellers do not stay active on the site for very long. Sales volume is increasing. Sales currently corresponded to approximately some USD million per month for the entire marketplace, corresponding to some thousand USD per month in commissions for Silk Road operators. Some of the possible policy remedies were discussed. A surprising result is the tight coupling between Silk Road and the Bitcoin market – the daily sales on Silk Road correspond to almost 20% of the average daily volume of USD-BTC exchanges on Mt.Gox, the largest exchange forum. As a result, it seems like a potentially

effective intervention policy would be to destabilize the value of the Bitcoin, to create instability in the marketplace.

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