How thin is the market for illegal ammunition?

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Abstract

This paper provides an empirical test of the hypothesis that the illegal market for ammunition may be an example of a "thin" market where buyers and sellers have difficulty transacting. Using data from a widely available but previously unused source of information on illegal ammunition—recovered illegal firearms themselves—this analysis introduces two measures of ammunition thinness—weapon fullness and ammunition "scrounging." Examination of these two measures reveals that ammunition is seemingly quite accessible even in jurisdictions with restrictive ammunition and firearm regulations. This finding suggests diversion of ammunition from the legal to the illegal market, like other diverted non-durable goods (e.g., cigarettes), is not as restricted as hypothesized by some models of ammunition diversion. This analysis also provides preliminary evidence for another posited illegal firearm possession behavior—carrying unloaded firearms for the sole purposive of defensive brandishing or coercive threatening. The included results provide minimal empirical support for these posited behaviors. Taken together, these results suggest that access to diverted ammunition is sub-optimally constrained by existing regulatory and enforcement actions and that most illegal possessors appear both interested and able to fill their firearms, albeit with unknown search and financial costs.

Introduction

Gun violence represents the biggest public safety challenge facing the United States today (Gramlich 2023). In 2021, 21,000 individuals were murdered with firearms and another 40,000 individuals were injured with firearms (GVA 2023). Some estimates put the toll of firearm victimization even higher (Kena and Truman 2022). A substantial portion of this safety challenge comes from the diversion of legally purchased firearms into the illegal market for firearms where

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they are then used to commit crimes ranging from armed robbery to homicide. This diversion in the face of regulatory prohibitions and enforcement actions by the Bureau of Alcohol, Tobacco, and Firearms (ATF) as well as local law enforcement agencies has focused scholarly attention on the pathways through which firearms make their way into the hands of prohibited possessors. To date, this scholarship has documented that the market for illegal firearms involves a mixture of theft, straw purchasing for prohibited end-users by non-prohibited intermediaries, brokerage through associates and other third-parties, and, increasingly, the purchase of semi-finished firearms from private manufacturers (Braga et al. 2002, 2021; Harlow et al. 2001; Pierce et al. 2004; Sheley and Wright 1993). In some jurisdictions, tracing of recovered firearms has revealed that many illegal firearms come from out-of-jurisdiction supply sources. In others, tracing has revealed that most recovered firearms come from within jurisdiction sources. This informal supply network has been alternatively characterized as an "iron pipeline" and a "diffuse network of capillaries," reflecting the diversity of supply routes observed through tracing recovered firearms and interviews with market participants (Chesnut et al. 2017).

These alternative conceptualizations, however, suggest a larger conceptual ambiguity—is the market for illegal firearms and ammunition best understood as a robust supply channel as reflected in the popular press with such quotes as "Some criminals claim that it is as easy to buy a gun on the streets as it is to buy fast food. One Chicago gang member stated, 'It's like going through the drive through window. Give me some fries, a Coke, and a 9-millimeter.' (Terry 1992)" Or is it a "thin" market, where buyers incur large transactions costs due to the difficulty of connecting interested buyers and willing sellers, as suggested by recent scholarship (Cook et al. 2007). If the former is correct, then current regulatory and enforcement efforts are largely ineffective, and regulators might need to substantially rethink the current regulatory and enforcement paradigm. If

the latter is correct, then smaller adjustments might exacerbate the already precarious situation for market participants leading to a more dysfunctional market but safer world.

Part of the challenge in adjudicating between these competing conceptualizations is that the primary empirical evidence used to both develop and validate each comes from specially designed and rarely administered interviews of special populations including jail inmates, gun brokers, and gang members. These populations are not routinely accessible to scholars. This situation also limits the ability of researchers to study changes in diversion over time since intermittent data collection makes it impossible to routinely ascertain the level of variation in market indicators. The latter problem is partially resolved by the availability of firearm trace data, but this also suffers from intermittent analysis as well as the absence of information on ammunition.

To address these known limitations of the existing empirical literature, this paper proposes and demonstrates the utility of examining information found in the ammunition observed in firearms recovered by local law enforcement. While recovered firearms have previously been used to measure firearm popularity as well as the impact of changes in weapon caliber on the probability of mortality (Zimring 1972), this appears to be the first effort to examine ammunition loads rather than recovered weapons. Based on this novel and yet widely available source of information, we examine two measures of ammunition thinness—firearm fullness and ammunition "scrounging." Using data from the Boston Police Department to illustrate the utility of this information and these two measures, we show that most recovered firearms are substantially full, that the mode of recovery has little impact on the degree of fullness, that scrounging provides somewhat greater evidence of market thinness, and that firearm cost is uncorrelated with firearm fullness but is weakly correlated with ammunition scrounging. Additional results indicate that many weapons are ready for immediate use due to the common practice of chambering of rounds and minimal

evidence is found for narratives that firearms are carried empty to minimize risk of injury to prohibited possessors or threatened individuals.

Prior Research on Illegal Firearm and Ammunition Markets

Guns and ammunition, like other manufactured goods, are distributed and sold through several distinct channels. They can be purchased from retail outlets, online stores, at gun shows and conventions, and they can be exchanged with or without financial remuneration. This constitutes the legal market for guns and ammunition. Unlike many other manufactured goods, however, they are also subject to distinctive regulatory restrictions that limit their purchase, ownership, possession and use. This regulatory regime dictates who can legally purchase firearms, and to a lesser extent, who can legally purchase ammunition. Noteworthy prohibited groups include convicted criminals, certain individuals experiencing acute mental health crisis, as well as large numbers of children. While specifics vary from state to state, this basic framework is shared in common and most acts of regulatory compliance are carried out by the Bureau of Alcohol, Tobacco, and Firearms (ATF), which is a federal agency with oversight across all local jurisdictions.

The exclusion of a population of potential consumers from the legal market for firearms and ammunition would not be enough to spawn an illegal market for firearms in the absence of some latent demand for firearms from within the excluded population. Decades of research and writing has repeatedly documented that there is latent demand among these groups of excluded purchasers and possessors. And given this latent demand, scholars have spent the last twenty years trying to form a clearer picture for how legally manufactured and distributed firearms and ammunition move from the shelves of legal sellers into the hands of prohibited possessors and

other excluded end-users. Is this primarily through fraudulent direct purchases from Federal Firearm Licensed merchants? Is it through purchases at less closely monitored gun shows? Are thefts from vehicles, homes, and businesses the most common channel? Available evidence suggests that all of these routes play important roles in facilitating the acquisition and use of firearms by prohibited groups (Braga et al. 2012; Pierce et al. 2004; Sorenson and Vittes 2003). And while some regions show evidence of trafficking pipelines or other discrete point sources for the diversion of legal firearms, other jurisdictions appear to have much more diffuse diversion processes at work with theft and secondary sales being the primary pathways through which guns are diverted (Braga et al. 2002, 2021; Decker, Pennell, and Caldwell 1995; Newbold 1999; Pierce et al. 2004).

Far less research has focused on the topic of ammunition, much of it illegally obtained and then illegally used. Studies have examined ammunition in Chicago, Los Angeles, the Netherlands, as well as the United Kingdom. These inquiries have simultaneously highlighted the duality of routine availability of ammunition and indicia of market thinness. For example, during an effort to further regulate the sale of ammunition in California, Tita and colleagues examined the records of FFLs in Los Angeles (Tita et al. 2006). Their analysis uncovered that 2.6% of purchasers at FFLs were prohibited by law from purchasing ammunition. These prohibited purchasers purchased 10,050 rounds or 2.3% of rounds sold to all purchasers during the study period. A subsequent study in Los Angeles using interviews of jail inmates, revealed that local retail establishments, especially those with substantial sporting goods sections (e.g., Big 5 Sporting Goods, Walmart), were the primary locations at which they purchased ammunition (Chesnut et al. 2017). Respondents also reported that ammunition, at least in Los Angeles, was easier to obtain than firearms themselves.

Corresponding work in the Netherlands has described a very similar situation with ammunition easily diverted from retail or sporting establishments (de Vries 2013).

By contrast, studies in Chicago have revealed a somewhat different impression of the illegal market for ammunition and firearms. Using interviews with market participants and trace data on recovered firearms, Cook et al. observed many indicators of market thinness for both firearms and ammunition (Cook et al. 2007). Their respondents reported large markups over retail prices for both, difficulty in buyers and sellers successfully transacting, and a generally fragile market for illegal weapons. Their results even hinted at the possibility that the market for illegal ammunition in Chicago, unlike in Los Angeles, might be much thinner than the market for illegal firearms. These indicators of market thinness, including large mark-ups for ammunition, have also been reported in the United Kingdom (Hales, Lewis, and Silverstone 2006).

The reasons for this added possible thinness for ammunition relative to firearms are not well understood. It has been posited that there are fewer sellers or middlemen willing to sell ammunition. The added risk of providing unknown buyers ammunition is also potentially physically risky for ammunition sellers in a way that selling an unloaded firearm is not. An additional explanation offered is that sellers of illegal firearms do not want to contribute to victimization within their communities and they view the sale of firearms for self-protection as morally acceptable, but the sale of ammunition as morally questionable (Cook et al. 2007). Another way of reconciling the competing results from Los Angeles and Chicago (or the Netherlands and the United Kingdom for that matter), is to say that illegal markets, just like legal markets, can vary. Los Angeles and the Netherlands both seem to share certain regulatory features that would make for relatively thick ammunition markets—plentiful supply, few regulatory hurdles, and the potential for prohibited possessors to access the legal market itself. Chicago and the United

Kingdom, by contrast, have minimal supply, longstanding and substantial regulatory hurdles, and seemingly little direct legal market access. However, these are all just postulated theories for observed empirical differences.

To really understand why one setting might have a thinner or thicker illegal ammunition market or an illegal ammunition market that is thinner than the illegal firearm market, it is necessary to have comparable data on illegal ammunition and firearms across settings. It would also be ideal to have this data across time, which would allow for a more empirical assessment of whether changes in the regulatory environment or enforcement impact ammunition availability or price. While, theoretically, this form of routine information collection could be obtained from uniformly administered interviews of market participants or surveys of jail inmates, the recent history of surveys and interviews suggests that this is not the most promising route. Routine surveys of inmates have declined or refocused to other topics and interviews of illegal market participants are necessarily few and far between. Instead, collection and analysis of administrative data, if sufficiently substitutable, could overcome these problems.

Historically, administrative data on illegal firearm markets has been limited to information on firearms recovered by law enforcement. This information has allowed scholars to figure out the "time-to-crime" for trafficked weapons (Braga et al. 2012; Cook 2000), the popularity and lethality of different weapons (Zimring 1972), as well as other features of the illegal firearms market. At the same time, this information has not previously been used to study the market for illegal ammunition. This could be due to the lack of routine sharing of this information by law enforcement, which generally keeps information on recovered ammunition in their evidence recovery files rather than in their crime statistics databases. Another reason why this information may have been under-utilized is the challenge of inferring features of the illegal ammunition

market from recovered ammunition when it does not include classic market transaction information (e.g., price, mark-up, search costs). However, lurking within recovered ammunition is a surprising amount of information that speaks to the ease or difficulty with which market participants can obtain it. Consider, for the moment, how the preferences and constraints of market participants manifest within the ammunition found after shootings or in the firearms recovered after arrests.

If the market for ammunition is thin, we would expect to see shooting incidents with fairly low numbers of recovered shell casings since shooters would be attempting to preserve at least some of their ammunition for future use. Alternatively, if the exigencies of a given shooting require use of a shooters' full ammunition reserve, then we would expect to see long latencies between shootings with the same shooter or firearm as he or she searched for replacement ammunition. Likewise, if the market for ammunition is thin, then recovered firearms, especially those not recovered in the context of a shooting incident, should be routinely not full and often nearly empty. When multiple firearms are recovered, the ammunition levels should not even be adequate to fill a single firearm let alone two or more. And when firearms are recovered in a shooting, especially a non-domestic violence case, there should almost always be at least one round remaining in the firearm to preserve the utility of the firearm until more ammunition can be procured. All these statements are conjectures, but they illustrate the way in which the needs of prohibited possessors should interact with the features of their supply markets, especially thin supply markets, to manifest in observable patterns of recovered ammunition within recovered firearms themselves.

To make sense of these possibilities, which we discuss with greater specificity in the following sections, we examine the fill levels for firearms recovered in the City of Boston. Boston serves as a particularly useful setting to investigate the thinness for illegal ammunition because

Massachusetts is one of just four states that have extended state firearm licensing requirements to the purchase of ammunition.[2] Along with Connecticut, New Jersey, and Illinois, Massachusetts requires a firearm license to purchase or possess ammunition. This puts Massachusetts, and by extension Boston, at the far end of the distribution of localities with respect to regulatory scrutiny of would-be purchasers. If anywhere is likely to have a think market for ammunition, it should be Boston. For this reason, illustrating the benefits of new metrics for market thinness in this context is doubly useful.

Data

The data for this study comes from a unique source of information on recovered firearms—social media.[3] The Boston Police Department, which is a large metropolitan police department, has for many years posted photographs and descriptions of most recovered firearms on the Department's social media channels as part of the Department's efforts to highlight the ongoing work of the Department to combat the issue of gun violence in Boston. Unlike other, more occasional efforts, the Department reports posting nearly all recovered firearms with limited exclusions (i.e., homicides, domestic violence cases, as well as situations where the public affairs office is unable to track down the detective handling the case to get a photo).[4] This makes the posted photos to X (formerly known as Twitter), Facebook, and the Department's website a large repository of information on the condition of recovered firearms and their contents. Also unusual, compared to other Departments, is the quality of information posted. Most posting include not

[2] California has experimented with licensing requirements for ammunition. However, ongoing litigation has meant that California has inconsistently been a member of this group of states.
[3] BPD firearm postings were originally located on the social media website formerly known as twitter. The full sample, however, was downloaded from the Boston Police Department's own news website--https://police.boston.gov/index.php. It is also available through the Department's Facebook page.
[4] Author's personal communication with Boston Police Department May 26, 2023.

only a photo of the weapon but a photo of the ammunition and ammunition storage devices recovered. This makes it possible to infer weapon manufacturer, caliber, maximum load level, observed load level, and ammunition mix. In addition, the textual description of the weapons and the circumstances of the arrest allow for further case details to be ascertained and/or verified. Figure 1 presents an illustrative example of the information routinely available. The weapon can clearly be identified as a Ruger LC9, which is a 9mm pistol. It appears in good shape. The seven rounds recovered from the clip are arrayed adjacent to the clip itself, which has a capacity of seven rounds. A single round recovered from the chamber of the firearm can be seen adjacent to the slide, indicating that the person who possessed this firearm chambered a round in addition to loading it with a full clip of ammunition. A careful examination of the picture also reveals that there are two distinct bullet types—one is a conical bullet and the other is a flat nosed bullet. All rounds appear to be in good condition.

Figure 2 shows another recovered firearm. This picture illustrates the firearm itself, a second firearm, as well as a more expansive set of drug and weapon paraphernalia. Ignoring the drug paraphernalia for the sake of brevity, the firearms, found as part of a warrant search connected to a drug investigation, suggest that the possessor of these weapons might also have been in the business of selling ammunition alongside narcotics. A large bag of mixed ammunition is observable alongside two smaller baggies filled with roughly the ammunition required to load a pistol. A second large bag also includes additional ammunition. This photograph potentially provides confirmatory evidence for the existence of middlemen for ammunition and the overlap between illegal drug and ammunition markets.

Each posted firearm from January 1, 2023 until September 18, 2023 was individually reviewed and coded. Information available from the visual images of recovered firearms included the

condition of the firearm, the type of firearm (e.g., semi-automatic pistol, revolver, rifle), the capacity of the recovered clip, the number of rounds recovered in the firearm, and the bullet type (e.g., conical, flat nosed, full metal jacketed, hollow point), as well as the condition of the recovered rounds. Information obtained from the textual description of the firearm recovery included the date of the recovery, the circumstance of the recovery (e.g., search warrant, traffic stop), the lead arrest charge (e.g., illegal possession of a firearm), the manufacturer of the firearm, and the model of the firearm.[5]

Given that the recovered firearms publicly shared via the internet represents a subset of all recovered firearms, which itself represents a subset of all illegal firearms in the City of Boston, one key empirical question is whether there is reason to believe that the probability of observation is sufficiently uncorrelated with the attributes of recovered firearms and recovered ammunition that any patterns observed in this sample is likely to adequately represent the full unobserved distribution. A second key empirical question is whether the information on ammunition count and quality contains a sufficiently clear signal that this can be used to assess market thinness in the absence of classic market indicators such as price, mark-up, as well as search costs. In the next section, we explore both questions in more depth.

Methods and Measures

Thin markets have few buyers and sellers. This situation, whether caused by information asymmetries, regulation, taxes, or lack of liquidity, makes it difficult for buyers and sellers to transact (Hayenga, Gardner, and Houck 1978; Lehmann 1938). Classic measures of market

[5] Not all textual description contained manufacturer and model information. For these cases, as well as most other cases, each weapon was checked against the manufacturer's website to determine whether the manufacturer and model information was correct.

thinness include low volumes of transactions, high price volatility and large gaps between what buyers wish to pay and sellers expect to receive (Durlauf and Blume 2016). As a model for illegal ammunition markets, it offers a conceptual tool for making sense of high observed mark-ups between legal and illegal sale prices for the same good (Cook et al. 2007; Hales et al. 2006). It also helps explain why the volume of completed transactions might be lower than predicted if the illegal ammunition market were perfectly competitive. Finally, it dovetails nicely with the sort of information that can be obtained from interviewing buyers and sellers in illegal ammunition markets—prices paid, number of transactions completed per unit time, and the number of failed transactions.

However, "thinness" is fundamentally not about how long it takes people to transact in quantitative terms or how well-priced assets are relatively to some theoretical value. It is about whether willing buyers and willing sellers transact. If buyers and sellers cannot successfully transact, then the market is thin. If they can, then it is not. Restating this for the case of illegally obtained ammunition—If buyers or end-users would like more ammunition than they have, then the market is thin. Whether due to price mark-ups or difficulty finding sellers, existing market transactions are insufficient to meet their latent demand. Conversely, if they have enough ammunition for their purposes, then the market is not thin. This suggests that "thinness" in illegal ammunition markets is usefully assessed not only based on transaction records, but also based on the amount of ammunition that interested buyers can obtain, since ammunition is the good being transacted and its presence or absence serves as the clearest signal of whether transactions have successfully occurred. Therefore, we will now consider how ammunition found in recovered firearms can be used to assess the degree to which the willing buyers in this market are able to obtain sufficient ammunition to meet their needs.

At a basic level, two principal metrics are available from firearms recovered by police—the number and type of rounds recovered.[6] However, these two measures by themselves likely are imperfect proxies for market thinness due the lack of any information regarding the desired number or type of rounds. They become more useful as proxies for market thinness when they are converted into two related metrics—the ammunition fill level and the firearm ammunition mix. The ammunition fill level offers the clearest indication of the thinness of the market for ammunition. If recovered firearms are mostly full, then willing buyers were able to obtain an adequate supply of ammunition. If recovered firearms are routinely observed to be partially filled in the absence of an indication that they have recently been fired, it can be reasoned that illegal firearm possessors have incomplete or insufficient access to ammunition. This necessarily tests a particular form of market thinness—that the price of ammunition is so high, or the availability is so low, that would-be weapon carriers are unable to obtain ammunition and are forced to carry an empty or substantially empty weapon. An empirical test, described in greater detail below, will assess how reasonable this test likely is.

Operationalizing this metric requires computing the fill level. For revolvers this is trivial. The number of chambers represents the maximum capacity of the firearm. For most semi-automated pistols this is also relatively uncomplicated. Based on the specifications of the manufactured firearm and the observed clip, it is possible to calculate how full the firearm is at the time of recovery. The existence of extended magazines or pistols that can accommodate different sized magazines raises the question of whether a weapon is full when the number of observed rounds matches the smallest capacity of the firearm or instead the full capacity of whichever magazine was recovered with the weapon itself. Similarly, there is a question of whether to include

[6] A third feature, condition or quality of rounds recovered, is also available.

an additional chambered round in the full capacity of a semi-automatic pistol or not. Firearm manufacturers do not uniformly report the capacity of their firearms. Some exclude chambered rounds in their capacity specifications while others include it, usually in the form of a number followed by +1, where the first number represents the round capacity of the magazine and the +1 represents the round that can be stored in the chamber. Since the calculation of fullness is designed to assist in measuring the difficulty of obtaining ammunition, not the degree of "readiness" of the possessor, we opted to consider a firearm as full if it contained a complete magazine regardless of whether it also contained a chambered round. We similarly chose to consider the capacity of the magazine as the effective capacity of the firearm even if the magazine was non-standard or extended, assuming that its size could be inferred. If it could not be inferred, the capacity of the most common version of the firearm was used. This set of counting rules ensures that the theoretical construct at the heart of this study can be tested—as a greater fraction of recovered firearms are found to be fuller, the likelihood of market thinness goes down. Conversely, as a greater fraction of recovered firearms are found to be less full, the likelihood of market thinness goes up.

Ammunition mix represents a second informative metric. Like other goods that require consumable components to operate (e.g.. razors/razor blades; cars/gas; flashlights/batteries), firearms require consumables to function. Multiple manufacturers' ammunition, due to standardization, can be used within a given firearm, similar to batteries. However, unlike most consumer electronics, firearms can be operated even if they are incompletely loaded. In this respect, they are more like gasoline for cars. A car can still be driven with a partial tank, assuming the correct type of gasoline (e.g., diesel versus unleaded) has been added regardless of brand (e.g., Exxon, Chevron, etc.). What all of this suggests is that features of the market for ammunition could

manifest in the particular mix of ammunition observed within recovered firearms. If firearms are loaded with a single manufacturer's ammunition, then it was likely loaded from a single batch or box, indicating that the possessor was able to obtain a large enough supply to meet, at a minimum, his or her instantaneous needs for a loaded firearm. If firearms are loaded with more than one manufacturer's ammunition, then there are likely two different scenarios that could be occurring. In the first, an end user is refilling a partially full weapon from a new supply of ammunition and this process is observed *in media res*. While the exact split observed will vary, the weapon should still be full (or full enough) and the ratio of one ammo type to the next should form a relatively even distribution. The other possibility is that more than two kinds of ammo are observed within a single recovered firearm. This almost certainly indicates that the firearm is not being reloaded from a standard source or supplier, which normally sells ammunition in boxes measured in dozens of bullets. A more cobbled together ammunition fill combining three or more distinct ammunition types suggests that the end user is scrounging for ammunition across multiple sources, any one of which can only offer a single or a few bullets, or that the end user is receiving from a supplier who has aggregated from a similarly defuse set of sources such that they cannot offer a single type of ammunition. Given that the act of aggregation, whether by the end user or a middleman, necessarily involves search costs, it seems reasonable to assume that evidence of aggregation should not be interpreted as a taste preference in the same way that adding parts to a classic car can be considered a taste for exotic but functionally equivalent components. Instead, it is more logical to view this as evidence of a constraint that limits aggregators from accessing more conventional supplies of ammunition.

Considering these two measures of thinness together suggests that they may or may not provide consistent signals—individuals could have fully loaded weapons with many varieties of

ammunition, or they could have near empty weapons with a single variety. However, the interactions of these two metrics are finite. In the simplest case, an individual reloading their empty firearm will use ammunition obtained from a supplier that sells it in standard size batches. This could be a manufacturer, a vendor, or a private purchaser who shares or resells previously purchased ammunition. If the individual reloader has access to such a supply or supplier, the recovered firearm is likely to be filled with a single variety of ammunition corresponding to a portion of a standard batch. If the firearm is not empty but the individual wants to load it fully, then loading from a single new batch will generate a pattern indistinguishable from an empty firearm loaded from two separate sources, a situation that is ambiguous. If the weapon is fully loaded but with three or more varieties, there is evidence of effective access but also of scrounging on the part of the reloader or the supplier. And if the weapon is not fully loaded, the same logic can be deployed in reverse. The exact distribution of empirical results could take several forms, but it seems unlikely that the number of ambiguous scenarios will exceed the number of unambiguous scenarios. Why? Carrying an unloaded or almost empty firearm is contrary to the logic of carrying a firearm in the first place. This constrains the empirical distribution to be mostly situations in which firearms are mostly loaded. This then leaves as the only ambiguous scenario the two variety fully loaded situation, which is not particularly ambiguous. The weapon is full or nearly full and there happen to be two varieties. As it happens, even this scenario can be further dissected by examining the ratio of the two varieties. Further consideration of this possibility is left for future consideration.

We now return to the potential problem of unrepresentativeness of recovered firearms as stand-ins for all firearms. This issue would be particularly concerning if all firearms were recovered via the same search strategy by police. For example, if all or nearly all firearms were

recovered via pedestrian stops or car stops. One could imagine, in this case, that perhaps only those with access to sufficient ammunition would dare to venture out with their weapons, thereby creating an empirical distribution that is a poor proxy for the overall distribution of end-users. However, this is not the case. Firearms are routinely recovered through a variety of different police search strategies. Pedestrian and car stops are two, but warrant searches, calls of an armed gunman, shooting reports, and drug investigations are also common routes to a recovered firearm. This diversity of routes loosely corresponds to the multiple sampling strategies used in sampling other hidden populations with the exception that those enumeration exercises are mostly interested in prevalence estimates and multiple list comparison techniques to understand list overlaps (Chan, Silverman, and Vincent 2021). For our purposes, multiple recovery strategies provide an opportunity to test whether the route of recovery predicts the observed distribution of either fullness or ammunition mix (alongside firearm type, caliber, etc.).

This range of circumstances leading to the recovery of illegally firearms can usefully be grouped into three distinct modes of recovery. First, firearms can be recovered after a shooting or after a report of a person with a gun. These situations almost always occur in public and most often involve the visible display and sometimes discharge of the firearm. Second, firearms can be recovered from a person after a traffic stop, a pedestrian stop, or some other police search of an individual observed in public. Finally, firearms can be recovered from a private residence after the execution of a search warrant, often involving a drug investigation, or after responding to a call of domestic violence. The assumption of our sensitivity test is that any bias in our estimates due to a positive correlation between ammunition load level and probability of recovery will be most likely to be observed in our first two categories since these weapons are being carried into public spaces for potential or actual use. By contrast, we assume that weapons recovered in private dwellings in

searches that should not be temporally correlated with the load status of the recovered weapons can serve as an empirical check on the degree of any induced correlation in our estimates.

To test this, we fit a regression model predicting the probability of a firearm being full on the mode of recovery, weapon characteristics and ammunition mix. Doing so also provides an opportunity to test for other potential observable threats to the validity of inference. For example, firearms recovered immediately after a reported shooting should be observed to have lower fullness levels, albeit unrelated to market thinness. Weapons involving higher calibers, which cost more to load, should be more likely to be empty or partially full. We explore these and related questions in our next section.

Results

Ammunition Levels

Table 1 reports the basic level of fullness for the firearms recovered by the BPD between January and September of 2023. Of the 194 weapons studied, 90% had sufficient information available that fullness could be inferred. The remaining 10% may or may not be missing at random and additional analyses of these weapons are ongoing. Just under 50% of firearms (48.5%) were found to be fully loaded. Another 18% were found to be between 80% and 99% loaded when recovered. 15% were found to between 50% and 79% loaded. And just under 8% were found to be less than 50% loaded. Of these, just 1% were found to be empty. This last result is discussed in more detail below. Figure 3 reports the same results graphically, but the exclusion of missing values shrinks the denominator and leads to slightly higher estimates of remaining categories. For example, the percentage of fully loaded firearms goes from 48% to 54% of cases. Regardless of how missing values are handled, the overall estimate is similar—approximately half of all

recovered firearms are full, most non-full firearms are substantially full, and a minority of firearms are less than half full.

Ammunition Mix

Table 2 reports the basic results on the mix of ammunitions found in recovered firearms. Due to the way in which BPD photographed ammunition, the data missingness rises to 26% of firearms. Still, the results for non-missing cases are intriguing and show a less skewed distribution than was observed for ammunition levels. 33% of firearms were found to have a single type of ammunition regardless of fill level. Another 19% were found to have two distinct types of ammunition. And 22% of recovered firearms were found to have 3 or more distinct types of ammunition. This reduced level of skewness across the ammunition mix metric hints at the possibility, discussed earlier in the paper, that the two measures of market thinness in this paper could diverge from each other in important respects. Figure 4 graphically explores this possibility by re-graphing Figure 3 over the three substantive categories and the missing category of the ammunition mix metric. While small differences, some of which could be statistically significant in a larger sample, can be seen, the overall shape of the distributions is largely the same across categories. It also closely resembles the distribution seen in Figure 3. Whether prohibited possessors are scrounging, loading, or doing something in-between (e.g., scrounging or reloading), the probability of their having a full or nearly full firearm is quite comparable. This suggests that these metrics give different impressions of market thinness due to their lack of obvious co-variation. One interesting further example of complex relationship between different measures of ammunition can be seen in the relationship between ammunition quality and ammunition mix or scrounging. In additional results (not shown), it was observed that not all cases of ammunition

scrounging (3+) included visually low-quality ammunition. However, most low-quality ammunition was observed in cases involving scrounging.

Sensitivity Check

Figure 5 serves as a preliminary and visual check of the sensitivity of our primary measure—ammunition level—to concerns about omitted variable bias. If the distribution of ammunition load levels differs notably depending on the mode of firearm recovery (e.g., recovered after a shooting, recovered after a traffic stop, recovered after a warrant search of a dwelling), then the validity of this as a measure of thinness in the market for illegal ammunition will be reasonably called into question. However, Figure 4 reveals that load level distributions look generally quite similar across mode of recovery. Weapons recovered in private residences appear have very similar load distributions as weapons recovered in public places. Weapons recovered after the report of a shooting, or a public firearm are the only category that suggest that hints at a deviation from the overall distribution for recovered firearms. However, the deviation is consistent with the hypothesis that firearms recovered through this recovery pathway should have at least a slightly lower probability of being found full. Therefore, Table 4 tends to confirm that mode of recovery has a minimal relationship with the probability of recovering a full firearm.

Table 3 reports the results of our test of our formal test of whether ammunition levels varied with mode of recovery. Because of the extreme skewness of the distribution of the outcome measure, as seen in Figure 3, we elected to use a limited dependent variable model to represent the outcome. This model predicted the probability of a recovered firearm being full on the indicators for the three modes of recovery with recovered from a traffic/pedestrian stop being the hold out category. Additional indicators for number of batches, and weapon manufacturer were also added

to this regression model. The results reveal that there were no statistically significant differences between the modes of recovery, confirming the graphical results seen in Figure 5. Similarly, the results for ammunition mix also showed no significant differences, confirming the graphical results seen in Figure. Interestingly, no clear pattern of coefficients or significance levels appeared for manufacturers either. Given the sizable price differentials between a good condition Glock or Smith & Wesson compared to a Taurus, it appears based on this sample that price and ammunition level are not well-correlated. However, some of these results could change with a larger sample size (see Figure 6 for details).

Inferring Firearm Use Intent

It is common to encounter a range of public and scholarly narratives regarding the intent of illegal gun possessors. Some clearly emphasize that illegal possessors carry their firearms for aggressive purposes—to seek revenge or otherwise enact violence, a view consistent with the observed levels of actual gun violence. Others narratives indicate that illegal possessors often carry illegal firearms for purely defense purposes and would only brandish or discharge their firearms if first threatened (Decker et al. 1995; Watkins, Huebner, and Decker 2008). Still others admit to aggressive uses (e.g., brandishing or threatening) but distinguish their more "virtuous" illegal possessions from more problematic ones by stating that their weapons are carried empty. As one such individual reported in a recent ethnography, "I'm stealing a lot of car radios right now, and sometimes, if I get really brave I may try to take a purse. For that shit, I keep the gun, but I never use it, you know. I don't even load it, I keep the bullets I got for the bigger shit I do." (Cook et al. 2007:F598)

In the past, the only way of measuring the prevalence of these different states of intent was to ask respondents using self-report surveys or interviews. However, there is some reason to be concerned that the concept of defense carrying, which is reported by most respondents in self-report surveys, is being over-reported since it also happens to be the socially acceptable response. Theoretically, criminal history searches could also be used to establish how often individuals arrested for illegal firearm possession had previously or subsequently been arrested for illegal discharge of a firearm as another way of making sense of how often firearm possession is a reasonable proxy for firearm use intent. However, with homicide clearance rates at or below fifty percent for many cities and non-fatal shooting rates substantially lower, it's not clear how well official records capture the true extent of firearm violence involvement among firearm possession arrestee populations.

Here again recovered ammunition offers a window into something that previously was partially visible. The relevant information comes in two forms. First, within the larger distribution of ammunition levels observed in recovered firearms is the very particular number of zero, reflecting those situations in which police recovered an unloaded firearm. This can either be because the firearm was empty, and the illegal possessor lacked ammunition, or because the firearm was empty, and the illegal possessor was found to have ammunition separately in his or her possession. The frequency with which either of these situations occurs, but especially the first situation, serves as a reasonable and direct measure of possession without the practical intent of harming through firearm discharge if it is assumed that an empty firearm is known and intended to be empty by the possessor.[7] Table 1 previously reported that of the 194 recovered firearms in

[7] Empty firearms, in this interpretation, are treated as choices rather than as undesired or less desired outcomes of a constrained decision process. While this assumption is different than the previous assumption that empty firearms are a signal of highly constrained choices, the practical significance of this alternative interpretation is likely to be

this study, roughly 1 percent were found to be empty. This suggests that empty weapon possession is not well-established by examining recovered firearms. However, a closer examination of the two cases that contribute to the 1 percent estimate reveals an even starker picture. In the first of these two cases, the firearm, a revolver, was recovered through service of a warrant in a drug investigation and though empty, 32 rounds of matching .22 caliber ammunition were also recovered. In the other case, the firearm, a Smith & Wesson, was recovered empty after police received a report of a person with a gun, which could indicate that a shooting had taken place. Whether the exact estimate from this sample is rendered as 1%, .05%, or 0%, the implication is the same—illegal firearm possessors don't normal possess empty firearms.

Table 4 reports descriptive statistics for the other extreme of firearm use intent. It reports how often recovered firearms have a round chambered and therefore ready for immediate discharge. This is observed in just under half (46%) of recovered firearms. However, this result ignores that while most recovered firearms are semi-automatic pistols, in which a chambered round no longer requires racking of the slide prior to discharge of the weapon, a small number of recovered firearms were revolvers, which, when fully loaded, also have a round chambered. Including the four fully loaded revolvers with the existing count of chambered firearms in Table 4 bumps up the observed percentage of chambered firearms to 48% of all weapons.

Figure 7 explores chambering behavior in more detail by comparing the probability of chambering to the overall ammunition level in recovered firearms. If chambering is simply reflective of possessors' desire to carry their weapons in a state of maximum fullness, then there should be little chambering at lower levels of fullness. Conversely, if chambering is observed across levels of fullness, then the decision to chamber a round is likely more reflective of intent to

quite limited. The applicability of each theory can be most clearly seen in whether any empty firearms are recovered with accompanying but unloaded ammunition or if they are recovered without ammunition at all.

have firearms "ready-to-go." Figure 5 shows that there is a weak but positive relationship between ammunition level and probability of chambering. To remove any motive contamination from our estimate of chambering for "ready-to-go" purposes, we then computed the percent of weapon chambered among full and not full firearms separately. The full firearms were observed to have a fifty percent probability of having a round chambered, reflecting the fact that our definition of "full" was restricted to full clips only. The not full firearms were observed to have a 43 percent probability of having a round chambered. The similarity of these two estimates, which could disappear or gain statistical significance in a larger sample, for now suggests that many illegal possessors are interested in having their weapons "ready to go," not simply that they want to make sure that they have maximum ammunition loads.

Discussion

Scholars have long sought to better understand the dynamics of the illegal market for firearms and ammunition. And using interviews of market participants, firearm tracing, and surveys of jail inmates, the literature on illegal firearm markets is now rich with hypothesized mechanisms, variables, nuances, and narratives. However, determining which of these are the dominant features of the illegal market for ammunition and which of these are comparatively bit players in the informal market through which guns and ammunition transition from store shelves to the streets remains an ongoing and well-recognized problem. The present investigation has proposed one often-overlooked source of information that could shed new and potentially inexpensive light on the supply channel for ammunition. This information is available retrospectively and prospectively, in small and large jurisdictions, as well as potentially being already digitized for jurisdictions that have digitized their evidence-recovery systems.

Using this information for one major metropolitan jurisdiction, we have shown that the market for illegal ammunition, at least in this jurisdiction, is only somewhat thin. While many weapons have a mixture of multiple types of ammunition, roughly fifty percent of weapons are recovered with full magazines and another sizable portion are recovered substantially full. This pattern might be interpreted more optimistically if these results were observed in a jurisdiction with a weaker ammunition regulatory regime in place, but the research setting happens to have one of the most restrictive regulatory regimes in the country. This suggests that access to ammunition is a surmountable problem if it's even a problem. This result should not be interpreted as indicating the fruitlessness of attempting to interrupt the diversion of ammunition into the illegal firearms and ammunition market. However, it should temper our understanding of the effectiveness of existing measures. At a theoretical level, it should also temper our enthusiasm for the attractiveness of theories of illegal markets that emphasize their distinctiveness relative more conventional markets. Minors routinely obtain cigarettes and alcohol. Prohibited possessors of firearms, of which a decent subset are also minors, have little trouble obtaining firearms. Why should ammunition be any different?

A separate point also bears mentioning. An ongoing theoretical and policy debate has focused on the degree to which these same prohibited possessors, again many of them juvenile, are carrying firearms defensively due to fears for their personal safety. Examples of this can be seen in debates on the proper sentences for gun possession cases (Friedersdorf 2022). This is a larger discussion than this narrow analysis can address. However, on one sub-point of this larger debate the finding of this descriptive analysis is quite clear. It has been posited that some fraction of prohibited possessors carries unloaded or minimally loaded firearms to avoid injuring others.

These unloaded but carried firearms, so the theory goes, can be used to deter would-be assailants, pacify robbery victims without risk of accidental discharge, or otherwise "safely" avoid actual violence through the possession of a weapon that can be visually confused for one with the real potential for violence. While this may be true somewhere at some time, it is disconfirmed by what has been observed in this specific place in this specific time.

At the same time, the results reported in this initial empirical inquiry should not be over-interpreted. This is a study of only 7.5 months of data for one city. Additional work to lower the observed level of missingness remains to be completed and having a large N would likely shift some of the statistically insignificant relationships observed into significance. Furthermore, despite the sensitivity checks reported in this paper, it is possible that recovered firearms are an imperfect proxy for unrecovered illegal firearms. However, given the volume of recovered firearms, it seems unlikely that the distributions would be entirely non-overlapping. Firearm fullness, while useful as an instantaneous measure of ammunition accessibility, provides little insight into other aspects of the illegal ammunition market. For example, it provides little insight into price and search costs. Both of which have been speculated about in the qualitative literature but have remained unexamined in more systematic fashion.

In future work, beyond replicating the results reported in this paper with larger samples and different police agencies, there are a large range of additional inquiries that could be pursued with this administrative data. For example, studies could be conducted comparing ammunition levels in cities with greater number of "community guns" (e.g., New York City), gang- controlled guns (e.g., Chicago), as well as individually obtained firearms (e.g., Washington, D.C.). Likewise, studies could compare ammunition levels in firearms linked to shootings and those that are not to examine whether there is a split-market for ammunition between violence-connected and violence-

unconnected firearms. Apart from comparing jurisdictions based on features of their gun violence patterns or their regulatory regimes, the measures reported in this paper could also be used to explore the impact of specific enforcement actions at relatively low cost.

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Tables and Figures

Table 1. Fullness of Recovered Firearms

Fullness	Percentage	N
100%	48.45%	94
80 – 99%	18.04%	35
50 – 79%	15.46%	30
01 – 49%	06.70%	13
Empty	01.03%	02
Missing Fullness Information	10.31%	20
N		194

Table 2. Number of Distinct Ammunition Varieties in Recovered Firearms

# of Observed Ammo Types	Percentage	N
1	32.99%	65
2	19.07%	40
3 or more	22.16%	44
Missing Type Information	25.77%	55
N		194

Table 3. Logistic Regression of Fullness of Recovered Firearms on Select Features of Firearms and Circumstances of Recovery

Mode of Recovery	
Search of a Private Residence	0.961
	(0.397)
Report of a Gun or Shooting	0.847
	(0.376)
Ammunition Mix	
Two Types	0.833
	(0.382)
Three or more Types	1.290
	(0.549)
Missing Type Info	1.081
	(0.509)
Manufacturer	
Smith & Wesson	0.611
	(0.325)
Taurus	1.077
	(0.605)
Ruger	0.515
	(0.332)
P80/Ghost Gun	0.515
	(0.332)
Other	0.520
	0.218
Constant	1.563
	(0.604)
N	165

Table 4. Frequency of Chambered Ammunition in Recovered Firearms

Chambered Round	Percentage	N
Yes	46.39%	90
No	52.06%	101
Missing Chamber Info	01.55%	3
N		194

Figure 1. Example of Recovered Firearm and Ammunition



Source: Boston Police Department

Figure 2. Example of Recovered Firearm and Individually Packaged Ammunition



Source: Boston Police Department

Figure 3. Distribution of Ammunition Levels Found in Recovered Firearms

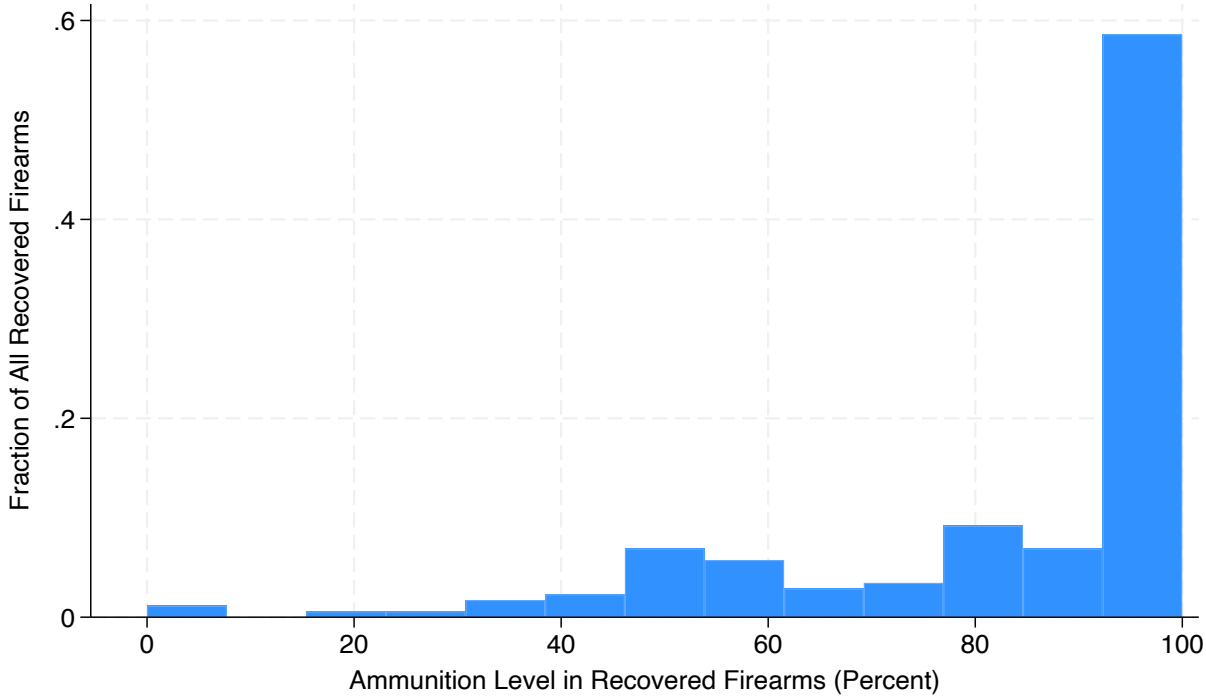


Figure 4. Distribution of Ammunition Levels Found in Recovered Firearms by Number of Distinct Ammunition Types

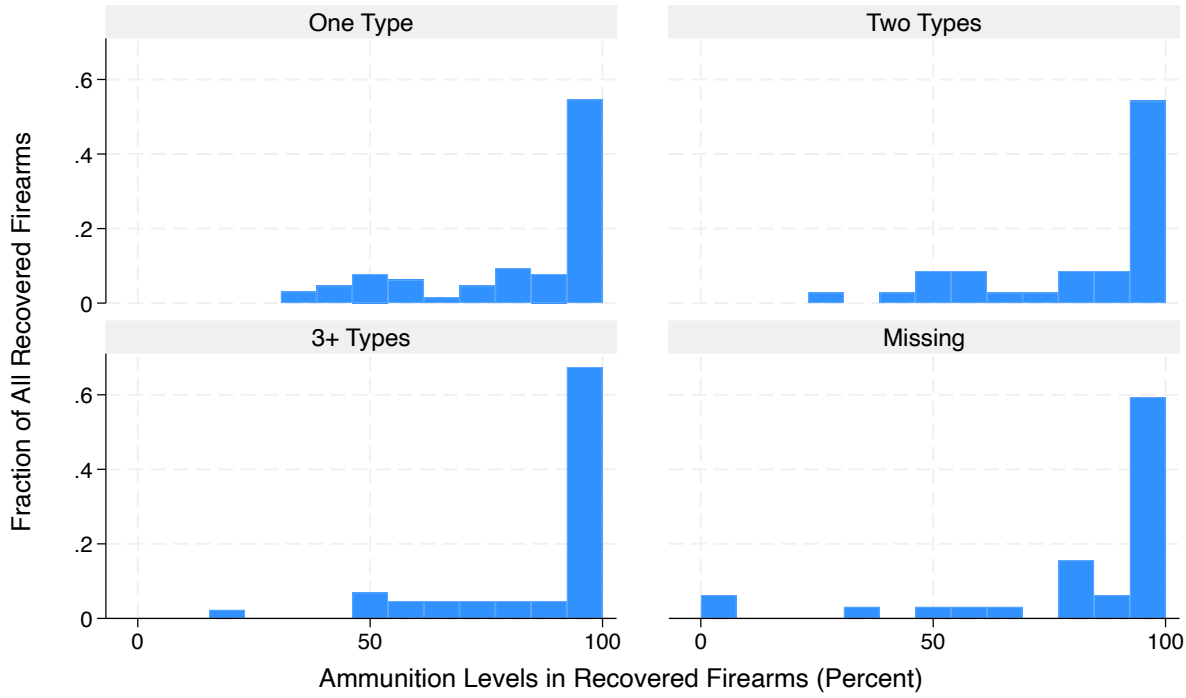


Figure 5. Distribution of Ammunition Levels Found in Recovered Firearms by Circumstances of Recovery

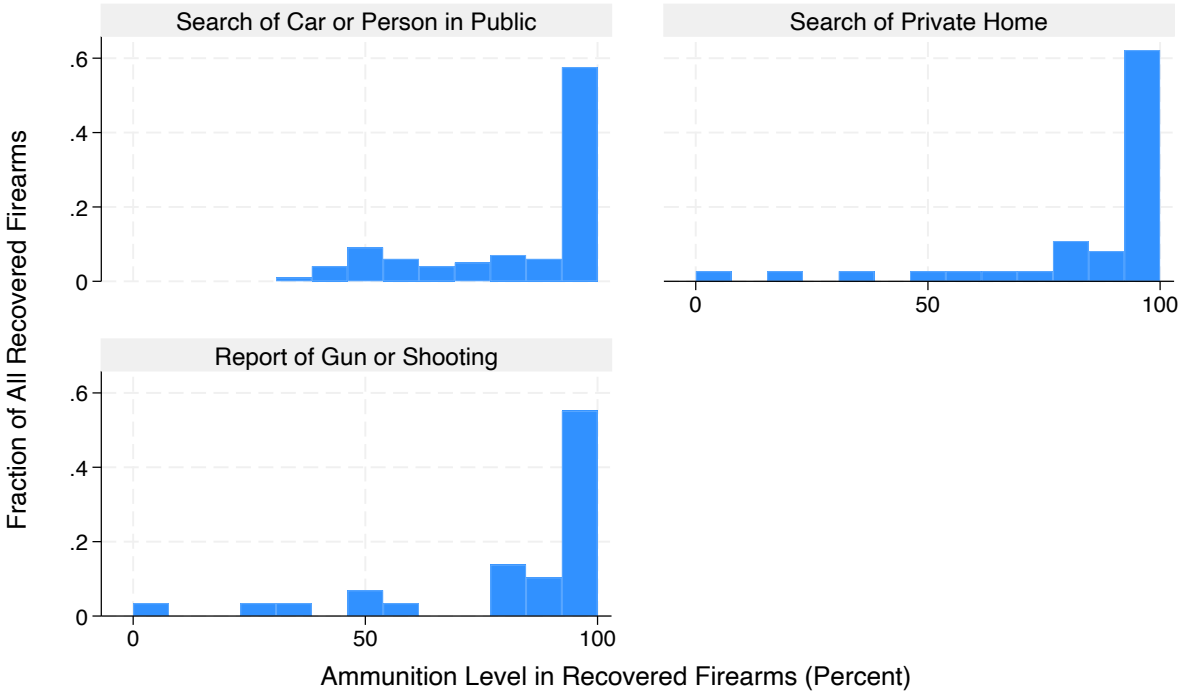


Figure 6. Distribution of Ammunition Levels Found in Recovered Firearms by Firearm Manufacturer

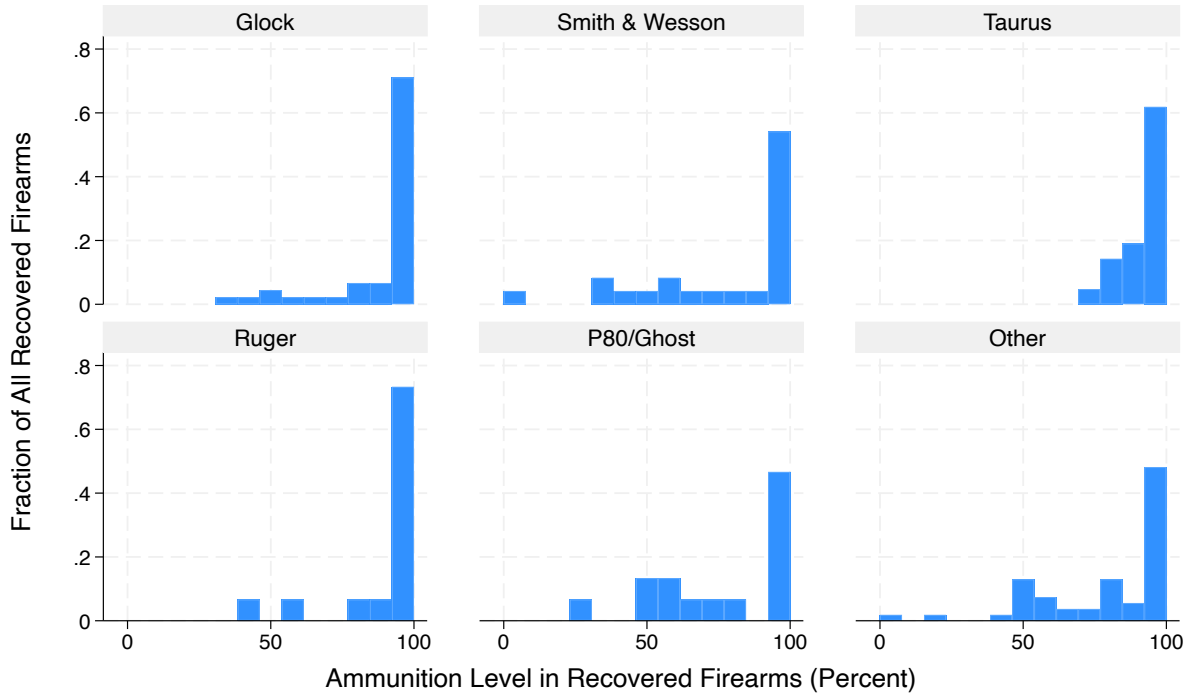


Figure 7. Lowess Smoother Estimate of Round Chambering by Ammunition Levels

