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# Is today's marijuana more potent simply because it's fresher?

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**The average potency of illicit marijuana in the USA has increased substantially over the past four decades, and observers have suggested a number of likely reasons for this. One set of hypotheses points to a market that has evolved from foreign to domestic sources of supply, and to continuing advances in sophisticated cultivation techniques. Another set of hypotheses points to testing artifacts related to changes in the sampling, handling, and testing of illicit marijuana. The current study uses data from the federally sponsored Potency Monitoring Program, which performs ongoing forensic analysis of seized marijuana samples, to assess the extent to which the observed increase in cannabis potency in the USA between 1970 and 2010 is a function of genuine shifts in illicit marijuana markets or testing artifacts related to changes in the quality of seized marijuana. The study finds, after adjusting for marijuana quality, that the apparent 10.5 factor increase in mean reported THC% between the 1970s and the 2000s is instead on the order of a six- to seven-fold increase. By this accounting, then, the reported long-term rise in potency is roughly 57–67% as great when the quality of the tested marijuana is taken into account. This study's findings, therefore, caution against the uncritical use of potency monitoring data and highlight the importance of assessing potency measurement reliability and addressing data quality issues in future policy analytic research.**


**Keywords:** cannabis; potency; trends; testing artifacts

## Introduction

Evidence from both international and domestic seizures suggests that marijuana (cannabis) potency has increased steadily over the past four decades. Recent systematic reviews report that average concentrations of $\Delta^9$-tetrahydrocannabinol (THC) – the main psychoactive component of marijuana – have increased from about 1–2% during the early 1970s to 8–9% as of the late 2000s.[1,2] In the USA and elsewhere, this increase has been attributed to a number of factors, including the shift from foreign to domestic sources of supply during the early 1980s as production moved closer to consumers, subsequent improvements beginning in the late 1980s in sophisticated indoor and hydroponic cultivation methods, and, since the early 2000s, expanded production of high-potency sinsemilla (i.e. buds from unpollinated female plants).[3–7]

Alternatively, it has been argued that the noted increase in cannabis potency could be an artifact of systematic changes in the sampling, handling, and testing of seized marijuana. In particular, questions have been raised about the comparability and accuracy of potency measurements across time due to a lack of representativeness of marijuana seizures, variations in the quality of tested marijuana (e.g. due to improvements in drug evidence handling protocols and storage conditions), and changes in forensic laboratory analysis methods and equipment.[8–10]

This study uses data from the federally sponsored Potency Monitoring Program to assess the extent to which the observed increase in cannabis potency in the USA between 1970 and 2010 is a function of genuine shifts in illicit marijuana markets or testing artifacts related to changes in the quality of laboratory tested marijuana. If more recently analyzed marijuana is relatively fresher because of shorter testing delays or better drug evidence storage conditions rather than the faster time-to-market of domestic versus foreign-sourced product, then the apparent increase in potency may be less than reported. Discerning the relative merits of these competing propositions is important because both public opinion and public policies on marijuana are shaped by claims that the marijuana available to today's consumers is much more powerful and dangerous than it was just a generation or two ago.[11,12]

## Data and methods

### Potency monitoring data

Data on marijuana potency and related characteristics come from the Potency Monitoring Program (PMP), a project administered by the National Center for Natural Projects Research (NCNPR) at the University of Mississippi and funded by the National Institute on Drug Abuse (NIDA). Since the 1970s, the PMP has performed forensic analysis of seized cannabis specimens (marijuana, hashish, hash oil) submitted by Drug Enforcement Administration (DEA) regional laboratories, state cannabis eradication programs, and other local sources.[13–15]

This study focuses on federally seized PMP specimens originating from regional DEA labs, as these seizures represent finished product of mature plant material.[2] PMP specimens originating from state eradication programs represent plants confiscated at varying stages of maturity, including seedlings and immature plants of low potency, so these data were not analyzed. The original PMP data file of DEA lab submissions contained 52 192 observations,

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which was reduced to 46 274 observations after dropping cases appearing in duplicate ($n=2$), falling outside the 1970-2010 study period ($n=800$), characterized as ditchweed, hashish, or hash oil ($n=2,330$), seized outside the United States ($n=1,827$), or logged into the database but not yet analyzed for cannabinoid content ($n=2,007$).

### Measurement and analysis

Several metrics were operationalized to assess the type, freshness, maturity, and potency of the seized marijuana samples. Product type was coded based on the physical attributes of the plant material: (1) *kilobrick* – compressed leaves, stems, and seeds (typically of foreign origin), (2) *mid-grade* – loose material or buds with stems and seeds, and (3) *sinsemilla* – seedless buds of unpollinated female plants.

Cannabinol (CBN), which is not present in fresh marijuana, is a primary degradation product of $\Delta^9$-tetrahydrocannabinol (THC);[16] marijuana freshness was therefore assessed in two ways based on the relative concentration of these two cannabinoids. First, following Grlic's[17] classification scheme differentiating marijuana by its degree of 'ripeness', *overripe* marijuana was indicated by a predominance of CBN (i.e. CBN > THC). Second, based on Ross and ElSohly's[18] research showing the *CBN:THC ratio* to be most predictive of the age of marijuana samples, freshness was also calculated by the formula (CBN*10)/THC.† According to this metric, the larger the ratio, the more degraded the marijuana.

Marijuana maturity was similarly derived using two approaches. *Cannabinoid-based age* was estimated by reference to the expected change in the CBN:THC ratio as a function of time. Parameter values used to derive these estimates were obtained from Trofin *et al.*,[19] who analyzed the cannabinoid content of marijuana plants seized from ten world regions that were then stored under laboratory conditions (either in darkness at 4°C or natural light at 22°C) over a four-year period.‡ Estimates were derived as follows. First, the mean CBN:THC ratio was calculated from Trofin *et al.'s* results at each reported time point (i.e. 0, 12, 24, 36, and 48 months) for drug-type samples (fibre-type samples from one world region were excluded) stored at 22°C under natural light (being more typical of illicit marijuana trafficking and storage conditions).§ Second, interim monthly CBN:THC values were linearly interpolated. Because the mean concentration of CBN was nonzero at $t=0$ (indicating deterioration had already commenced), values were also linearly extrapolated until the CBN:THC ratio $\approx 0$. This occurred at $t=-2$, so two months were added to Trofin *et al.'s* observation period, resulting in a reference time series spanning 0 to 50 months with corresponding mean CBN:THC ratios (range: 0.07, 22.6). Third, the reference CBN:THC ratios were mapped onto the actual CBN:THC ratios to derive the estimated age of each PMP specimen. For example, samples with CBN:THC ratios $\geq 0$ and $< 0.07$ were assumed to be 0 months old, those with CBN:THC ratios $\geq 0.07$ and $< 0.25$ were assumed to be 1 month old, and so on. Lastly, about 1% of the PMP cases ($n=455$) had a CBN:THC ratio $\geq 22.6$, so the age of these samples was top-coded at 51 months.

Alternatively, marijuana maturity was operationalized as the *seizure-to-analysis lag*, that is, the number of months between a specimen's seizure and analysis dates. Specifically, the time from seizure to analysis was obtained as (analysis date – seizure date) / 30.42. Prior to performing this operation, the data were treated as follows: (1) the 15th day of the month was used as a standard replacement value when information was reported only for month and year, and (2) erroneous seizure or analysis dates (e.g., when seizure-to-analysis lag $< 0$) were manually recoded for $n=103$ cases by reference to sample receipt and log dates also reported in the PMP data.¶

Marijuana potency was measured in two ways. First, as the standard reported measure of potency, *THC%* was defined simply as the THC concentration by weight obtained by PMP forensic analysis. This unadjusted series reflects potency at the time of assay, and therefore ignores potentially confounding testing artifacts. Thus, to better ascertain marijuana potency at the time of likely consumption, a quality-adjusted measure was developed to account for the testing lag between specimen seizure and analysis, with lower and upper bounds reflecting the variability in drug evidence handling protocols and storage conditions likely to be encountered at DEA Field Divisions and Regional Laboratories.[20–23] Specifically, *adjusted THC%* was estimated using an exponential decay model, $THC_0 = THC_a / e^{-(k)(t)}$, where $THC_0$ is the unknown initial concentration, $THC_a$ is the assayed concentration, $k$ is the decay rate constant, and $t$ is the seizure-to-analysis lag. Drawing once again on Trofin *et al.'s*[19] work examining the degradation of stored marijuana samples over a four-year period, the lower-bound decay constant, $k=0.0263$, was derived as the average decay rate reported for drug-type samples stored in darkness at 4°C, whereas the upper-bound constant, $k=0.0342$, was derived as the average decay rate for drug-type samples stored in natural light of laboratory at 22°C. Lastly, after prediction, the top 0.1% ($n=46$) of the lower- and upper-bound quality-adjusted potency values were Winsorized to 32.1 and 34.3, respectively, because the imputed values were either impossibly or unreasonably high.

## Results

As noted above, there has been some debate in the literature over the extent to which observed trends in cannabis potency over the past four decades are a function of genuine shifts in cannabis markets or an artifact of changes in the quality of the tested marijuana. To explore these competing hypotheses, Table 1 presents trends in the characteristics of confiscated marijuana over the period 1970–2010. First, as the table shows, the reported average THC% of seized marijuana increased from ≤ 1% in the

†The numerator was multiplied by a factor of 10 to place the measure on a similar scale to other indicators.

‡Ross and ElSohly[18] also reported on the deterioration of marijuana samples stored over a four-year period, but the range of the initial THC concentrations in the samples they analyzed – 1.6% to 5.3% – were less reflective of the PMP data than the range of THC concentrations in samples analyzed by Trofin *et al.* [19] – 1.2% to 19.9%.

§Cannabinoid concentrations were reported in Trofin *et al.*[19] Tables 1 and 4. Table 4 contained two obvious typographical errors that were corrected prior to calculating the mean CBN:THC ratio as follows: CBN% for region C2 at time 1 (12 months) was changed from 1.11 to 3.11, and CBN% for region C9 at time 4 (48 months) was changed from 0.10 to 1.00.

¶For example, one case reported the following dates for the specimen's seizure (05dec1996), laboratory receipt (15mar1996), database logging (29mar1996), and analysis (15may1996). In this instance, the seizure date was recoded to 05dec1995 in order to be temporally consistent with the other three reported dates.

  

**Table 1.** Characteristics of confiscated marijuana, United States, 1970-2010

| Year Seized | Potency | | Product Type | | | Freshness | | | Maturity (in Months) | | | | Quality-Adjusted Potency | | | | Total N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | THC% | | Kilobrick | Mid-Grade | Sinsemilla | "Overripe" | CBN:THC Ratio | | Cannabinoid-Based Age | | Seizure-to-Analysis Lag | | Adjusted THC %, Lower Bound | | Adjusted THC %Upper Bound | | |
| | Mean | (SD) | % | % | % | % | Mean | (SD) | Mean | (SD) | Mean | (SD) | Mean | (SD) | Mean | (SD) | |
| 1970 | 0.5 | (0.7) | 66.7 | 33.3 | 0.0 | 66.7 | 40.0 | (34.1) | 35.3 | (27.1) | 85.2 | (52.6) | 2.0 | (0.4) | 4.0 | (0.9) | 3 |
| 1971 | 1.1 | (0.8) | 0.0 | 100.0 | 0.0 | 0.0 | 1.1 | (1.0) | 6.3 | (5.5) | 11.8 | (2.1) | 1.6 | (1.2) | 1.8 | (1.3) | 3 |
| 1972 | 0.9 | (0.6) | 0.0 | 100.0 | 0.0 | 30.8 | 23.4 | (41.5) | 20.5 | (21.0) | 34.0 | (43.9) | 1.5 | (0.6) | 2.1 | (1.3) | 13 |
| 1973 | 0.2 | (0.1) | 42.9 | 57.1 | 0.0 | 100.0 | 39.6 | (15.3) | 49.8 | (2.9) | 56.7 | (35.0) | 1.1 | (1.1) | 1.9 | (2.5) | 14 |
| 1974 | 0.4 | (0.5) | 77.8 | 22.2 | 0.0 | 78.1 | 33.3 | (33.0) | 42.7 | (13.6) | 44.7 | (24.0) | 1.2 | (1.0) | 1.6 | (1.6) | 64 |
| 1975 | 0.6 | (0.6) | 69.4 | 30.7 | 0.0 | 52.4 | 22.9 | (29.9) | 34.8 | (16.7) | 37.3 | (21.2) | 1.0 | (1.0) | 1.4 | (1.7) | 124 |
| 1976 | 0.6 | (0.7) | 91.2 | 8.9 | 0.0 | 33.9 | 11.6 | (12.9) | 29.8 | (14.8) | 39.1 | (12.4) | 0.9 | (1.3) | 1.2 | (1.8) | 192 |
| 1977 | 0.7 | (0.7) | 78.9 | 21.1 | 0.0 | 42.0 | 11.0 | (9.9) | 32.0 | (13.6) | 25.6 | (12.0) | 1.1 | (1.3) | 1.4 | (1.6) | 205 |
| 1978 | 1.2 | (0.9) | 59.2 | 40.8 | 0.0 | 35.0 | 12.6 | (16.6) | 29.0 | (15.9) | 18.0 | (13.3) | 1.8 | (1.3) | 2.1 | (1.5) | 100 |
| 1979 | 1.8 | (1.7) | 30.5 | 52.5 | 17.0 | 38.3 | 12.8 | (16.7) | 25.3 | (20.3) | 13.0 | (12.4) | 2.2 | (1.7) | 2.4 | (1.7) | 60 |
| 1980 | 1.1 | (0.8) | 7.5 | 91.0 | 1.5 | 35.3 | 10.2 | (11.3) | 30.2 | (13.4) | 12.7 | (7.7) | 1.5 | (1.0) | 1.6 | (1.2) | 68 |
| 1981 | 2.7 | (2.5) | 2.0 | 82.4 | 15.5 | 17.6 | 4.4 | (8.4) | 12.7 | (17.2) | 6.6 | (5.8) | 3.1 | (2.7) | 3.3 | (2.8) | 148 |
| 1982 | 4.1 | (2.3) | 0.0 | 97.3 | 2.7 | 8.2 | 2.9 | (5.6) | 10.3 | (14.3) | 4.0 | (6.1) | 4.6 | (2.9) | 4.8 | (3.3) | 231 |
| 1983 | 3.9 | (2.2) | 0.0 | 98.7 | 1.4 | 5.6 | 2.6 | (7.6) | 8.6 | (12.0) | 2.7 | (1.6) | 4.1 | (2.3) | 4.2 | (2.3) | 746 |
| 1984 | 3.6 | (1.9) | 3.0 | 96.3 | 0.7 | 2.9 | 2.1 | (5.7) | 8.6 | (10.1) | 3.2 | (1.6) | 3.9 | (2.1) | 4.1 | (2.2) | 700 |
| 1985 | 3.5 | (2.0) | 10.2 | 88.2 | 1.7 | 5.0 | 2.0 | (3.9) | 8.3 | (10.9) | 4.7 | (2.3) | 4.0 | (2.2) | 4.1 | (2.3) | 718 |
| 1986 | 2.9 | (2.0) | 14.4 | 83.5 | 2.1 | 7.4 | 3.1 | (8.5) | 9.8 | (12.9) | 5.6 | (2.5) | 3.4 | (2.3) | 3.5 | (2.4) | 678 |
| 1987 | 3.3 | (1.8) | 17.6 | 80.9 | 1.5 | 2.7 | 2.1 | (4.1) | 9.2 | (9.9) | 6.2 | (4.3) | 3.8 | (2.3) | 4.0 | (2.4) | 1,108 |
| 1988 | 3.8 | (1.9) | 12.7 | 84.7 | 2.6 | 3.1 | 1.9 | (5.3) | 7.9 | (9.6) | 4.9 | (2.1) | 4.3 | (2.2) | 4.4 | (2.3) | 1,120 |
| 1989 | 3.8 | (1.8) | 6.8 | 89.1 | 4.1 | 3.4 | 2.0 | (7.6) | 6.7 | (9.5) | 5.5 | (2.4) | 4.4 | (2.1) | 4.6 | (2.3) | 734 |
| 1990 | 3.8 | (2.5) | 14.7 | 83.3 | 2.0 | 3.2 | 2.3 | (10.7) | 6.4 | (9.7) | 5.5 | (3.4) | 4.4 | (2.9) | 4.6 | (3.0) | 742 |
| 1991 | 3.3 | (2.4) | 33.3 | 64.9 | 1.9 | 1.8 | 1.6 | (10.4) | 5.6 | (8.2) | 6.2 | (4.3) | 3.9 | (2.9) | 4.1 | (3.0) | 1,519 |
| 1992 | 3.2 | (2.2) | 42.9 | 55.8 | 1.4 | 3.8 | 2.5 | (4.2) | 11.1 | (10.8) | 8.0 | (2.6) | 3.9 | (2.6) | 4.1 | (2.7) | 2,452 |
| 1993 | 3.7 | (2.1) | 50.9 | 48.9 | 0.3 | 2.0 | 1.7 | (3.4) | 7.6 | (9.1) | 5.6 | (3.4) | 4.2 | (2.4) | 4.4 | (2.5) | 1,978 |
| 1994 | 3.8 | (1.9) | 59.0 | 40.6 | 0.5 | 3.1 | 1.6 | (4.0) | 6.8 | (9.7) | 6.6 | (3.9) | 4.5 | (2.4) | 4.8 | (2.6) | 2,042 |
| 1995 | 4.0 | (1.8) | 72.5 | 27.0 | 0.5 | 1.0 | 1.4 | (2.6) | 6.9 | (6.9) | 8.8 | (3.1) | 5.0 | (2.3) | 5.4 | (2.5) | 3,744 |
| 1996 | 4.5 | (2.3) | 45.2 | 53.3 | 1.6 | 2.4 | 1.6 | (5.5) | 6.4 | (8.2) | 8.8 | (4.6) | 5.7 | (2.9) | 6.1 | (3.2) | 1,382 |
| 1997 | 5.0 | (2.7) | 38.6 | 60.0 | 1.4 | 1.2 | 1.0 | (1.9) | 5.1 | (6.7) | 7.1 | (3.1) | 6.1 | (3.2) | 6.4 | (3.4) | 1,323 |
| 1998 | 4.9 | (3.0) | 35.9 | 61.4 | 2.8 | 1.7 | 1.5 | (5.6) | 5.8 | (7.8) | 8.1 | (4.1) | 6.0 | (3.6) | 6.5 | (3.9) | 1,307 |
| 1999 | 4.6 | (3.4) | 32.8 | 64.0 | 3.2 | 4.4 | 2.3 | (4.4) | 10.0 | (10.8) | 11.1 | (6.0) | 6.1 | (4.3) | 6.6 | (4.7) | 1,790 |
| 2000 | 5.4 | (3.5) | 32.6 | 64.2 | 3.2 | 1.8 | 2.0 | (11.8) | 7.9 | (8.0) | 11.5 | (3.5) | 7.3 | (4.8) | 8.0 | (5.2) | 1,898 |
| 2001 | 6.1 | (3.7) | 36.9 | 57.5 | 5.7 | 0.7 | 1.0 | (1.9) | 5.3 | (6.2) | 8.1 | (2.5) | 7.6 | (4.6) | 8.1 | (4.9) | 1,666 |
| 2002 | 7.3 | (4.8) | 40.7 | 41.0 | 18.3 | 0.4 | 0.6 | (1.0) | 3.3 | (4.4) | 5.4 | (2.2) | 8.4 | (5.5) | 8.8 | (5.8) | 1,648 |
| 2003 | 7.2 | (4.7) | 48.4 | 33.0 | 18.7 | 0.2 | 0.6 | (1.1) | 3.5 | (4.6) | 4.3 | (2.3) | 8.1 | (5.3) | 8.3 | (5.5) | 1,833 |
| 2004 | 8.2 | (5.3) | 39.1 | 35.2 | 25.7 | 0.6 | 0.9 | (2.8) | 4.1 | (6.0) | 5.7 | (2.8) | 9.6 | (6.2) | 10.0 | (6.5) | 1,871 |
| 2005 | 8.1 | (5.0) | 40.7 | 29.5 | 29.8 | 1.3 | 1.0 | (2.9) | 4.6 | (7.2) | 6.7 | (2.7) | 9.6 | (6.0) | 10.2 | (6.4) | 2,245 |

*(Continues)*

**Table 1.** *(Continued)*

| Year Seized | Potency | Product Type | | | Freshness | | Maturity (in Months) | | Quality-Adjusted Potency | | Total N |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | THC% | Kilobrick | Mid-Grade | Sinsemilla | "Overripe" | CBN:THC Ratio | Cannabinoid-Based Age | Seizure-to-Analysis Lag | Adjusted THC %, Lower Bound | Adjusted THC %Upper Bound | |
| | Mean (SD) | % | % | % | % | Mean (SD) | Mean (SD) | Mean (SD) | Mean (SD) | Mean (SD) | |
| 2006 | 8.8 (5.7) | 30.4 | 37.0 | 32.6 | 1.5 | 0.9 (3.3) | 3.9 (7.2) | 5.6 (2.6) | 10.2 (6.6) | 10.7 (6.9) | 2,024 |
| 2007 | 9.6 (5.5) | 21.4 | 39.5 | 39.1 | 0.4 | 0.5 (2.3) | 2.6 (4.3) | 4.5 (2.6) | 10.8 (6.1) | 11.2 (6.4) | 2,090 |
| 2008 | 10.0 (5.4) | 13.6 | 39.0 | 47.4 | 0.7 | 0.7 (3.3) | 3.3 (5.3) | 4.7 (2.0) | 11.3 (6.1) | 11.8 (6.4) | 1,932 |
| 2009 | 9.9 (5.6) | 13.7 | 35.5 | 50.8 | 1.3 | 1.1 (6.4) | 3.9 (6.3) | 4.9 (3.0) | 11.2 (6.4) | 11.7 (6.7) | 1,730 |
| 2010 | 10.6 (6.3) | 13.3 | 26.4 | 60.4 | 0.5 | 0.7 (2.3) | 3.4 (4.8) | 6.4 (2.5) | 12.6 (7.4) | 13.2 (7.8) | 2,029 |
| N | 46,274 | | 46,158 | | 46,153 | 46,153 | 46,153 | 45,926 | 45,926 | 45,926 | 46,274 |

early 1970s to 10–11% in the late 2000s.[||] More generally, by decade, mean THC content was relatively low throughout the 1970s (0.8), jumped in the 1980s (3.5), continued to increase steadily during the 1990s (4.0), and spiked considerably over the course of the 2000s (8.4).

Turning to potential drivers of potency trends, product type is moderately positively correlated with THC%, Spearman's $r = 0.34$, $n = 46{,}158$, $p < 0.001$.[††] As shown in Table 1, the predominant product type varies across years. In the 1970s, when marijuana was primarily smuggled in bulk from Colombia, Jamaica, and other source counties,[24] seizures of lower-potency kilobrick marijuana predominated (72%); sinsemilla, on the other hand, scarcely registered (1.3%). Then, in the 1980s, as domestic production increased, relatively higher-potency mid-grade marijuana accounted for nearly nine of every ten (88%) seizures. Although mid-grade forms of cannabis continued to represent a majority (51%) of seizures in the 1990s, kilobrick seizures resurged to become nearly as common (48%). Even so, the average reported THC% continued to climb – a finding that is likely attributable to the appearance of more potent kilobrick marijuana in the 1990s compared to the 1970s as well as to continued advancements in domestic marijuana cultivation methods. Continuation of the latter trend is apparent in the dramatic upsurge in high-potency sinsemilla seizures during the 2000s, when the share of sinsemilla increased from 3.2% in 2000 to 60% in 2010 (with a corresponding increase in mean annual THC% from 5.4 to 10.6).

Next, indicators of marijuana freshness are presented in Table 1. Notwithstanding the volatility in the early 1970s due to small sample sizes, the first indicator reveals a dramatic long-term decrease in the percentage of overripe or seriously degraded marijuana samples, and this measure has a moderate negative correlation with reported THC%, Spearman's $r = -0.27$, $n = 46{,}153$, $p < 0.001$. In the 1970s, for instance, 44% of seizures were highly deteriorated when assayed, a figure that dropped to 4.9% during the 1980s (despite 35% and 18% of seizures being overripe in 1980 and 1981, respectively), 2.4% during the 1990s, and 0.9% during the 2000s. The second indicator, the CBN:THC ratio, has a strong negative correlation with THC%, Spearman's $r = -0.58$, $n = 46{,}153$, $p < 0.001$. As reported in Table 1, this is reflected by the substantial drop in the mean CBN:THC ratio, which fell from an average of 16.0 in the 1970s to 2.4 in the 1980s, 1.7 in the 1990s, and 0.9 in the 2000s.

Indicators of marijuana maturity are presented next in Table 1. First, cannabinoid-based age is strongly negatively correlated with THC%, Spearman's $r = -0.58$, $n = 46{,}153$, $p < 0.001$. The time series shows that earlier tested marijuana samples are considerably more aged than recently tested samples. In particular, marijuana specimens averaged 32 months old when assayed in the 1970s, a figure that trended downward to 8.9 months in the 1980s, 7.5 months in the 1990s, and 4.2 months in the 2000s. The decreasing age of marijuana samples could signify a market shift toward domestic production, but evidence of decreasing seizure-to-analysis times also points to the role of testing artifacts. The seizure-to-analysis lag is only weakly to moderately correlated

[||]Note that here and throughout reference to the '2000s' includes the year 2010.

[††]Spearman's $r$ is used in this paper to assess strength of association because of the highly skewed distribution of THC%. In the present case, it is also used because of the ordinal nature of marijuana product type.

with THC%, Spearman's $r = -0.19$, $n = 45{,}926$, $p < 0.001$, but the average delay from police seizure to laboratory analysis decreased from a high of 27.4 months in the 1970s to a low of 4.9 months in the 1980s, thereafter edging upward in the 1990s (7.8 months) before falling again in the 2000s (6.2 months).

Changes in the observed characteristics of tested marijuana with respect to potency, product type, and quality (freshness and maturity) can be summarized in broad strokes by decade: the 1970s with a preponderance of low-potency and poor-quality kilobrick marijuana; the 1980s with mostly mid-grade marijuana of increasing potency and quality stabilizing at moderately high levels; the 1990s with an equal mix of kilobrick and mid-grade marijuana edging steadily higher in quality and potency; and the 2000s with the dramatically increasing market share and ultimate predominance of superior-quality, high-potency sinsemilla.

As it happens, these trends and associations offer support for both the market evolution and testing artifact theses. On the one hand, the increase in potency over the past four decades can be explained, in part, by a market that has evolved, perhaps unsteadily, toward greater domestic production and sophisticated cultivation techniques. On the other hand, the quality of laboratory tested marijuana has progressively improved over time. While it is plausible that quality may have increased precisely because of market shifts (e.g. domestic production equals a shorter time to market and therefore better-quality marijuana available to consumers), that interpretation is mitigated by the fact that the average number of months between seizure and analysis also declined from the 1970s to the 2000s. In short, the evidence suggests that both factors are at play.

The relative influence of these two dynamics can be further ascertained by comparing the adjusted and unadjusted potency series. To be sure, as shown in Figure 1 (see also Table 1), the noted upward trend in potency over the past four decades remains even after adjusting for marijuana quality. Although the mean absolute increase in potency from the 1970s to the 2000s is greater for quality-adjusted THC% (mean difference = 0.8–0.9), the relative magnitude of the increase is considerably less. Indeed, rather than a 10.5 factor increase in mean reported THC% between the 1970s to 2000s (0.8 *vs*. 8.4), we instead observe a seven-fold increase for the lower-bound adjusted THC% (1.4 *vs*. 9.8) and a six-fold increase for the upper-bound adjusted THC% (1.7 *vs*. 10.2).

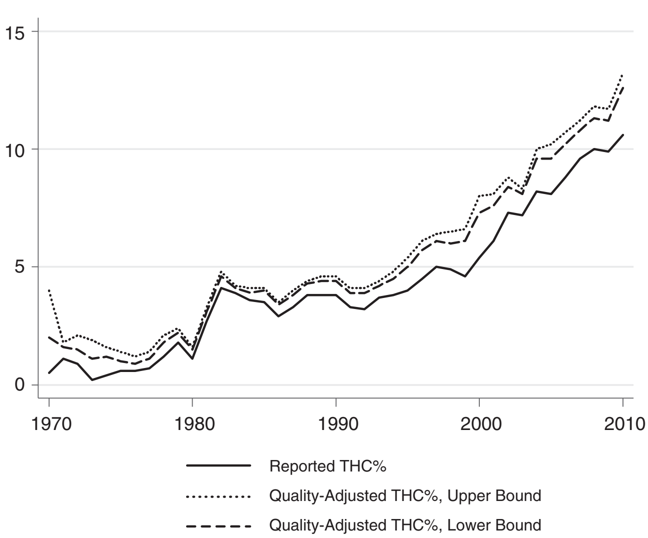


**Figure 1.** Trends in Marijuana Potency, 1970-2010.

By this accounting, then, the reported long-term relative increase in potency is roughly 57–67% as great when the quality of the tested marijuana is taken into account. This difference is largely a function of the relatively inferior quality and low baseline THC values of marijuana tested in the 1970s. Indeed, when assessed against a 1980s baseline instead, both the unadjusted (3.5 *vs*. 8.4) and quality-adjusted THC% series (lower-bound: 4.0 *vs*. 9.8, upper-bound: 4.1 *vs*. 10.2) point to roughly equivalent 2.4–2.5 factor increases in potency through the 2000s.

## Conclusions and discussion

The short answer to the question of whether today's marijuana is relatively more potent because it's fresher is a qualified yes. That is, the inferior quality of earlier versus later tested marijuana, combined with the low baseline THC values of the 1970s, makes the four-decade-long increase in potency seem greater than it actuality was. In particular, the nominal increase in reported THC% was judged to be overstated as a factor of 10.5, and the quality-adjusted difference – from 10.5:1 to 6:1 or 7:1 – is the counterfactual that can be attributed to testing artifacts. But that is only part of the story, and the smaller part. If the distribution of seized marijuana products reflects changes in the composition of the actual market, then market-related factors have been a more influential driver of potency, especially since the 1980s when marijuana quality improved considerably. From this 1980s baseline, then, one can reliably conclude that average marijuana potency more than doubled over the last three decades, with most of this increase occurring since 2000 as high-potency sinsemilla came to dominate the market.

This study is not without its limitations. First, the PMP data reflect a nonrandom sample of law enforcement seizures, and therefore are not necessarily representative of the marijuana available to consumers. Second, PMP sample preparation protocols and chromatographic analysis equipment have changed over time[13–15], raising the specter of another potential, but unaccounted for, testing artifact. Third, this analysis used simple means to determine marijuana potency and related characteristics irrespective of the underlying quantity of the seized product. It is unclear how the use of a weighted average might have affected the findings reported here, but prior research has shown these differences can be nontrivial.[13] Future research should explore this issue. Fourth, the analysis relied on parameter values derived from Trofin *et al*.;[19] some of the reported results are therefore likely to be sensitive to the use of these parameter values.

Despite these limitations, this is the first study to report on potency trends adjusted for quality. After accounting for possible testing artifacts, the apparent 10.5 factor increase in potency noted over the past four decades was revised downward to a more modest 6 to 7 factor increase. To be sure, any debate over whether there has been a ten-fold versus a six- or seven-fold increase in potency might seem moot, but both perceptions and evidence matter when it comes to public policy. Ill-defined problems beget ill-conceived solutions. If an exaggerated increase in potency leads to greater enforcement and tougher sanctions, for instance, not only will scarce resources be misappropriated but illegal growers might respond to the amplified risk by producing even more potent cultivars that garner a higher price for the same weight.[25] Conversely, overstated claims of rising potency and consequent harms could be met with serious reservations and consequent policy inaction even when the reality warrants stepped-up intervention, such as greater youth prevention and treatment programming.[26] All conjectures aside, this study concludes with a fair degree of confidence that average marijuana potency in the USA increased more than six-fold since the 1970s and more than two-fold since the mid-1980s. Equally noteworthy, this study's findings caution against the uncritical use of PMP data, especially prior to the 1980s, and highlight the importance of assessing potency measurement reliability and data quality in future policy analytic research.

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