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DATA INSIGHT

ADDICTION SSA

Rapid changes in illegally manufactured fentanyl products and prices in the United States

Beau Kilmer[1] | Bryce Pardo[2] | Toyya A. Pujol[2] | Jonathan P. Caulkins[3]

[1]RAND Drug Policy Research Center, Santa Monica, CA, USA

[2]RAND Drug Policy Research Center, Arlington, VA, USA

[3]Carnegie Mellon University-Heinz College, Pittsburgh, PA, USA

Correspondence
Beau Kilmer, RAND Drug Policy Research Center, 1776 Main St., Santa Monica, CA 90407, USA.
Email: kilmer@rand.org

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Abstract

Background and aims: Synthetic opioids, mostly illegally manufactured fentanyl (IMF), were mentioned in 60% of United States (US) drug overdose deaths in 2020, with dramatic variation across states that mirrors variation in IMF supply. However, little is known about IMF markets in the United States and how they are changing. Researchers have previously used data from undercover cocaine, heroin, and methamphetamine purchases and seizures to examine how their use and related harms respond to changes in price and availability. This analysis used US Drug Enforcement Administration (DEA) data to address two questions: (i) "To what extent does IMF supply vary over time and geography?" and (ii) "What has happened to the purity-adjusted price of IMF?"

Methods: We developed descriptive statistics and visualizations using data from 66 713 observations mentioning IMF and/or heroin from the DEA's System to Retrieve Information from Drug Evidence (STRIDE; now STARLIMS) from 2013 to 2021. Price regressions were estimated with city-level fixed effects examining IMF-only powder observations with purity and price information at the low-to-medium wholesale level (>1 g to ≤100 g; n = 964).

Results: From 2013 to 2021, the share of heroin and/or IMF observations mentioning IMF grew from near zero to more than two-thirds. The share of heroin observations also containing IMF grew from <1% to ~40%. There is important geographic variation: in California, most IMF seizures involved counterfeit tablets, whereas New York and Massachusetts largely involved powder formulation. The median price per pure gram of IMF powder sold at the >10 to ≤100 g level fell by more than 50% from 2016 to 2021; regression analyses suggested an average annual decline of 17% (P < 0.001). However, this price decline appears to have been driven by observations from the Northeast.

Conclusions: Since 2013, the illegally manufactured fentanyl problem in the United States has become more deadly and more diverse.

KEYWORDS
Fentanyl, heroin, illegal markets, potency, price, synthetic opioids

INTRODUCTION

Drug markets in North America are increasingly exposed to illegally manufactured fentanyl (IMF) and other potent synthetic opioids. Between 2014 and 2020, synthetic opioids excluding methadone (largely IMF) [1] were mentioned in nearly 190 000 overdose deaths in the United States (US). In 2020, 60% of US drug overdose deaths involved IMF [2].

There is dramatic variation in overdoses across states that mirrors the variation in IMF supply as reflected in seizures [3]. However, little is known about IMF markets and how they are changing. Traditional surveys of users are hamstrung for understanding these markets because IMF often appears as adulterants without users' knowledge, and potentially useful data sources in the United States have been cut (e.g. Arrestee Drug Abuse Monitoring Program) or not systematically implemented (e.g. wastewater testing).

To compensate, researchers are examining law enforcement-generated drug market data. Zoorob [4] showed how IMF seizures were initially concentrated in the eastern United States, and unequal market exposure explained spatial variation in overdose mortality. Others documented IMF appearing in stimulants or sedatives; with variation by market level and geography [5, 6]. Drug seizures from Ohio show associations between the availability of IMF and highly potent carfentanil with overdose deaths [7, 8]. Carfentanil's potency may result in elevated overdose deaths where it is found, as reported by national drug seizure databases [9]. Using seizure data from the High Intensity Drug Trafficking Areas program, research has recently shown a dramatic increase in the number and share of IMF events involving counterfeit tablets [10].

To add to this growing literature, this paper examines data from the Drug Enforcement Administration's (DEA) System to Retrieve Information from Drug Evidence (STRIDE, now referred to as STARLIMS) database involving IMF and heroin in the United States, building off earlier work for the US Commission on Combatting Synthetic Opioid Trafficking [11]. We use these rich data to address two questions: (i) "To what extent does IMF supply vary over time and geography?" and (ii) "What has happened to the purity-adjusted price of IMF?"

DATA AND METHODS

Data

In the course of providing research support to the US Commission on Combatting Synthetic Opioid Trafficking, we were given access to DEA's STRIDE/STARLIMS data, which includes law enforcement event-level observations on illegally supplied drugs (e.g. undercover buys, seizures). Although STRIDE/STARLIMS data are a non-random sample of market transactions, they provide detailed information and large samples. For decades, these DEA data have been used by researchers to evaluate policy interventions, assess harms related to drug use, and help measure the size of illegal drug markets [12–14].

The data provided include all observations containing heroin, IMF, or other synthetic opioids from January 1, 2013 to August 4, 2021 (see Commission's Technical Appendix B for more information on the data) [11]. In total, there were 66 713 unique observations, of which almost two-thirds involved heroin (n = 49 110), 38% involve IMF (n = 25 968), and ∼15% (n = 10 160) contained both heroin and IMF. Because we focus on annual counts and do not have a full year of information for 2021, that year is dropped from visual analysis.

Measures include the date and location of the event (e.g. city and state), raw weight, formulation (e.g. powder, tablet, resin/gum, and other), the percentage of the package that is pure IMF, and price. Notably, purity is not always reported, and price is generally available for undercover purchases, but not seizures. In addition to national totals, we focus on California, Massachusetts, and New York because these three states comprise over a quarter of the observations and shed light on regional market variations.

Price analyses are based on a subset of these data. Of the 25 968 observations involving IMF, only 3220 report the purchase price and purity. We dropped observations from before 2016 (there were few), with <1 gram or >100 grams (there were relatively few), that contained other intoxicants, or were in a physical form other than powder to make sure we are comparing similar products over time. This leaves us with an analytic sample of 964 observations that contain IMF alone or IMF with non-intoxicating fillers in the package.

Methods

We begin by presenting the total number of observations involving IMF, heroin, or both substances and their distributions over time. We also calculate the median purity levels for IMF powder observations that exclude heroin.

Then, we present the per capita number of observations involving IMF and/or heroin. We report 2013 to 2020 annual counts for the entire country and California, Massachusetts, and New York for 12 mutually exclusive categories: three different drug mixtures (fentanyl, heroin/fentanyl, and heroin) and four different physical formulations (powder, tablet, gum/resin, and other).

We display the distribution of real prices per pure gram for each year using box and whisker plots, separately for observations whose net weight is <1 g to ≤10 g and <10 g to ≤100 g.

To gain insights about prices changes over time, we estimate a log-linear model separately for each weight category:

$$\ln(RealTotalPrice_{itc}) = \beta_0 + \beta_1[\ln(TotalRawWeight_i) + \ln(PctFentanyl_i)] + \beta_2 FillFlag_i + YearTrend_t + \alpha_t + \alpha_c + \epsilon_{itc}, \quad (1)$$

TABLE 1 Descriptive statistics of heroin and IMF observations.

	2013	2014	2015	2016	2017	2018	2019	2020	2021
Total observations	4571	5087	5986	6812	8642	10 132	11 911	9796	3776
% Heroin only	99	94	89	72	60	52	41	31	23
% IMF only	1	3	5	13	17	22	31	43	52
% IMF and heroin	0	3	5	12	18	21	22	21	16
Median (25th–75th quartiles) purity (%) for IMF powder observations excluding heroin, by total raw weight category									
≤1 g	–	–	–	4.1 (2.3–6.0)	3.0 (1.8–5.5)	3.0 (1.6–5.4)	3.0 (1.9–4.4)	4.0 (2.5–7.0)	4.0 (2.5–6.0)
>1 g to ≤10 g	–	–	–	2.5 (0.9–3.7)	1.7 (1.0–3.0)	2.8 (1.5–5.3)	2.6 (1.6–5.0)	3.7 (2.2–8.0)	3.9 (1.8–6.5)
>10 g to ≤100 g	–	–	–	1.4 (0.7–4.4)	1.2 (0.6–3.7)	1.7 (0.9–4.0)	2.5 (1.3–5.0)	3.1 (1.4–7.0)	3.5 (1.4–5.0)
>100 g	–	–	–	4.8 (1.9–7.8)	5.3 (3.5–7.5)	4.6 (1.2–8.0)	6.0 (2.0–9.0)	9.0 (1.7–15.0)	4.2 (2.2–10.0)

Notes: Shares of observations for heroin only, IMF only, and IMF and heroin may not sum to 100% because the share for drug mixtures containing analogues are not reported. Data for 2021 only go through August 4 of that year. Median and quartiles rounded to nearest tenth.

where *RealTotalPrice* is the natural log of the inflation-adjusted price ($2021) for product *i* at time *t* in city *c*. We operationalize pure grams of fentanyl as the sum of the natural log of the total raw weight of the purchase, *TotalRawWeight*, and the natural log of the purity of fentanyl, *PctFentanyl*. We include an indicator variable, *FillFlag*, which is set to 1 if the DEA reports other non-intoxicating powders in the package that is purchased, and a time trend, *YearTrend*, that equals 1 for 2016, 2 for 2017, … and 6 for 2021. The models include quarter indicator variables to control for seasonality, and city-level fixed effects (FE) to account for city-specific factors that do not change over time (α_t and $\alpha_{c,}$ respectively).

We also consider six alternative specifications in which we: (i) add covariate for total raw weight of the amount purchased; (ii) drop observations <5th or >95th percentiles of real price per pure gram; (iii) limit analysis to observations from 2017 to 2020, which account for the bulk of the observations; (iv) replicate the main model replacing city-level FE and clusters with state FE and clustering at the state level; (v) main model only including observations from the Northeast; and (vi) main model excluding observations from the Northeast.

Statistical significance was assessed at the $P < 0.05$ level. Analyses were conducted using Stata version 16 (StataCorp) and R (R Studio version 1.4.1717; R version 4.1.0).

RESULTS

Table 1 presents descriptive statistics about the 66 713 observations. The share of heroin-only observations declines over time and are overtaken by those involving IMF by 2019. From 2013 to 2021, the share of heroin and/or IMF observations mentioning IMF grew from near zero to more than two-thirds. The share of heroin observations also containing IMF grew from <1% to ~40%.

Table 1 shows annual data from 2016 to 2021 about the purity of seizures and purchases of IMF powder that do not include heroin (few observations from before 2016 include purity measures) for four levels of the market: ≤1 g; >1 g to ≤10 g; >10 g to ≤100 g; >100 g. The amount of IMF in these observations is low and variable. The median amount never exceeds 5% for observations below ≤100 g. For most years, the median purity for observations over 100 g is higher than those below ≤100 g, but never above 9%. Purity was highly variable; for almost all market levels and years, the interquartile range exceeded the median.

Figure 1 displays the annual per capita rate of IMF and heroin seizures for California, Massachusetts, and New York. Colors indicate the drug type (fentanyl, heroin/fentanyl, or heroin), whereas textures indicate the physical form (powder, tablet, gum/resin, or other). IMF-only observations skew heavily toward tablet formulations in California and very few observations mix heroin and IMF. Instead, heroin is found mostly in gum/resin form and not powder. Relative to New York, Massachusetts appears to have transitioned from heroin to IMF with less heroin/IMF mixing and now contains few heroin-only observations, where New York continues to see declining heroin-only observations in favor of heroin/IMF mixtures. Both, however, report growing shares of IMF-only observations in tablet form. The observed declines in 2020 may reflect coronavirus disease (COVID)-19 related interruption to data collection and processing.

Figure 2 displays a downward trend in the purity-adjusted price for IMF from 2016 to 2021 across two raw weight categories. The difference in means for 2016 and 2021 are statistically significant for both groups ($P < 0.001$).

Because this analysis focuses on price changes over time while controlling for other factors, Table S1 in the Supporting Information presents the coefficients on *YearTrend* for Equation (1) and six alternative specifications, separately for the two weight categories. For observations with raw weights between >10 g and ≤100 g, the coefficient of −0.185 (95% CI, [−0.260, −0.110]; P < 0.001) on *YearTrend* in the main model suggests an average annual decline in the price per pure gram of fentanyl of approximately 17% (conversion from $e^{(-0.185)} - 1$). The regression with observations between >1 g and ≤10 g produced a negative coefficient on *YearTrend*, but it is not statistically significant ($P = 0.081$).

For the other six models, the coefficient on *YearTrend* for the >10 g and ≤100 g category is roughly similar and remains statistically significant ($P < 0.001$) except for the final model, which limits the analysis to observations outside the Northeastern United States. The

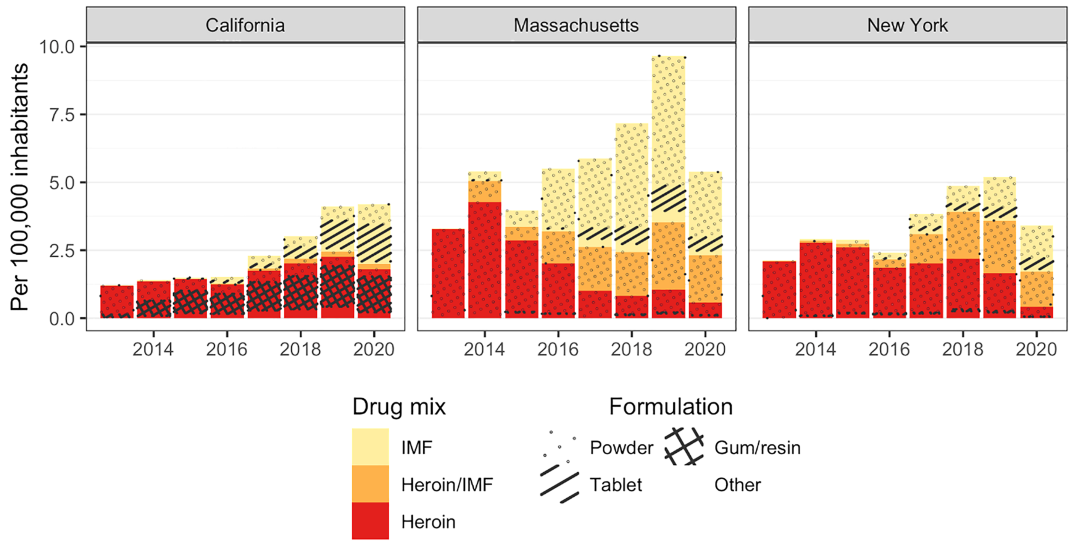

FIGURE 1 STRIDE/STARLIMS observations involving IMF, heroin, or both substances, 2013–2020, distinguishing drug (by color) and physical form (by pattern/texture). *Note:* Data come from the Drug Enforcement Administration's System to Retrieve Information from Drug Evidence, or STRIDE/STARLIMS

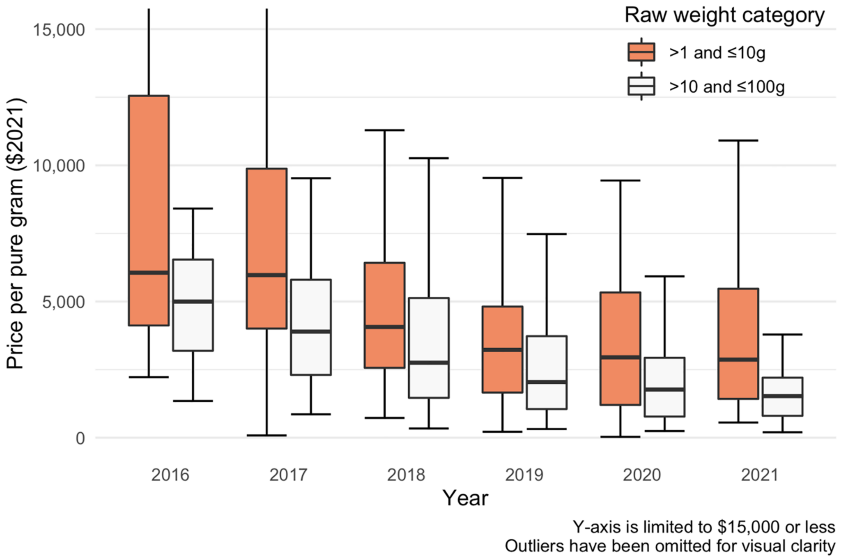

FIGURE 2 IMF price per pure gram by year and weight category

coefficient on *YearTrend* for the >1 g and ≤10 g category remains negative, but is only statistically significant in the model, which replaces the city-level FE and clustering with the state.

DISCUSSION

Drug markets in the United States appear to be favoring IMF over heroin, but in different forms in different regions. From the three states analyzed, IMF is increasingly found mixed with heroin in markets in the eastern United States, whereas it appears in the west increasingly on its own and often in tablet form. The data made available for this analysis do not allow us to calculate the share of stimulant or benzodiazepine observations that include IMF, but this is also a growing concern [3]. The purity-adjusted price of IMF powder is declining, with median prices in the >10 g to ≤100 g range falling by more than 50% between 2016 and 2021. Although the Northeast is likely overrepresented, prices are estimated to decline by 17% a year.

With respect to limitations beyond the non-representative nature of law enforcement samples, there are other approaches for assessing purity-adjusted prices of illegal drugs that could not be applied to observations containing IMF here because of the small samples. Assuming the number of IMF purchases reported to STRIDE/STARLIMS increases over time, it may be possible to apply the expected purity method [15] on IMF-only purchases in the future.

COVID-19 may have disrupted data collection and analysis starting in 2020. There have also been fewer retail-level undercover drug buys reported in STRIDE/STARLIMS in recent years, limiting assessment of changes in prices paid by end-users. Although we do not focus on retail transactions (because the sample sizes were low), it

may be possible to learn more about prices at this level if more data become available.

Efforts to reduce synthetic opioid supply have been successful in some European countries with a small number of suppliers [16,17], and there has been a supply shift in the United States. IMF seized at US ports of entry used to come primarily from China, but now Mexico is indicated by law enforcement to be the major source of IMF consumed in the United States [3]. This may help explain the recent increase in IMF tablets/pills showing up in California, but less is known about whether this shift affected IMF prices for all formulations or drug combinations. Our analyses suggest a substantial price decrease from 2016 to 2021 for transactions between >10 g to ≤100 g of powder that included IMF alone (no other intoxicating substances).

In summary, the IMF problem in the United States has become more deadly and more diverse. It is critical that data from law enforcement investigations continue to be collected and analyzed, especially with respect to purity and price. However, this will not be enough. Data collection on the illegal drug supply should be enhanced with information from people who use these substances (e.g. more qualitative research, resuscitating the Arrestee Drug Abuse Monitoring Program) as well as information from new sources (e.g. wastewater testing). Synthesizing information from all these sources will make it easier to monitor changes in IMF consumption and supply, and to evaluate efforts intended to reduce IMF-involved deaths and other harms.

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DECLARATION OF INTERESTS

None.

AUTHOR CONTRIBUTIONS

Beau Kilmer: Conceptualization; formal analysis; methodology. **Bryce Pardo:** Conceptualization; data curation; formal analysis; funding acquisition; methodology; visualization. **Toyya A. Pujol:** Data curation; formal analysis. **Jonathan P. Caulkins:** Conceptualization; formal analysis; methodology.

ORCID

Beau Kilmer https://orcid.org/0000-0002-9333-8080
Bryce Pardo https://orcid.org/0000-0002-9690-7875
Toyya A. Pujol https://orcid.org/0000-0002-3992-2710
Jonathan P. Caulkins https://orcid.org/0000-0002-7748-9989

REFERENCES

1. Hedegaard H., Bastian B. A., Trinidad J. P., Spencer M., Warner M. Drugs most frequently involved in drug overdose deaths: United States, 2011–2016. 2018.
2. Hedegaard H., Miniño A., Spencer M., Warner M. Drug overdose deaths in the United States, 1999–2020. NCHS Data Brief, No. 428. Natl Cent Health Stat. 2021.
3. Commission on Combating Synthetic Opioid Trafficking. Commission on Combating Synthetic Opioid Trafficking: Final Report. Rep Comm Combat Synth Opioid Traffick 2022 [Internet]. 2022 Feb 8 [cited 2022 Apr 4]; Available from: https://www.rand.org/pubs/external_publications/EP68838.html
4. Zoorob M. Fentanyl shock: The changing geography of overdose in the United States. Int J Drug Policy. 2019;70:40–6.
5. Park JN, Rashidi E, Foti K, Zoorob M, Sherman S, Alexander GC. Fentanyl and fentanyl analogs in the illicit stimulant supply: Results from US drug seizure data, 2011–2016. Drug Alcohol Depend. 2021;218:108416.
6. Pardo B. Insights into mixing fentanyl and benzodiazepines from Canadian drug seizures. JAMA Psychiat. 2022;79(1):81–3.
7. Zibbell JE, Aldridge AP, Cauchon D, DeFiore-Hyrmer J, Conway KP. Association of law enforcement seizures of heroin, fentanyl, and carfentanil with opioid overdose deaths in Ohio, 2014-2017. JAMA Netw Open. 2019;2(11):e1914666.
8. Rosenblum D, Unick J, Ciccarone D. The rapidly changing US illicit drug market and the potential for an improved early warning system: Evidence from Ohio drug crime labs. Drug Alcohol Depend. 2020;208:107779.
9. Jalal H, Burke DS. Carfentanil and the rise and fall of overdose deaths in the United States. Addiction. 2021;116(6):1593–9.
10. Palamar JJ, Ciccarone D, Rutherford C, Keyes KM, Carr TH, Cottler LB. Trends in seizures of powders and pills containing illicit fentanyl in the United States, 2018 through 2021. Drug Alcohol Depend. 2022;234:109398.
11. Commission on Combating Synthetic Opioid Trafficking. Commission on Combating Synthetic Opioid Trafficking: Technical Appendixes. Rep Comm Combat Synth Opioid Traffick 2022 [Internet]. 2022 Feb 8 [cited 2022 Apr 4]; Available from: https://www.rand.org/pubs/external_publications/EP68839.html
12. Caulkins JP, Kilmer B, Reuter PH, Midgette G. Cocaines fall and marijuanas rise: Questions and insights based on new estimates of consumption and expenditures in US drug markets. Addiction. 2015;110(5):728–36.
13. Ciccarone D, Unick GJ, Cohen JK, Mars SG, Rosenblum D. Nationwide increase in hospitalizations for heroin-related soft tissue infections: Associations with structural market conditions. Drug Alcohol Depend. 2016;163:126–33.
14. Dobkin C, Nicosia N. The war on drugs: Methamphetamine, public health, and crime. Am Econ Rev. 2009;99(1):324–49.
15. Caulkins JP. Developing a price series for cocaine Santa Monica, CA: RAND; 1994.
16. Abel-Ollo K. What lessons from Estonia's experience could be applied in the US in response to the addiction and overdose crisis? Addiction. 2022;117:1188–9.
17. Fugelstad A. What lessons from Sweden's experience could be applied in the US in response to the addiction and overdose crisis? Addiction. 2022;117:1189–91.

SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

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