HIGH-FREQUENCY DRUG PURITY AND PRICE SERIES AS TOOLS FOR EXPLAINING DRUG TRENDS
AND HARMS IN VICTORIA, AUSTRALIA

Scott, Nick
Burnet Institute, Centre for Population Health
Melbourne, VIC, Australia

Caulkins, Jonathan P.
Carnegie Mellon University Heinz College
Pittsburgh, PA, USA

Ritter, Alison
National Drug and Alcohol Research Centre
University of New South Wales, NSW, Australia

Quinn, Catherine
Victoria Police Forensic Services Department
VIC, Australia

Dietze, Paul
Burnet Institute, Centre for Population Health
Melbourne, VIC, Australia

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Abstract

Aims: Methamphetamine related harms in Victoria have recently increased, in the context of stable or declining use prevalence. We determine how changes in price and purity of methamphetamine compared to other drugs such as heroin may, in part, explain these divergent patterns.

Methods: Detailed methamphetamine and heroin purchase price data from 2152 participant interviews from the Melbourne Injecting Drug User cohort study were used to generate drug price series for the period January 2009 - June 2013. Data on drug purity from 8818 seizures made within Victoria were used to generate drug purity series over the same period. Purity-adjusted price data for methamphetamine and heroin were obtained for the period 2009-2013 by combining the two datasets.

Results: While the average purity of heroin seizures remained consistent and low, the average purity of powder and of crystal methamphetamine seizures increased from 12% (95%CI 10-14%) to 37% (20-54%) and 21% (95%CI 18-23%) to 64% (60-68%) respectively. Crystal methamphetamine purity was bimodal, with observations generally less than 20% or greater than 70%. The average unadjusted price per gram for heroin decreased from $374 (95%CI $367-381) to $294 ($280-308), powder methamphetamine didn’t change significantly from $252 (95%CI $233-271), and crystal methamphetamine increased substantially from $464 (95%CI $416-511) in 2009 to $795 ($737-853) in 2011. This increase was offset by an even greater increase in purity, meaning the average purity-adjusted price per gram declined. Furthermore, pure prices of both methamphetamine forms were similar, whereas their unadjusted prices were not. The pure price of heroin fluctuated with no ongoing trends.

Conclusions: Decreases in methamphetamine purity-adjusted price along with the bimodality of crystal methamphetamine purity may account for some of the recent increase in methamphetamine
related harm. For a given amount spent, methamphetamine purchase power has increased and the presence of extreme purity variations may challenge individuals’ control of consumption.
Introduction

Previous studies on illicit drug use indicate a strong link between market factors and behaviour\textsuperscript{(1-3)}. Epidemiological indicators suggest that there has been an increase in methamphetamine consumption and related harms in Victoria, Australia, with methamphetamine-related ambulance attendances, amphetamine-related treatment service presentations and amphetamine-related calls to helplines all increasing over the financial years 2010/11 -2011/12\textsuperscript{(4)}. However, reports from ongoing surveillance studies including among people who inject drugs (PWID)\textsuperscript{(5)} and regular ecstasy users interviewed in Melbourne show that increased prevalence of recent crystal methamphetamine use has been largely offset by declines in prevalence of powder methamphetamine use, producing overall declines in reports of recent methamphetamine use over the period 2010-2012\textsuperscript{(6, 7)}. These findings from sentinel groups correspond with relative stability or declines in the prevalence of use observed through household surveys\textsuperscript{(8)}, surveys of school students\textsuperscript{(9)} and surveys of young people more broadly\textsuperscript{(10)}.

Further data are needed to reconcile the puzzle of increasing harms despite declining or stable prevalence. This paper illustrates how high-frequency (in this context meaning more than quarterly) price and purity series can help resolve the apparent paradox observed in these indicator series.

Australia’s surveillance and monitoring systems that capture information on drug price, purity and availability include the Illicit Drug Reporting (IDRS\textsuperscript{(11)}) and the Ecstasy and Related Drug Reporting (EDRS\textsuperscript{(12)}) Systems. These systems gather information on prices users paid for different quantities of key drugs, along with their perceptions of drug purity, and independent low-frequency secondary indicators of drug purity such as analyses of police seizures. These data show large increases in the purity of methamphetamine seized by Victoria Police over the period 2009-2012\textsuperscript{(6)}. This increase in purity was initially accompanied by an increase in reported prices paid by drug users, but recent figures have shown a decline in the price paid (based on very small numbers\textsuperscript{(6)}). This suggests that the purity-adjusted price\textsuperscript{(5)} of methamphetamine may have been declining over the period during
which harms increased, however the small numbers reporting prices in the IDRS and EDRS should be treated with caution.

In Victoria, two unique datasets are available. Victoria Police Forensic Services Department (VPFSD) analyse the majority of drug seizures made in the state to determine the size and purity of seizures, among other characteristics. This information can be used to generate a high-frequency purity series by drug and drug form\(^5\). The Melbourne Injecting Drug User Cohort Study (MIX\(^{1,3}\)) collects detailed information on cohort members’ purchases across a range of drugs. Participants are asked to report on their last three purchases of each drug for which they report recent use, indicating the amount paid for a given quantity (all prices described herein are self-reported by MIX participants unless otherwise cited). Pooling answers across individuals and interviews, one can create a high-frequency purchase series. Combining these two data sources allows generation of a high-frequency purity-adjusted price series that can be used to explore the markets for drugs consumed by PWID in Melbourne and how they change over time.

Although methamphetamine is the primary drug of interest here, heroin is the drug of choice for the majority of the MIX cohort, making it important to understand trends in the heroin market, as the price of one drug can affect the demand for another\(^{1,3}\).

In this paper variations in the average unadjusted and purity-adjusted prices paid for methamphetamine and heroin are estimated and compared, to provide an economic perspective on the divergent trends in consumption and harm indicators for methamphetamine.

**Methods**

**Data sources**

Data on drug purchasing was obtained from MIX. MIX is a prospective cohort study of young (≤30 years of age) PWID recruited between May 2008 and January 2010. Experienced fieldworkers interview the 688 participants approximately annually in face-to-face interviews. The numbers of

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interviews occurring each year between January 1st 2009 and June 30th 2013 are shown in Table 1. Further details of the MIX cohort can be found elsewhere\(^{(13)}\). The questions relevant here relate to the amount spent on their last three purchases of a range of different drugs, as well as the size of each purchase in user-nominated units (e.g. rock, gram, point, dollar value). This study analyses responses concerning two forms of methamphetamine (speed/powder and ice/crystal) and heroin.

Since 1998 the majority of Victorian seizures of heroin and methamphetamine have been analysed by the VPFSD. The seizures’ characteristics are entered into a database managed by the Forensic Drug Branch. We obtained an extract on September 16th 2013 covering the period January 1st 2008 to June 30th 2013. Each observation records the type of drug, purity, number of packages within which the drugs were contained, total mass, and an assessment of the “form” of the seizure. For this analysis, where multiple packages were recorded (70% of heroin and methamphetamine entries) the seizure was considered as a single observation, with mass equal to the individual packet size (a bundle of 1-gram bags is assumed to be indicative of purity at the 1-gram market level rather than the market level of the total seizure weight). Purity observations for seizures greater than 10 grams were removed to form a data set comparative to MIX purchase sizes (99.6% of methamphetamine purchases and 99.7% of heroin purchases in MIX are of 10 grams or less).

*Methamphetamine purity data*

Table 1 breaks down the 7261 methamphetamine observations of 10 grams or less by form and year. The number of ice/crystal and crystalline seizures each year increased from 2009 until 2012, and there was a decline in observations with form described as “amorphous”. Observations of “Powder (damp)” and “Other” methamphetamine seizure purities were dropped as MIX purchases of such forms would be classed as “other” (2.0% of methamphetamine purchases) rather than the “powder” or “crystal” purchases considered in this study. No consistent difference was found between the sample mean purities of compressed methamphetamine, amorphous methamphetamine and granular methamphetamine forms ($F_{(2,1487)}=0.98$, mean purities 17.2%,}
15.8% and 17.9% respectively), which have been grouped together and are hereon referred to as “powder” methamphetamine. Both the ice/crystal methamphetamine and crystalline methamphetamine categories consist of seizures considered by VPFSD chemists to have obvious crystal structure, and have been grouped together based on physical appearance for consistency with the allowed response of “crystal” in the MIX survey. These seizures are hereon referred to as “crystal” methamphetamine.

For each year between 2008 and 2013 there were no significant differences between the sample mean purities of powder methamphetamine seizures weighing less than 1 gram vs. those weighing between 1 and 10 grams (F test statistics indicate p>0.05 each year), while crystal methamphetamine seizures weighing less than one gram were slightly less pure than those weighing between 1 and 10 grams in 2010, 2011 and 2013 (38.0% vs. 43.3%, 47.6% vs. 53.6%, 60.0% vs. 73.7% respectively, p<0.05); however, as these differences were either small relative to trends over time (2010 and 2011) or based on a small number of observations (n=59 for 1-10 gram seizures in 2013) all seizures of less than 10 grams or less have been combined.

Heroin purity data

Table 1 breaks down the 3962 heroin observations of 10 grams or less by form and year. The majority (89.3%) were categorised as “compressed” powder, with “amorphous” powder (7.1%) the next most common form. There was a significant difference between the average purity of the compressed and amorphous heroin forms ($F_{(1,3819)}=188.66$, p<0.001), so we restricted analysis to the more common compressed powder form.

For each year between 2008 and 2013 there were no significant differences between the sample mean purities of compressed form heroin seizures weighing less than 1 gram vs. those weighing between 1 and 10 grams (F test statistics indicate p>0.05 each year), so all seizures of less than 10 grams or less have been combined.
Table 1: Heroin and methamphetamine VPFSD seizures of 10 grams or less and MIX purchase observations.

Price data

Purchase size is reported in MIX in a variety of units. We converted all units to grams by assigning weights of 0.1 gram to “points” or “caps”\(^6\), and excluding entries with size recorded in dollars or ambiguous units such as “line” or “rock”.

Purchases with price per gram less than $50 or more than double that of a “point” reported in the IDRS between 2008 and 2012 ($1000 for heroin, $2000 for crystal methamphetamine and $1000 for powder methamphetamine) were removed as outliers (3%, 1% and 4% of heroin, crystal methamphetamine and powder methamphetamine observations respectively), and categorical answers to the question “When was the drug purchased?” have been date stamped as 0, 1, 4, 19, 45 and 45 days prior to the interview date for the responses today, yesterday, within the last week, within the last month, more than a month ago and not purchased in the last month respectively.

Prices have been inflated to 2013 Australian dollars (AUD) using the All Groups CPI\(^{14}\), and rolling averages were calculated using the (unweighted) previous 60 days’ purchases to approximate trends in the price per gram of heroin, powder methamphetamine and crystal methamphetamine.

Valid price per gram observation in MIX were purity-adjusted by dividing by the value of the corresponding purity series on the purchase date\(^{15}\), and rolling averages were calculated using the (unweighted) previous 60 days’ purity-adjusted data points. Due to a pilot phase followed by a gap in observations in 2008, all series were developed for the period 2009 to end June 2013.

Statistical analysis

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As a tool to determine the significance of changes in the rolling purity, price and purity-adjusted price series, for each year between 2010 and 2013 F-tests were used to compare differences in the annual mean purity, price and purity-adjusted price (obtained by dividing each price observation by the mean purity of the corresponding year) for heroin and methamphetamine to the means observed in 2009.

Illicit drug markets are known to exhibit quantity discounting and commonly present a log-linear relationship between price and transaction size\(^{16}\). Valid price per pure gram observations were pooled into bimonthly (heroin) or four-monthly (methamphetamine) bins and purity-adjusted by the average purity of seizures in the corresponding period. Separately for each period \(t\), the predicted value for the logarithm of the price per pure gram can be determined by regressing the log price per pure gram on the log of transaction size, with the intercept of this regression determining the price of one gram since when the transaction size is one pure gram, \(\log(1) = 0\). The number of observations varies between time periods, but is always at least 10, providing adequate degrees of freedom since each regression has just two coefficients (intercept and slope). For each time period, the predicted price of one pure gram was determined by exponentiating the intercept and multiplying by the period’s smearing constant\(^{17}\) to remove re-transformation bias. In symbols, the regression for an arbitrary period \(t\) was

\[
\log(P_i) = \beta_t \log(Q_i) + \alpha_t + \varepsilon,
\]

where \(P_i\) is the price per pure gram ($) of the \(i\)th observation in time period \(t\) and \(Q_i\) is the size (in grams) of the \(i\)th observation in time period \(t\).

**Results**

*Prices not adjusted for purity*

Figure 1 (left panel) shows the average price per gram (not adjusted for purity) for heroin, powder methamphetamine and crystal methamphetamine between January 2009 and July 2013. During this
period, the annual average price per gram of heroin decreased steadily from $374 (95%CI $367-381) in 2009 to $294 ($280-308) in 2013 ($F_{(1,1178)}=109.41, p<0.001) mostly due to increasing CPI, powder methamphetamine did not change significantly from $252 (95%CI $233-271) (p>0.05 for each year), and crystal methamphetamine increased substantially from $464 (95%CI $416-511) in 2009 to $795 ($737-853) in 2011 ($F_{(1,149)}=58.72, p<0.001) before remaining at that level.

In particular, the price gap between the two forms of methamphetamine grew throughout 2010; the average price per gram of crystal methamphetamine increased from double that of powder methamphetamine (in 2009) to more than three times as much (2011 onwards).

**Purity analysis**

Figure 2 shows the purity of heroin and methamphetamine seizures between January 2009 and July 2013. During this period the annual average purity of heroin each year did not vary by more than 2% from the 2009 mean of 16% (95%CI 15-16%) (statistically significant variations were trivial). The annual average purity of crystal methamphetamine rose from 21% (95%CI 18-23%) in 2009 to 64% (60-68%) in 2013 ($F_{(1,682)}=385.83, p<0.001), and the annual average purity of powder methamphetamine rose from 12% (95%CI 10-14%) in 2009 to 37% (20-54%) in 2013 ($F_{(1,287)}=27.19, p<0.001).

Figure 1: Average price (MIX) and purity-adjusted price (MIX prices adjusted by average VPFSD seizure purities) per gram of heroin and methamphetamine, Jan-09 to Jul-13.

Figure 1 (right panel) shows the purity-adjusted price series for heroin and methamphetamine between January 2009 and July 2013. The purity-adjusted price per gram of heroin fluctuated, with periods of slightly lower average pure price in 2011 ($2028, 95%CI $1980-2077) and 2013 ($1887,
$1799-1976) than in 2009 ($2380, $2335-2425) ($F_{(1,1554)}=105.62, F_{(1,1178)}=102.16$ respectively, $p<0.001$). For methamphetamine, the apparent price disparity between the powder and crystal forms has disappeared, and the purity-adjusted prices of both forms have been decreasing in parallel throughout this period (annual average of powder from $2028 (95\% CI$ $1874-2182)$ in 2009 to $716 ($491-941)$ in 2013 and crystal from $2275 (95\% CI$ $2041-2508)$ in 2009 to $1163 ($1035-1290)$ in 2013, $F_{(1,156)}=15.01$ and $F_{(1,113)}=74.64$ respectively, $p<0.001$).

Figure 2: Average purity of VPFSD seizures, Jan-09 to Jul-13.

Prices adjusted for size and purity

For each bimonthly (heroin) or four-monthly (methamphetamine) period, the exponentiated log-linear regression constants representing the price of one pure gram are shown in Figure 3 with 95% confidence intervals. Trends previously observed for the mean purity-adjusted price are maintained when controlling for purchase size, although the price series are slightly lower. This is likely because most MIX purchases are for less than one pure gram, so users often experience a “mark up” and therefore higher price per gram relative to a one-pure-gram purchase.

Figure 3: Price series and 95% confidence intervals for one pure gram of heroin and methamphetamine based on regressions controlling for quantity discounts, MIX prices adjusted by VPFSD seizure purities, Jan-09 to Jul-13. Crystal methamphetamine series has been slightly right-shifted for clarity.
Interpreting trends in use and use related harms

The analysis above suggests that the increase in methamphetamine related harms in Victoria may follow from greater pure gram consumption. Between January 2009 and June 2013, the median amount spent on each methamphetamine purchase reported in MIX declined from $111 in 2009 to $100 in 2013, due to an increasing CPI. Since price per pure gram fell by an even greater amount (Figure 1 shows the pure price of methamphetamine decreasing by 60-70% between 2009 and 2013), this amount of spending leads to larger (pure) quantities purchased. Furthermore, between the third and fourth interview waves (data between October 2011 and July 2013) the number of participants reporting more than one recent methamphetamine purchase increased from 12% (steady for the first 3 interview waves) to 17% ($\chi^2=7.3, p<0.01$) while those not reporting a recent purchase remained at 73%. This suggests that those using methamphetamine may also have been purchasing more frequently.

Another contributor to harms, in particular overdoses, is large variations in purity. Figure 4 shows that heroin and powder methamphetamine are consistently low in purity but crystal methamphetamine is bimodal, with seizures tending to be very high or very low, rather than evenly distributed. There has also been a substantial decrease in the proportion of crystal methamphetamine seizures less than 10% pure, matched by an increase in those of 80-89% purity.

This bimodality means that a “random” purchase could result in consumption of more than 5 times the amount intended. For example, the average purity of crystal methamphetamine was 79% for observations at least 50% pure, and 14% for those less that 50% pure. The ratio of 79 to 14 is a measure of the risk of overdose if someone accustomed to purchasing from the low-purity submarket unwittingly obtains a sample from the high-purity submarket. The risk of overdose is

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Figure 4: Purity of VPFSD seizures, 2008 – 2012.

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further enhanced by the fact that users and dealers may not even be aware of the content of their drugs\(^{(18)}\).

**Discussion**

We have shown that user self-reports of drug market purchases can be combined with data from forensic analysis of drug seizures to produce high-frequency series for price per gram, purity and purity-adjusted price per gram series for heroin, methamphetamine (powder) and methamphetamine (crystal). Doing so for the Australian State of Victoria between January 2009 and June 2013 offers a plausible explanation for two puzzles concerning drug market trends.

First, the law of one price suggests that the prices of equivalent products ought to be the same. While powder and crystal methamphetamine are not identical, both contain similar chemicals with similar effects, so they should be close substitutes, in the economic sense of the term. Hence, one would expect their prices to move together. That expectation appeared to be contradicted by the data. Crystal methamphetamine prices rose from approximately $450 to $800 per gram between January 2009 and July 2013, even though powder methamphetamine prices were stable at approximately $250 per gram. This apparent paradox is quickly resolved, however, by factoring in trends in purity. Once both series have been adjusted for purity, they not only exhibit parallel trends (both decreasing), they also display the same levels; the price per pure gram is effectively the same for both crystal and powder forms of methamphetamine. This similarity in price per pure unit, after adjusting for quantity discounts, has also been observed for crack and powder cocaine in the United States\(^{(19)}\).

Second, various indicators of methamphetamine harm were increasing over this period, which would be surprising if prices were rising for crystal methamphetamine and stable for methamphetamine powder given the conventional notion of a downward sloping demand curve. Normally one would expect greater consumption to accompany lower, not higher prices, except
perhaps early in a drug epidemic, and the methamphetamine market in Victoria was already well-established. Again, however, this apparent paradox is readily explained by factoring in trends in purity. The purity of methamphetamine powder was rising, and the purity of crystal methamphetamine rose faster (from approximately 20% to 65%) than did its prices unadjusted for purity, so the price per pure gram of both forms was falling, both in absolute terms and relative to the steady purity-adjusted prices in the co-existing heroin market. This is consistent with an increase in methamphetamine production indicated by the Australian Crime Commission\(^{(20)}\).

Detailed analysis points to another issue potentially pertinent to harms, such as overdose and ambulance attendance\(^{(4)}\). The purity of heroin in the Victorian seizure data has a low mean of 16% and only a relative handful of high purity outliers around 70%. The distribution of methamphetamine is entirely different; it is bimodal, in two respects. First, the average purity of the seizures categorised as crystal form is much higher than those categorised as powder form. Second, even within the subset of observations labelled as “crystal” the distribution of purities was bimodal, with a cluster of very high purities (over 80%) and another cluster of very low purities (below 20%), and relatively fewer observations in between. Furthermore, within the seizure database, the composition evolved over time, away from powder and low-purity crystal and toward high-purity crystal.

To the extent that there are distinguishable low- and high-purity submarkets, and the latter market was growing over time, it seems plausible that there have been instances in which PWID who were accustomed to obtaining lower-purity methamphetamine, suddenly and unwittingly obtained much higher-purity methamphetamine, perhaps three or four times as potent. That might increase the risk of harms such as overdose relative to a circumstance in which the distribution of purities is unimodal and fairly tight, even if the mean of that distribution were to rise substantially over time as long as the increase were gradual. This is the case for heroin, where both higher purity and greater
purity variance have been independently associated with increased overdose\textsuperscript{(21)}. In contrast, heroin purity, purity variation and harms were stable between 2009 and mid-2013.

There are two main limitations to this study. Firstly, MIX is a convenience sample of PWID (the majority of whom nominate heroin as their drug of choice) and reports of purchases may not represent those made by typical heroin and methamphetamine users. Secondly, purity observations are not linked to purchase observations and seizures may have been systematically biased by police operations at the time they were made. Moreover, the seizure data relate to the whole of the state of Victoria, whereas MIX recruitment occurred in metropolitan Melbourne alone. However, given the large number and high-frequency of both price and purity observations it seems reasonable to accept the purity of seized drugs as a fair approximation for the purity of drugs sold in the current market, and the reported drug purchases as representative of current market prices, especially given that in 2011 around 75\% of the Victorian population lived in the greater Melbourne metropolitan area\textsuperscript{(14)}.

**Further work and conclusions**

Future work is needed to replicate these analyses in other jurisdictions; and extend the analysis to include prescription pharmaceuticals, which may be a substitute for heroin, which itself might plausibly interact with methamphetamine consumption given the extent of polydrug use among PWID. It is possible to investigate whether patterns of polydrug use among MIX respondents switched to favour more methamphetamine use as its purity-adjusted price fell relative to that of heroin. The high-frequency drug use and harm indicator series enables investigation of whether the relatively brief spikes and troughs in purity-adjusted prices of heroin and methamphetamine seen here coincide with troughs and peaks in those indicators of use.
References


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**HEROIN PURITY OBSERVATIONS**

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**METHAMPHETAMINE PURITY OBSERVATIONS**

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<td>Powder (ice/crystal)</td>
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**MIX PURCHASE OBSERVATIONS**

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^ January 1st to June 30th. Numbers may be lower due to a lag on database entry.
* "powder (crystalline)", "powder (damp)" and "powder (wet)".
** "paste", "compressed substance" and "illicit tablet".
*** "tablets", "beads", "paste", "liquid (viscous)", "liquid (aqueous)", "powder (wet)" and "powder (fluffy)".

Table 1: Heroin and methamphetamine VPFSD seizures of 10 grams or less and MIX purchase observations

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Figure 1: Average price (MIX) and purity-adjusted price (MIX prices adjusted by average VPFSD seizure purities) per gram of heroin and methamphetamine, Jan-09 to Jul-13

Figure 2: Average purity of VPFSD seizures, Jan-09 to Jul-13
Figure 3: Price series and 95% confidence intervals for one pure gram of heroin and methamphetamine based on regressions controlling for quantity discounts, MIX prices adjusted by VPFSD seizure purities, Jan-09 to Jul-13. Crystal methamphetamine series has been slightly right-shifted for clarity.

Figure 4: Purity of VPFSD seizures, 2008 - 2012