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Abstract | In illicit drug markets, the price and purity of drugs change frequently. While it is well known that purity-adjusted price affects drug use, impacts on other outcomes are less clear. This rapid review examines the relationship between price, purity and seven population level measures of drug-related harm and any differences across three drug types. With a few exceptions, it found an inverse relationship between purity-adjusted price and drug-related harm, with higher purity-adjusted price associated with less drug-related harm, and lower purity-adjusted price associated with increased harm. This shows the value of price and purity data for predicting drug market impacts and the importance of improving price and purity data collection and analyses, particularly in Australia.

The relationship between drug price and purity and population level harm

Caitlin Hughes, Shann Hulme and Alison Ritter

Introduction

National and international drug markets feature frequent changes in the price and purity of illicit drugs (Australian Criminal Intelligence Commission 2019; European Monitoring Centre for Drugs and Drug Addiction 2018; United Nations Office on Drugs and Crime 2018). For example, the average price of cocaine per gram in the United States decreased more than threefold between 1977 and 1989, from US$316 to US$97 (Caulkins 2001). There can be even greater variation over the short term—for example, the retail purity of heroin sold in New South Wales varied between 13 and 80 percent over a two-year period (Weatherburn et al. 1995). International research has further shown that price and purity can shape drug consumption and in turn drug-related harm. For example, Caulkins (2001) showed that the fall in the retail price of pure cocaine in the United States was associated with increased cocaine-related emergency department (ED) presentations. However, there remains limited understanding of the universality of the relationship—that is, to what extent relationships between price, purity and drug-related harm vary by place, time and drug type. Clarifying the relationship is important to inform targeted law enforcement and harm minimisation strategies, and illicit drug monitoring systems.

Serious & Organised Crime
Research Laboratory

This project aimed to review existing research that has examined the relationship between price, purity and drug-related harm at the population level. More specifically, it aimed:

- to examine the relationship between retail-level price and purity, and seven population level drug-related harms (ambulance call-outs, ED presentations, hospital admissions, treatment admissions, fatal and non-fatal overdoses, property crime, and violent crime);
- to identify differences in the relationship between price, purity and harm across three drug types: heroin, cocaine and meth/amphetamine; and
- to identify factors that may moderate these relationships.

Price and purity in illicit drug markets

As outlined by Caulkins and Reuter (1998), there are many reasons why it is important to understand price and purity in illicit drug markets. Firstly, it helps us understand whether and how illicit drug markets differ to other illicit and licit markets. Here research has shown that the price of illicit drugs is extraordinarily high—particularly given drugs are relatively inexpensive to make, with much of their mark-up compensating for the risks of criminal sanctions or theft and violence from other market players (Reuter & Kleiman 1986). Secondly, price and purity data can inform analysis of the impacts of enforcement (Bright & Ritter 2010; Caulkins & Reuter 1998). Evidence suggests that law enforcement tends to have short-term rather than long-term impacts (Bright & Ritter 2010). Herein we focus on a third application—impacts of price and purity on drug-related harms, both health and criminal justice related.

Several concepts and assumptions underpin this work. The first is that people who use drugs are price-sensitive—that is, there is elasticity of demand: when prices increase, consumption decreases. Numerous studies have found changes in consumption as a result of changes in price, and that these changes occur in non-dependent and dependent populations and across multiple illicit drugs (Caulkins 2007; Gallet 2014; Rhodes et al. 2000). The second assumption is that drug consumption is associated with harm, and that price-driven changes in consumption will influence harms. Again, a clear body of work shows the multiple harms associated with drug consumption such as overdose, property crime and violence (Babor et al. 2018; Degenhardt et al. 2013). Given that around 20 percent of people consume around 80 percent of drugs, harms are most notable among people who are drug dependent or who consume drugs regularly. For example, in Australia the annual social cost of health, crime and road accidents for someone who is opiate dependent is estimated to be $105,342, compared to $1,965 for someone who is non-dependent (Moore 2007).

Third, consistent with basic economic theory, we anticipate that the relationship between price and harms will vary according to the outcome of interest and the length of time since the price or purity changed. For health harms (eg overdose) we anticipate that, if price increases, consumption and associated health harms will fall, and that this relationship will hold over the short and long term. For treatment outcomes, we anticipate that, if price increases, treatment admissions will fall, but the relationship will be shaped by the supply of treatment, including levels of funding, availability and quality. For impacts on drug-related crime, as outlined by Caulkins and Reuter (1998) we expect the relationship will be ambiguous. This is because increased price may lead to more property crime to support purchasing at higher prices. However, if people who use drugs are more sensitive to price, then increased price may lead to reduced property crime due to declines in consumption among heavy users. Similar arguments can be made in relation to violence. Economic theory also suggests impacts on drug-related crime and treatment may differ in the short and long run due to delays in behavioural adaptation.

A further important principle is the difference between price, purity and purity-adjusted price (PAP). The actual value of an illicit drug is a function of the quantity purchased, the price paid and the purity of the drug (Caulkins 2007). As such, even when prices unadjusted for purity are quite flat (see, for example, the Illicit Drug Reporting System and Ecstasy and Related Drug Reporting System price series for Australia, in which price has been remarkably stable over many years; Peacock et al. 2018) this can mask large variations in the purity of the drug. This was clearly demonstrated during the Australian heroin shortage, when the price of heroin in Victoria increased from $300 per gram in 2000 to $450 in 2001—a 50 percent increase—but purity declined from 46 percent to 16 percent, meaning PAP for heroin increased by 325 percent (Caulkins 2007). For this reason, the strongest evidence comes from studies measuring PAP, not price or purity alone.

Finally, it is important to distinguish between (a) the relationship between PAP and harm (eg inverse or direct) and (b) the impacts on harm (eg increased or reduced), as impacts are shaped by both the relationship between PAP and harm and the trends in PAP. For example, if there is an inverse relationship and PAP is decreasing, harms will increase, but if there is an inverse relationship and PAP is increasing, harms will reduce.

Method

This study employed a rapid review methodology—a form of evidence synthesis that provides a rigorous method for locating, appraising and synthesising evidence from previous studies, and producing results in a timelier manner than a systematic review (Ganann, Ciliska & Thomas 2010). Consistent with rapid review methodologies, this study was designed in consultation with end users (the Australian Institute of Criminology), used a limited number of electronic databases (five), and involved tight inclusion criteria and one principal coder. A potential limitation of a rapid review is that some studies may not be identified; however, this can be mitigated by including grey literature as well as journal articles and by consulting experts in relation to the included literature (Ganann, Ciliska & Thomas 2010). Both steps were adopted for this review (see below).

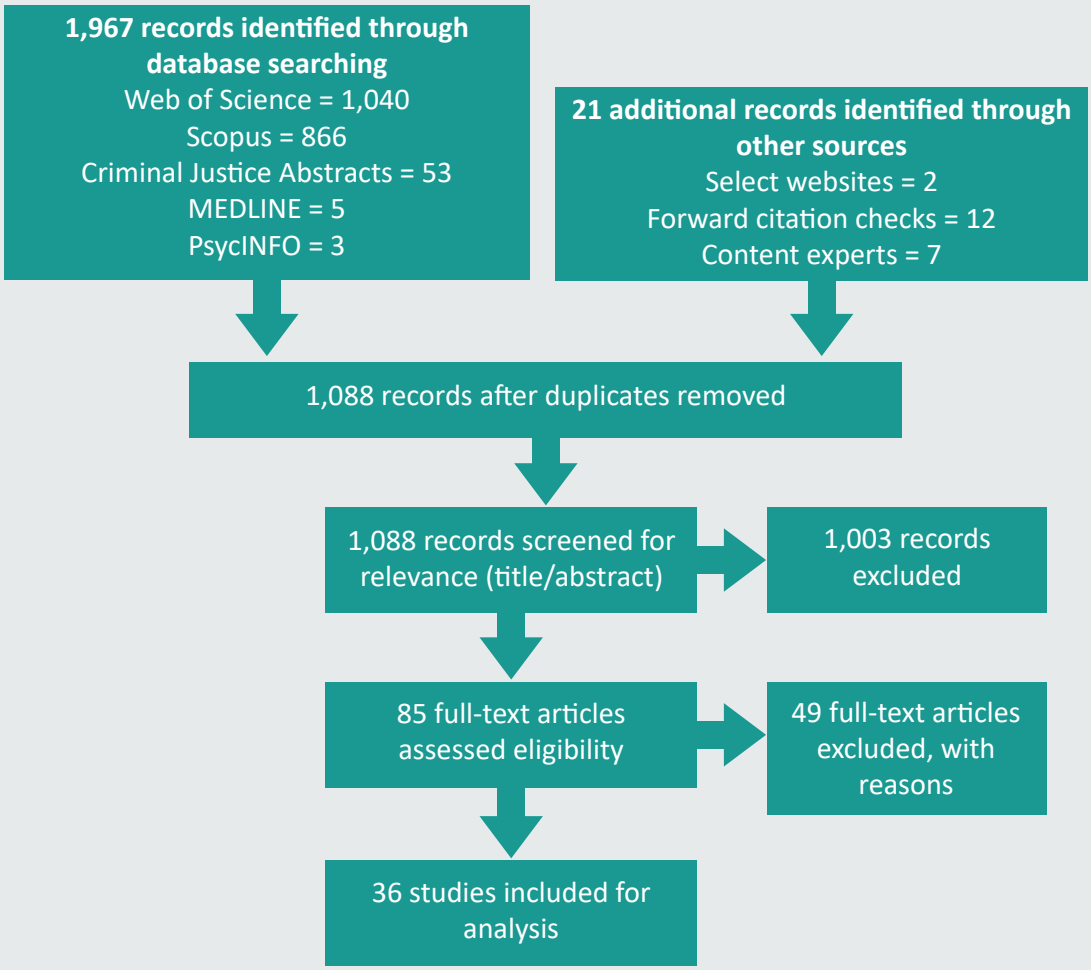
Search strategy

The search strategy involved four stages. First, comprehensive searches were conducted in five databases of peer-reviewed articles: Web of Science, PsycINFO, MEDLINE, Scopus, and Criminal Justice Abstracts. Search terms were specified based on the research questions, as follows:

- price OR purity; (AND) drug OR heroin OR cocaine OR amphetamine OR methamphetamine; (AND) overdose OR ambulance OR emergency OR hospital OR property OR violent OR crime; (AND) effect* OR impact* OR relationship)
- (NOT) pharma* OR medic*

Second, we manually searched for grey literature via the websites of the International Society for the Study of Drug Policy, National Drug Law Enforcement Research Fund, European Monitoring Centre for Drugs and Drug Addiction and RAND Corporation. Third, we used Google Scholar to identify relevant studies that had cited those identified in the first two stages. Finally, three international experts were consulted to identify other relevant studies. The search resulted in identification of 1,988 records, all of which were screened for inclusion. This screening process resulted in 85 full-text articles that were assessed for eligibility and 36 that were included in the analysis (Figure 1).

Figure 1: Search results



Study selection

Inclusion and exclusion criteria were developed with a focus on including empirical, quantitative studies related to drug prices, purity and at least one of the population level harms specified above. The searches were limited to studies examining heroin, cocaine and meth/amphetamine and excluded studies examining cannabis or other drugs. Only studies published in the English language between 1990 and March 2019 (when the searches were conducted) were included. Opinion pieces, commentaries and qualitative studies were also excluded.

Literature was excluded if it examined drug price or purity in the absence of any focus on harm—for example, studies focusing on the price elasticity of demand or the relationship between price, purity and drug consumption. The focus on harms meant that this review was intrinsically biased towards impacts from heavy use rather than occasional use, but this was consistent with our research questions. Harm is also the outcome of most concern to policymakers (Dave 2006).

Data extraction and synthesis

A data extraction spreadsheet was used to ensure that consistent information was coded from each study, including:

- study description—authors, title, journal/source, publication year, study aim, drug type(s), drug form(s);
- context—location, time period of analysis, other;
- methods—study design, data source for price and purity information, PAP (yes/no), data source for outcome(s);
- price and purity—trends in raw price, raw purity and PAP;
- effect—nature of relationship between PAP and drug-related harm (inverse, direct, mixed, null);
- impact on drug-related harms—impact on ambulance attendances, ED visits, hospital admissions, treatment admissions, fatal and non-fatal overdose, property crime, violent crime, drug possession and supply offences (increased, reduced, mixed, null); and quantitative effect size; and
- other—key findings/implications, moderators/mediators.

This spreadsheet (available at https://ndarc.med.unsw.edu.au/project/relationship-between-price-purity-and-population-level-drug-related-harm) became the basis for data analysis and synthesis, with referral back to the original articles as required.

Results

Study characteristics

Of the 36 included studies, 47 percent were from North America (1 from Canada and 16 from the United States), with a further 42 percent from Australasia (all from Australia) and 11 percent from Europe (including the United Kingdom, Netherlands, Austria and Turkey; Table 1). Most studies (67%) focused on heroin. The main data source was law enforcement seizures and 36 percent used data from the US System To Retrieve Information from Drug Evidence (STRIDE) or STARLIMS, which replaced STRIDE in October 2014. Since 1973 these systems have provided transaction level data on undercover buys including the date, city, price, quantity and purity of each buy (for details see Caulkins 1994). A further 22 percent used other law enforcement data systems, and one used drug checking data. Across the entire sample, only 47 percent of studies employed PAP.

As outlined in Table 1, there were two main study types—analyses of specific supply events (eg the Australian heroin shortage) and non-event analyses focusing on PAP trends over time. These differed significantly in method, quality, breadth and location, and hence warranted separate analyses. Compared to the event studies (*n*=18), the non-event analyses (*n*=18) employed more rigorous study designs (econometrics, quasi-experimental or time-series) and were more likely to use PAP (78% vs 17%). They also assessed relationships across a broader set of drug types and contexts. Event studies tended to assume changes in price and purity based on third-party data, and seldom included price/purity/PAP data in their analyses.

Table 1: Characteristics of included studies (*n*=36)						
	All studies (*n*=36)		Non-event studies (*n*=18)		Event studies (*n*=18)	
	n	%	*n*	%	*n*	%
Publication year						
1995–1999	4	11	4	22	0	0
2000–2005	16	44	3	17	13	72
2006–2010	10	28	6	33	4	22
2011–2019	6	17	5	28	1	6
Continent						
North America	17	47	10	56	7	39
Australasia	15	42	4	22	11	61
Europe	4	11	4	22	0	0
Study design						
Descriptive	3	8	0	0	3	17
Correlational/econometric	12	33	11	61	1	5
Quasi-experimental/time-series	21	58	7	39	14	78
Drug type[a]						
Heroin	24	67	13	72	11	61
Meth/amphetamine	9	25	2	11	7	39
Cocaine	8	22	8	44	0	0
Data source for price and purity[a]						
Law enforcement—STRIDE/STARLIMS	13	36	10	56	3	17
Law enforcement—other	8	22	7	39	1	5
Consumer reports	9	25	4	22	5	28
Expert reports	2	6	0	0	2	11
Drug checking service	1	3	1	5	0	0
No price or purity data presented[b]	9	25	0	0	9	50
Employs PAP	17	47	14	78	3	17
Health outcomes examined[a]						
Fatal or non-fatal overdose	12	33	7	39	5	28
Hospital admissions	8	22	5	28	3	17
Emergency department admissions	6	17	5	28	1	6
Ambulance attendance	4	11	1	6	3	17
Treatment outcomes examined[a]	13	36	4	22	9	50
Crime outcomes examined[a]						
Drug possession and supply offences	8	22	3	17	5	28
Property offences	7	19	1	6	6	33
Violent offences	2	6	1	6	1	6

a: Categories and sub-categories of health, treatment and crime outcomes are not mutually exclusive

b: Event-oriented studies that did not include price or purity data but relied on other studies for context

Findings from non-event studies examining trends over time

Health outcomes

Five US studies examined the relationship between price, purity and PAP and ED admissions. All except one (which did not employ PAP: Zhu et al. (2014)) found an inverse relationship between PAP and ED admissions (Table A1). This means an increase in PAP was associated with a reduction in ED admissions. For example, Dave (2006) found a 10 percent increase in PAP prevented 10,723 cocaine- and heroin-related ED visits, with cost savings of $21m to $47m. In one study the inverse relationship meant a reduction in PAP was associated with an increase in ED admissions: Davies (2010) found a nine percent reduction in average cocaine purity led to 399 more ED admissions per 100,000 population. Davies found that the level of variance in purity also shapes health outcomes, as higher variation in cocaine purity was associated with lower ED admissions. Importantly, Caulkins (2001) found trends in PAP accounted for 95 to 98 percent of variation in US ED admissions for cocaine and heroin. This shows PAP can be a very strong predictor of this health-related harm.

Three studies examined relationships between PAP and hospital admissions, and all identified that reductions in heroin and cocaine PAP were associated with increased hospital admissions for those drugs (an inverse relationship). For example, Ciccarone et al. (2016) found that reductions in heroin PAP contributed to a doubling in the rate of US hospitalisations for heroin-related skin and soft tissue infection (SSTI) admissions. They further concluded that each $100 increase in the yearly average price per gram of pure heroin could be associated with a three percent decrease in the rate of heroin-related SSTI admissions. Ciccarone et al. (2016) also found the source and form of heroin influenced hospital admissions, as cities where Mexican black tar heroin dominated (eg San Diego and Seattle) had twice the rate of SSTI admissions as cities where Colombian powder heroin dominated (eg Chicago and New York). A Dutch study by Brunt et al. (2010) examining hospital admissions over a 17-year period found a strong inverse relationship between PAP and cocaine-related harm: as cocaine PAP fell, hospital admissions for cocaine increased. But this same study also found changes in amphetamine PAP were not associated with changes in hospital admissions for amphetamines. As such we note that relationships between PAP and hospital admissions may vary by form, source and drug type.

Eight studies looked at the relationship between PAP and fatal or non-fatal overdoses, with seven showing an inverse relationship. The only one that did not find an inverse relationship was one that did not adjust prices for purity (Toprak & Cetin 2009). In Australia Moore et al. (2005) found that every 10 percent increase in heroin PAP was associated with an 11 percent decrease in the number of ambulance calls for non-fatal heroin overdoses, and Darke et al. (1999) found a similar relationship between PAP and fatal heroin overdoses. Darke et al. (1999) and Davies (2010) both found that the range of heroin purity was an independent predictor of the number of fatalities per fortnight. Hyatt and Rhodes (1995) found significant declines in cocaine PAP contributed to a rise in cocaine-related fatalities in the United States, a finding that was reproduced by Schifano and Corkery (2008) in the United Kingdom for cocaine and crack cocaine. Finally, Unick et al. (2014) found that street price, independent of purity, was not associated with heroin overdose, but there was a moderate inverse relationship between heroin PAP and heroin overdose (r=−0.17). Specifically, each $100 increase in the price per gram of pure heroin resulted in a three percent decrease in the number of heroin overdose hospitalisations. Moreover, the reduction in heroin PAP in the US market—from an average PAP of US$1,368 per gram in 1993 to US$688 in 2008—accounted for a 20 percent increase in heroin overdose hospitalisations.

Treatment outcomes

Four studies examined impacts on treatment admissions, with variable findings (see Table A2). Brunt et al. (2010) found an inverse relationship between PAP and treatment admissions for both cocaine and amphetamines (as PAP reduced, treatment admissions rose), with that relationship strongest for cocaine. Bach and Lantos (1999) found an inverse relationship, namely that as heroin PAP decreased, the doses of opioid agonists used in treatment increased. In contrast, Weatherburn and Lind (1997) found no relationship between heroin PAP and treatment admissions, a finding echoed by Schifano and Corkery (2008) for cocaine and crack cocaine looking at price and purity separately (not PAP). The variability across studies is consistent with economic theory about the large number of factors that may affect treatment admissions. While some studies noted differences in the quality of treatment offered (Bach & Lantos 1999), none assessed the ease of access to treatment, which other research has shown can vary significantly (Ritter, Chalmers & Gomez 2019; Ritter et al. 2019).

Crime outcomes

Three studies examined impacts on crime, and all found an inverse relationship between PAP and crime (see Table A3). For example, in the United Kingdom, Schifano and Corkery (2008) found reduced price (not adjusted for purity) was associated with increased cocaine and crack cocaine offences. The most notable study to test the relationship between PAP and crime was a US study by DeSimone (2001) that analysed impacts on seven types of crime: murder and manslaughter, forcible rape, aggravated assault, robbery, burglary, larceny, and motor vehicle theft. They observed an inverse relationship (increased PAP, decreased crime) for all offences except for aggravated assault, which had no relationship, and that the strength of the relationship further differed across the other six offence types. DeSimone (2001) demonstrated that the US decline in cocaine PAP in the 1980s increased violent and property crime substantially. For example, the average sample price fell from US$192 in 1984 to US$69 in 1989, which predicted increases of 52 percent for vehicle theft, 46 percent for murder, 32 percent for robbery and 17 percent for rape. One limitation is that all studies looked at cocaine specifically, which leaves unanswered the question of whether relationships between PAP and crime differ by drug type.

Findings from event studies

Australian heroin shortage

Out of the 17 event studies, 11 examined the Australian heroin shortage of early 2001, when there was a sudden and dramatic reduction in the availability of heroin in Australia and an accompanying change in the retail price and purity of heroin. Consumer reports indicated that in 2001 the retail price of heroin increased from $220 to $320 per gram in New South Wales and from $330 to $450 in Victoria (Day 2004a, 2004b). Prior to 2001, prices had been stable (Mattick, Topp & Degenhardt 2004). Heroin purity in New South Wales declined from 65 percent to 28 percent between March 2000 and June 2001, with similar patterns observed in Victoria, South Australia (Day 2004a) and the Australian Capital Territory (Smithson et al. 2004). All relevant studies examining the outcomes of the heroin shortage are summarised in Table A4.

Notably, only one study (Weatherburn et al. 2003) employed PAP, with the rest either including purity alone or cross-referencing other studies documenting changes in price and purity. This study showed that the price per gram of pure heroin in New South Wales rose by 112 percent between 2000 and 2001, that the rise in PAP was associated with a significant reduction in overdoses (53%), but that impacts on property crime (break and enter and robbery) varied over time, as evidenced by a short-term increase followed by a longer term fall.

Consistent with Weatherburn et al. (2003), the five other studies examining health outcomes (fatal and non-fatal overdoses) also showed an inverse relationship. Specifically, the heroin shortage and the accompanying increase in PAP was associated with a significant reduction in fatal and non-fatal overdoses in New South Wales, Victoria and the Australian Capital Territory (Degenhardt et al. 2005c, 2005d, 2005e; Smithson et al. 2004; Weatherburn et al. 2003). The strength of the relationship was moderated by age, whereby younger age groups experienced greater declines in overdose than older age groups (Degenhardt et al. 2005d).

Again in keeping with Weatherburn et al. (2003), the three other studies that examined impacts on crime found that there was a short-term increase in property offences (including burglary, break-and-enter dwelling and non-dwelling, and robbery with and without a weapon) in the initial period following the shortage (Degenhardt et al. 2005b, 2005e; Smithson et al. 2004). However, the increase was not sustained, and acquisitive crime subsequently decreased in New South Wales, Victoria, South Australia and the Australian Capital Territory (Degenhardt et al. 2005e; Smithson et al. 2004). Geography appeared to moderate the relationship between heroin price and property crime, as the strength of the relationships varied across states (highest in NSW, lowest in SA). This was attributed to variations in the size and characteristics of the heroin markets.

Finally, most studies found an inverse relationship between heroin prices and treatment outcomes, whereby the heroin shortage was associated with declining numbers of people entering pharmacological and non-pharmacological treatment (Degenhardt et al. 2005a, 2005d, 2005e). But Smithson et al. (2004) showed that methadone treatment enrolments initially increased and then declined, a finding that was also observed in Victoria. No relationship was observed in South Australia.

Methamphetamine precursor controls in North America

Six studies examined a series of methamphetamine precursor controls introduced in North America in the 1990s/2000s in response to increasing problems related to methamphetamine use and supply (Callaghan et al. 2009; Nonnemaker, Engelen & Shive 2011). The new regulations sought to control the wholesale supply and retail sale of pseudoephedrine and ephedrine—the primary precursors used in the manufacture of methamphetamine. The US regulations were as follows:

- 1989—the *Chemical Diversion and Trafficking Act* (US) regulated wholesale supply of ephedrine and pseudoephedrine in bulk powder form. Distributors of these chemicals were required to register with the Drug Enforcement Administration and keep records of sales and customers;
- 1995—the *Domestic Chemical Diversion and Control Act* (US) partially regulated wholesale distribution of products containing ephedrine as the only active medicinal ingredient;
- 1996—the *Comprehensive Methamphetamine Control Act* (US) regulated retail sale of products that included ephedrine in combination with other active medicinal ingredients (eg cold medicines);

- 1997—the *Comprehensive Methamphetamine Control Act* (US) regulated wholesale supply of products that included pseudoephedrine, regardless of whether they contained other active medicinal ingredients; and
- 2000—the *California Uniform Controlled Substances Act* regulated retail sale by rescheduling pseudoephedrine so it was only available behind the counter and in restricted quantities (<9 grams; Cunningham & Liu 2008, 2005, 2003; Cunningham, Liu & Callaghan 2009).

The relationships between these precursor controls and price, purity and PAP at the street level were studied by several researchers. Cunningham, Liu and Callaghan (2009) used STRIDE data to show the mean methamphetamine PAP rose sharply, albeit temporarily, after each of the 1989, 1995 and 1997 regulations targeting wholesale supply. In contrast, trends differed for the two regulations targeting retail sale. The methamphetamine PAP changed little after the 1996 regulation (Cunningham, Liu & Callaghan 2009), and fell significantly in California (from US$83.62 to US$59.69 per pure gram) after the 2000 regulation (Nonnemaker, Engelen & Shive 2011).

In line with these trends, Cunningham and Liu (2003) found an inverse relationship (increased PAP and reduced drug-related health harms) associated with some but not all reforms. Specifically, they showed that the 1989, 1995 and 1997 regulations targeting wholesale supply resulted in a significant decline of between 35 percent and 71 percent in methamphetamine-related hospital admissions (see also Cunningham & Liu 2008). However, the 1996 regulation targeting retail sales had no effect on admissions, a finding that was echoed by Nonnemaker, Engelen and Shive (2011) following the 2000 reform. Analysis of precursor reforms in Canada also found no inverse relationship in this setting, but this study did not employ PAP (Callaghan et al. 2009).

In relation to crime outcomes, Cunningham and Liu (2005) found that methamphetamine arrests decreased by approximately 31 to 45 percent when the 1989, 1995 and 1997 regulations were implemented, but again these declines were not observed for the 1996 regulation. Finally, Dobkin and Nicosia (2009) found an inverse relationship following the 1995 California precursor controls: an increase in methamphetamine PAP led to a rapid 50 percent reduction in amphetamine-related hospital admissions and felony drug offences and a lagged 35 percent reduction in treatment admissions. But there was no compelling evidence of impacts on property or violent crime and all impacts were temporary—approaching pre-intervention levels within 18 months. This indicates that for precursor controls the type of regulation employed is likely to be a key moderator of impacts on PAP and harm. Cunningham and Liu (2005, 2003) and Callaghan et al. (2009) note relationships may be shaped by the extent to which regulations adequately target the source(s) of supply (which is why wholesale controls may elicit greater desired effects).

Discussion

This study involved a rapid review of existing research on the relationship between price, purity and drug-related harm at the population level, focusing on seven key outcomes and three drug types. Analysis of non-event studies suggests that, with a few exceptions, there is a consistent inverse relationship between price, purity and drug-related harm. That is, increased PAP is associated with lower harm, and reduced PAP is associated with increased harm. All exceptions can be explained by the price series failing to adjust for purity (eg Zhu et al. 2014) or the study's focus on outcomes for which theory predicts effects may differ (eg treatment). In that regard, consistent with economic theory, there were subtle differences in outcomes. We saw the clearest relationship with ED admissions and overdoses, followed by hospital admissions and crime, while there was no clear relationship with treatment.

For event studies the evidence base on the relationship between price, purity and harm was clearly less reliable, with the majority (particularly those on the Australian heroin shortage) relying on known or assumed changes in price and purity rather than empirical PAP data and its association with harms. Nevertheless, these studies also showed that actual or assumed increases in price per pure gram were associated with reductions in health-related harms and treatment admissions. Impacts on crime varied, as exemplified by reductions following some but not all events, or by short-term increases followed by longer term reductions. A further universal finding was that impacts of supply shocks dissipated with time.

Across both event and non-event studies we found only subtle differences in the relationship between PAP and harm for cocaine and heroin (albeit with a slightly stronger relationship for cocaine). There is comparatively little data in this area; hence future research examining relationships by drug type is advised, particularly in relation to methamphetamine. Finally, several moderators of the relationship were identified, including geography, age, variation or range in purity, drug source, drug form and in the case of precursor controls the type of regulation employed. For example, changes in PAP appear more likely to influence harm in larger or more established markets and among young cohorts. Again, more research is needed to understand these moderators.

There are several limitations to the analysis, including the limited pool of studies and quantitative estimates, and the focus on harms alone. Nevertheless, as the first such review it has important implications.

Implications for policy and practice

First, this review shows the value of price and purity data for foreseeing drug market impacts. As noted by Caulkins (2001), the relationship between PAP and ED admissions is very strong, accounting for 95 to 98 percent of trends in ED admissions. That this appears to hold across health and crime harms, multiple drug types and contexts as well as directionality (higher PAP is associated with less harm, and lower PAP is associated with greater harm) provides further evidence of the relationship. In the context of a rapidly evolving drug market and where there is a multiplicity of drug policy options and scarce resources, this is welcome news.

Second, the review reinforces that PAP rather than price or purity alone influences harm. While there can be a strong relationship between PAP and harm, the same harm can have a null or even a counter relationship with price or purity alone (particularly price). Analysis of price alone could thus lead to erroneous conclusions being drawn.

Third, the review brings to light the large variability in the quality of research and underlying data systems on price and purity, including the data source(s) (eg police, consumers or drug checking services), the frequency of data collection, the timeliness of reporting, the ability to match price/purity/PAP with outcomes of interest and the extent to which systems employ PAP. The predominance of evidence (and high-quality evidence) comes from US studies, as a direct consequence of that country's investment in a PAP system (STRIDE/STARLIMS). Routine investment in PAP has a number of benefits, including improving understanding of the causes of crime trends and demands on health care and criminal justice systems, increasing the ability to foresee future needs, and better informing decisions about optimal policy options to increase PAP or keep PAP high. We conclude that PAP should form part of routine data collection systems—including in Australia. With that in mind, it is important to critically examine the current Australian surveillance and monitoring systems.

Existing Australian systems to monitor drug price, purity and PAP

As of 2020 Australia is fortunate to have several surveillance and monitoring systems that capture information on drug price and purity. These include the Illicit Drug Reporting System, the Ecstasy and Related Drug Reporting System and Drug Use Monitoring in Australia, which gather information on prices paid by people who use drugs, along with their perceptions of drug purity (high, medium, low; see, for example, Karlsson & Burns 2018; Patterson, Sullivan & Bricknell 2019; Peacock et al. 2018). The data gathered on price is deemed relatively reliable and useful. For example, Weatherburn et al. (1995) compared price data from undercover buys with the self-reports of people arrested in possession of heroin in Cabramatta; there were no significant differences between the arrest samples and the undercover buy samples in either price or PAP. (All heroin samples from undercover officers and arrestees were forensically analysed to produce PAP.) But the perceptions of purity gathered by the three existing monitoring programs cannot be matched to price, so PAP cannot be derived from these sources alone.

The Australian Criminal Intelligence Commission's *Illicit drug data report* provides data on prices for illicit drugs, collected from each police service based on information supplied by police conducting undercover buys and police informants (see, for example, ACIC 2019). Purity data are collected from police services and contributing forensic organisations. The limitation here is that analyses vary according to police priorities as well as jurisdictional laws, particularly drug trafficking threshold laws (Hughes et al. 2014). More specifically, with the exception of Victoria Police's Forensic Services Department, which analyses the size and purity of all drug seizures made in that state, most Australian states only analyse the purity of large seizures, and what gets analysed varies across states. For example, New South Wales tests the purity of seizures of a commercial quantity or greater, while South Australia tests the purity of all samples weighing over five grams irrespective of the drug type (Australian Criminal Intelligence Commission 2019). Methamphetamine purity data are thus collected on seizures of over 250 grams in New South Wales, over six grams in the Australian Capital Territory and over five grams in South Australia. Existing systems thus curtail state comparisons and limit data collection on retail-level seizures: the most important data for purity-adjusted price analyses.

There are several avenues to improve future analyses in Australia. First, existing high-quality price and purity data (eg Victoria Police data), either on their own or in concert with self-report price data from people who use drugs, could be better used to produce high-frequency PAP series (see, for example, Caulkins 2007; Caulkins, Rajderkar & Vasudev 2010; Scott et al. 2014). Second, law enforcement purity data gathered in states other than Victoria could be improved by supplementing purity analysis of large seizures with analysis of retail-level seizures, developing consistent measures for forensic testing across states, and/or investing in more undercover buys. Alternative data sources such as pill testing or drug checking could also be considered.

One motivator for improving data collection is the experience of the European Monitoring Centre for Drugs and Drug Addiction (EMCDDA), which committed to improving the monitoring of illicit drug supply in 2014, most notably by collecting data on price and purity. By 2017, 27 countries reported retail purity, and many also reported wholesale purity. The EMCDDA further note that the data collected on purity are 'consistently valuable for the strategic analysis of the European drug market' (EMCDDA & Europol 2018: 11). We similarly argue that improving Australian price and purity analysis (and routinely measuring PAP) will increase our capacity to understand the Australian drug market, to address key unknowns (such as the extent to which increasing methamphetamine PAP in Australia would reduce methamphetamine-related crime) and to identify new avenues to reduce drug-related harm.

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Appendix

Table A1: Key findings from non-event analyses of the relationship between price, purity and drug-related harm: Health outcomes

Study	Jurisdiction	Drug type	Outcome examined	Purity-adjusted price (PAP)?	Relationship between PAP (or raw purity) and harm	Impacts on drug-related harm	Other
Emergency department admissions							
Hyatt & Rhodes (1995)	USA	Cocaine	ED admissions	Yes	Inverse	As PAP decreased, ED admissions increased.	Significant relationship observed.
Caulkins (2001)	USA	Cocaine	ED admissions	Yes	Inverse	As PAP decreased, ED admissions increased.	Same pattern for both cocaine and heroin, but correlation between actual and expected ED admissions was 0.987 for cocaine and 0.975 for heroin. That is, price changes explained 97.5% of variation in ED admissions for cocaine and 95% of variation for heroin, with price elasticities of demand being estimated at –1.30 and –0.84, respectively.
		Heroin	ED admissions	Yes	Inverse	As PAP decreased, ED admissions increased.	
Dave (2006)	USA	Cocaine	ED admissions	Yes	Inverse	As PAP increased, ED admissions fell.	The elasticity of the probability of an ED admission was –0.27 for cocaine and –0.10 for heroin. This implied that a 10% increase in PAP could prevent 10,723 cocaine and heroin-related ED visits, with cost savings of between $21m and $47m.
		Heroin	ED admissions	Yes	Inverse	As PAP increased, ED admissions fell.	

Table A1: Key findings from non-event analyses of the relationship between price, purity and drug-related harm: Health outcomes (cont.)

Study	Jurisdiction	Drug type	Outcome examined	Purity-adjusted price (PAP)?	Relationship between PAP (or raw purity) and harm	Impacts on drug-related harm	Other
Davies (2010)	USA	Cocaine	ED admissions	Yes	Inverse	Higher average purity, higher coefficient of variance and higher skewness (ie longer tail in higher purities) associated with lower ED admissions.	During the 1990s, average cocaine purity fell by 9.3 percentage points. This translated into 399 more ED admissions per 100,000, a 7.6% increase relative to the sample mean.
		Heroin	ED admissions	Yes	Inverse	Lower coefficient of variance and lower skewness (but not lower average purity) associated with higher ED admissions.	The decline in heroin purity skewness of 0.56 in the 1990s (ie reduction in uncertainty in purity) translated into 766 more ED admissions, a rise of 31% relative to the mean.
Zhu et al. (2014)	USA	Cocaine	ED admissions	No (purity only)	Direct	As purity fell, ED visits fell.	
		Crack Cocaine	ED admissions	No (price only)	Null	No significant price relationship.	
Hospital admissions							
Brunt et al. (2010)	Netherlands	Amphetamine	Hospital admissions	Yes	Null	Neither purity nor PAP had a significant impact on hospital admissions.	Important differences observed by drug type, with strong negative correlation for cocaine PAP and purity but not amphetamine.
		Cocaine	Hospital admissions	Yes	Inverse	As PAP and price fell, health admissions increased.	Amphetamines: PAP β=–0.170 Purity β=0.0522 Cocaine: PAP β=–0.385* Purity β=–1.509*

Table A1: Key findings from non-event analyses of the relationship between price, purity and drug-related harm: Health outcomes (cont.)

Study	Jurisdiction	Drug type	Outcome examined	Purity-adjusted price (PAP)?	Relationship between PAP (or raw purity) and harm	Impacts on drug-related harm	Other
Ciccarone et al. (2016)	USA	Heroin	Hospital admissions for skin and soft-tissue infections	Yes	Inverse	As PAP fell, hospital admissions rose.	Heroin market features were strongly associated with changes in the rate of SSTI. Each $100 increase in yearly average price per gram of pure heroin was associated with a 3% decrease in the rate of heroin-related SSTI admissions.
Scott et al. (2014)	Australia	Methamphetamine	Hospital admissions	Yes	Inverse	As PAP fell, hospital admissions rose.	
		Heroin	Hospital admissions	Yes	Inverse	As PAP fell, hospital admissions rose.	
Fatal or non-fatal overdose							
Moore et al. (2005)	Australia	Heroin	Non-fatal overdose	Yes	Inverse	As PAP rose, non-fatal overdoses fell.	Every 10% increase in the PAP of heroin was associated with an 11.2% decrease in the number of ambulance calls for non-fatal heroin overdoses.
Darke et al. (1999)	Australia	Heroin	Fatal overdose	Yes	Inverse	As PAP increased, overdoses fell.	Significant moderate correlation (r=0.57) at time lag zero between mean purity of heroin sample per fortnight and number of overdose fatalities. Both mean heroin purity and range of heroin purity were independent predictors of the number of fatalities per fortnight.
Hyatt & Rhodes (1995)	USA	Cocaine	Fatal overdose	Yes	Inverse	As PAP increased, overdoses fell.	

Table A1: Key findings from non-event analyses of the relationship between price, purity and drug-related harm: Health outcomes (cont.)

Study	Jurisdiction	Drug type	Outcome examined	Purity-adjusted price (PAP)?	Relationship between PAP (or raw purity) and harm	Impacts on drug-related harm	Other
Scott et al. (2014)	Australia	Methamphetamine	Overdose deaths	Yes	Inverse	As PAP fell, overdose deaths increased.	
		Heroin	Overdose deaths	Yes	Inverse	As PAP fell, overdose deaths increased.	
Schifano & Corkery (2008)	UK	Cocaine	Cocaine related death	No (price only)	Inverse	As price fell, deaths rose.	The number of cocaine/crack cocaine related deaths (deaths from any cause where the presence of cocaine/crack cocaine was detected) showed a year-on-year increase and was inversely correlated with price. But the strength of relationship differed by form: • Cocaine: 0.882*** • Crack cocaine: –0.569* Concluded price decrease contributed to rise in cocaine-related fatalities.
		Crack cocaine	Crack cocaine related deaths	No (price & purity only)	Inverse	As price & purity fell, deaths rose.	
Toprak & Cetin (2009)	Turkey	Heroin	Overdose deaths	No (purity only)	Null	Null impact of purity on overdoses.	
Rosenblum, Unick & Ciccarone (2017)	USA	Heroin	Overdose admissions to hospital	Yes	Inverse	As PAP fell, admissions rose.	
Unick et al. (2014)	USA	Heroin	Overdose admissions to hospital	Yes	Inverse	As PAP increased, overdose admissions fell.	No evidence to support the hypothesis that actual street price of heroin, independent of purity, was associated with overdose. But, each $100 increase in the price per gram of pure heroin results in a 2.9% decrease in the number of overdose admissions.

Table A1: Key findings from non-event analyses of the relationship between price, purity and drug-related harm: Health outcomes (cont.)							
Study	**Jurisdiction**	**Drug type**	**Outcome examined**	**Purity-adjusted price (PAP)?**	**Relationship between PAP (or raw purity) and harm**	**Impacts on drug-related harm**	**Other**
Ambulance attendance							
Risser et al. (2007)	USA	Heroin	Ambulance call-outs	No (purity only)	Null	No relationship between purity and ambulance call-outs.	Low quality study.

***statistically significant at $p<0.001$, *statistically significant at $p<0.05$

Table A2: Key findings from non-event analyses of the relationship between price, purity and drug-related harm: Treatment outcomes							
Study	**Jurisdiction**	**Drug type**	**Outcome examined**	**Purity-adjusted price (PAP)?**	**Relationship between PAP (or raw purity) and harm**	**Impacts on drug-related harm**	**Other**
Brunt et al. (2010)	Netherlands	Amphetamine	Treatment admissions	Yes	Inverse	As PAP reduced, treatment admissions rose.	Strong relationship for cocaine and moderate relationship for amphetamines: Amphetamine: PAP β=–5.811* Purity β=3.101 Cocaine: PAP β=–6.607* Purity β=–11.679*
		Cocaine	Treatment admissions	Yes	Inverse	As PAP and purity reduced, treatment admissions rose.	
Weatherburn & Lind (1997)	Australia	Heroin	Methadone treatment admissions	Yes	Null		
Schifano & Corkery (2008)	UK	Cocaine and crack cocaine	Treatment admissions	No (price & purity only)	Null		Significant increase in treatment admissions not accounted for by changes in raw purity or price.

*statistically significant at $p<0.05$

Table A3: Key findings from non-event analyses of the relationship between price, purity and drug-related harm: Crime outcomes

Study	Jurisdiction	Drug type	Outcome examined	Purity-adjusted price (PAP)?	Relationship between PAP (or raw purity) and harm	Impacts on drug-related harm	Other
DiSimone (2001)	USA	Cocaine	Murder and non-negligent manslaughter, forcible rape, aggravated assault, robbery, burglary, larceny, and motor vehicle theft	Yes	Inverse	As price fell, crimes increased. Exception: aggravated assault.	Significant impacts across multiple crime types: Vehicle theft –0.291*** Murder –0.261*** Robbery –0.179*** Burglary –0.163*** Rape –0.094* Larceny –0.072** Aggravated assault –0.067 Implies that price increases resulting from exogenous supply shifts inversely impact both violent and property crime, and that the 1980s price decline increased crime substantially. For example, the average sample price fell from $192 in 1984 to $69 in 1989. This 178 percent price drop predicts increases of 52% for vehicle theft, 46% for murder, 32% for robbery, 29% for burglary, 17% for rape, 13% for larceny.
Schifano & Corkery (2008)	UK	Cocaine and crack cocaine	Drug offences	No (price only)	Inverse	As price fell, drug offences rose.	
Hyatt & Rhodes (1995)	USA	Cocaine	% of arrestees testing positive to drugs	Yes	Inverse	As PAP reduced, % of arrestees testing positive increased.	

***statistically significant at $p<0.001$, **statistically significant at $p<0.01$, *statistically significant at $p<0.05$

Table A4: Studies examining the Australian heroin shortage and the relationship between price, purity and drug-related harm[a]					
Study	**Jurisdiction**	**Outcome examined**	**Purity-adjusted price (PAP)?[b]**	**Relationship between PAP and harm**	**Result—trends in drug-related harm**
Health					
Weatherburn et al. (2003)	NSW	Fatal/non-fatal overdose	Yes	Inverse	As PAP rose, fatal overdoses fell by 74%.
Degenhardt et al. (2005c)	NSW	Non-fatal overdose	No	Inverse	As heroin price increased and purity fell, non-fatal overdoses decreased significantly as measured by ambulance call-outs (a 40% decrease from 302.7 to 111.6 ambulance call-outs per month).
	NSW	Fatal overdose	No	Inverse	43% decrease in fatal overdoses, mainly due to change in the number of deaths where heroin was involved. The proportion of deaths in which only heroin was detected decreased from around 25% to 10%.
Degenhardt et al. (2005d)	NSW	Fatal overdose	No	Inverse	15–24 years: 65% decrease 25–34 years: 39% decrease 35–44 years: 42% decrease Older age groups: no change
Degenhardt et al. (2005e)	NSW	Fatal overdose	No	Inverse	43% decrease
	SA	Fatal overdose	No	Null	Small number, precluded time-series
	Vic	Fatal overdose	No	Inverse	85% decrease
Smithson et al. (2004)	ACT	Ambulance call-outs	No (purity only)	Direct	As heroin purity fell, ambulance call-outs fell: significant decline from a peak of 55 in December 1999 to an average of 8 between June 2001 and March 2002.

Table A4: Studies examining the Australian heroin shortage and the relationship between price, purity and drug-related harm[a] (cont.)					
Study	**Jurisdiction**	**Outcome examined**	**Purity-adjusted price (PAP)?[b]**	**Relationship between PAP and harm**	**Result—trends in drug-related harm**
Treatment					
Degenhardt et al. (2005a)	Australia	Treatment entrants	No	Inverse	Mean treatment entrants per month reduced by 29%, from 285 in January 2001 to 123 by April 2001.
Degenhardt et al. (2005e)	NSW	Pharmacology treatment	No	Inverse	Decrease in number of new pharmacology treatment entrants.
	NSW	Non-pharmacology treatment	No	Inverse	Reduction in closed treatment episodes for heroin, particularly among younger age groups.
	SA	Pharmacology treatment	No	Null	No change
	SA	Non-pharmacology treatment	No	Inverse	Reduced demand for treatment, though there was a brief spike in demand in rural areas.
	Vic	Pharmacology treatment	No	Mixed	Initial decrease in pharmacology treatment episodes, not sustained.
	Vic	Non-pharmacology treatment	No	Inverse	25% decrease in number of courses of treatment, particularly among 15–24 and 25–34 year olds.
Degenhardt et al. (2005d)	NSW	Pharmacology treatment	No	Inverse	15–24 years: 26% decrease in new registrations 25–34 years: 41% decrease in new registrations Older age groups: no significant change
	NSW	Non-pharmacology treatment	No	Inverse	Decreased, more pronounced among younger age groups.
Smithson et al. (2004)	ACT	Methadone treatment entrants	No (purity only)	Mixed	As heroin purity fell, methadone treatment enrolments initially climbed (from around 600 in Jan 1999 to 671 in January 2001), then levelled off at around 640 for the remainder of that year.

Table A4: Studies examining the Australian heroin shortage and the relationship between price, purity and drug-related harm[a] (cont.)

Study	Jurisdiction	Outcome examined	Purity-adjusted price (PAP)?[b]	Relationship between PAP and harm	Result—trends in drug-related harm
Crime					
Weatherburn et al. (2003)	NSW	Property crime	Yes	Mixed	Rise in PAP associated with short-term rise in break-and-enter dwelling and robbery offences, then longer term fall. But the offences returned to 1999 levels by June 2001.
Degenhardt et al. (2005b)	NSW	Property crime	No	Mixed	Robbery without a weapon increased by 33%. Break-and-enter dwelling increased by 14%. Break-and-enter non-dwelling, motor-vehicle theft and stealing remained stable.
	NSW	Heroin use/ possession	No	Inverse	45% decrease
Degenhardt et al. (2005e)	NSW	Property crime	No	Mixed	Short-term increase in robbery with a weapon, then longer term fall.
	NSW	Heroin use/ possession	No	Inverse	Decreased, particularly pronounced among men aged 20–29 years.
	SA	Property crime	No	Mixed	Short-term increase in robbery without a weapon, then longer term fall.
	SA	Heroin use/ possession	No	Null	No difference attributable to the shortage.
	Vic	Property crime	No	Mixed	Short-term increase in residential burglary, then longer term fall.
	Vic	Heroin use/ possession	No	Inverse	40% decrease
Smithson et al. (2004)	ACT	Property crime	No (purity only)	Mixed	As heroin purity fell, robbery and burglary offences initially increased, then declined significantly. For example, burglary fell from 832 in November 1999 to less than half by August 2001. No impact on theft.

a: This table excludes descriptive and basic correlational studies examining the heroin shortage by Day (2004a, 2004b); Longo et al. (2004); and Mattick, Topp & Degenhardt (2004). The studies included in the table used interrupted time-series analyses to examine the impact of the shortage on various outcomes

b: The studies that did not use price, purity or PAP data used the heroin shortage as an intervention point and conducted time-series analyses on outcomes, cross-referencing descriptive studies of the changes in price and purity during the heroin shortage (eg Day 2004a)

Dr Caitlin Hughes is an Associate Professor in Criminology and Drug Policy at the Centre for Crime Policy and Research, Flinders University, and Visiting Fellow at the National Drug and Alcohol Research Centre, University of New South Wales.

Dr Shann Hulme is a Senior Analyst at RAND Europe.

Professor Alison Ritter AO is Director of the Drug Policy Modelling Program at the University of New South Wales.

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