+ Model
ARTICLE IN PRESS

Available online at www.sciencedirect.com
SCIENCE DIRECT®

ELSEVIER

Journal of Health Economics xxx (2005) xxx–xxx

JOURNAL OF HEALTH ECONOMICS

www.elsevier.com/locate/econbase

The effects of cocaine and heroin price on drug-related emergency department visits

Dhaval Dave *

Bentley University and National Bureau of Economic Research, Department of Economics, 175 Forest Street, AAC 195, Waltham, MA 02452, USA

Received 30 October 2004; received in revised form 5 August 2005; accepted 11 August 2005

Abstract

This paper estimates the empirical relationship between cocaine and heroin prices and drug-related hospital ED admissions for 21 U.S. cities. These outcomes bypass some of the problems with self-reports and directly measure a component of healthcare costs associated with heavy drug usage. The price elasticity of the probability of a cocaine and heroin episode is estimated at −0.27 and −0.10, respectively. A 10% increase in prices can prevent 10,723 cocaine and heroin-related ED visits, with cost savings between $21 million and $47 million. These low magnitudes of the drug outcome-price response have implications for the cost-effectiveness of enforcement-driven price increases.

JEL classification: I1

Keywords: Cocaine; Heroin; Drug abuse; Emergency department; Price

1. Introduction

Much of current drug control policy in the United States focuses on interdiction programs aimed at stopping the flow of drugs. The U.S. spends approximately $26 billion a year towards apprehension and punishment of drug offenders, the bulk of this aimed at dealers and sellers (Office of National Drug Control Policy, 2001). From an economic perspective, such drug enforcement, by raising the cost of supplying drugs to the U.S. market, acts as a non-monetary tax and increases

* Tel.: +1 781 891 2268; fax: +1 212 817 1597.
E-mail address: ddave@bentley.edu.

0167-6296/$ – see front matter © 2005 Elsevier B.V. All rights reserved.
doi:10.1016/j.jhealeco.2005.08.003

the transaction price of drugs.[1] Hence, a critical question concerns the extent to which drug use responds to prices, especially heavy or problematic use. Since manipulating prices is one mode of control that the public sector can exercise on the market for addictive unhealthy substances, empirical estimates of the relation between price variations and illicit drug consumption are key to informing and shaping public policy.

This paper estimates the empirical relationship between the prices of cocaine and heroin and objective indicators of their use. The set of outcomes is drug-related emergency room admissions where cocaine and heroin are cited, derived from the Drug Abuse Warning Network (DAWN). While this study is related to the new and growing empirical literature dealing with the price sensitivity of illegal drug consumption, it improves upon the prior estimates in a number of ways. The illegal drug use indicators employed in much of the literature are based on self-reports and may be measured inaccurately. In contrast, the indicators used in the present study are an alternative measure based on objective outcomes related to consumption. Moreover, much of the literature, by relying on self-reported national surveys, does not consider consumption by certain subgroups, who may behave very differently from the population at large. The persons sampled in DAWN are not representative of the general population. In particular, the focus is on persons whose substance use resulted in a visit to a hospital emergency room. These individuals are much more likely to be hardcore or chronic users of drugs than the users reflected in national surveys. Thus, they also impose the heaviest costs on society and are the target of much illegal drug policy. There were 19,698 deaths from drug-induced causes in 2000, up over 16% since 1998. Health care costs associated with drug abuse were estimated at around $15 billion for 2000, an increase of almost 40% since 1992 (ONDCP, 2003). In this respect, an estimate of the effect of drug prices on drug-related emergency department (ED) episodes is valuable in that it directly relates drug prices, an instrument of enforcement efforts, to the health consequences of heavy drug use.

Many studies based on survey data also rely on the respondent's state of residence as the geographic unit. Consequently, when estimating price responsiveness, these researchers have had to employ a state-average price despite the fact that there is considerable inter-city variation in drug prices even within a given state. This measurement error may lead to biased estimates. The present study overcomes this limitation by computing and merging drug prices at the city level. This analysis further exploits the time-series of city cross-sections and estimates various fixed effects specifications to account for endogeneity and control for unmeasured factors that may be correlated with price and consumption.

The remainder of the study proceeds as follows. Section 2 reviews prior empirical studies dealing with the price sensitivity of the consumption of illegal drugs. Section 3 describes the data assembled for use in this study. Section 4 outlines the analytical models that guide the empirical specifications. Section 5 presents the results and Section 6 offers some concluding remarks.

2. Prior studies

There is a rapidly growing empirical literature by economists dealing with the price sensitivity of consumption of illegal drugs. These demand studies primarily draw on illegal drug prices

---

[1] Costs for drug suppliers increase because: (1) they are forced to use underground distribution and transportation channels that can be hidden from authorities, (2) some drug shipments are captured by the authorities and destroyed, (3) suppliers are forced to use the threat of violence or other relatively costly methods to enforce their contracts rather than use the court system and (4) because of fines and imprisonment.

derived from local purchases made by drug enforcement agents while undercover. The studies typically combine these prices with self-reported measures of drug use from such national surveys as the National Household Survey of Drug Abuse (NHSDA) and Monitoring the Future. Grossman et al. (2002) provides a good review of this literature.

While the weight of the evidence from these studies suggests that cocaine and heroin use do respond negatively to price, there is little consensus about the magnitudes of the own-price elasticities. The illegal drug use indicators in the studies just cited may be plagued by inaccuracies if self-reports are subject to response error, and such surveys also fail to capture many hardcore or chronic drug users.[2] These considerations have led researchers to consider the price sensitivity of outcomes related to drug consumption. Model (1993) finds that marijuana-related hospital emergency room episodes are positively related to marijuana decriminalization, based on quarterly data from 1975 to 1978 for 21 metropolitan statistical areas (MSA) in the Drug Abuse Warning Network (DAWN). This study capitalizes on the decriminalization of the possession of small amounts of marijuana by 11 U.S. states between 1973 and 1978. This presumably reduced the full price of marijuana. Model does not include the money price of marijuana or other drugs in her study. Caulkins (2001b) estimates an elasticity of the number of hospital emergency room mentions for cocaine with respect to own-price of −1.30 and an elasticity of the number of hospital emergency room mentions for heroin with respect to own-price of −0.84. Caulkins employs an annual U.S. time series constructed from DAWN for the years 1978 to 1996. His models simply regress the given outcomes on price and do not control for any other factors that may have varied over time or for time trends.

Crane et al. (1997) employ aggregate time series from DAWN in order to estimate the price elasticity of demand for cocaine ranging from −0.29 to −0.63. This study also fails to control for time trends. Hyatt and Rhodes (1995) find that cocaine price is negatively related to the number of cocaine emergency room episode mentions, from DAWN. While this study adds city indicators to control for unobserved factors at the city level, it also does not control for time trends or any other factors that may have shifted over time. Furthermore, the price of cocaine is not adjusted for inflation. Since year indicators are not included, this leads to biased estimates. Thus, it is difficult to ascertain from these studies whether the negative correlation between the outcomes and price represents a causal effect or whether it reflects a spurious correlation due to other unobserved factors.

3. Data

The empirical work is based on objective outcomes related to cocaine and heroin consumption derived from the Drug Abuse Warning Network (DAWN). Since the early 1970's, DAWN has provided information on the use of emergency departments (ED) in the U.S. for the treatment of drug-related health problems. It is an ongoing national probability survey conducted annually in 21 large metropolitan areas by the Substance Abuse and Mental Health Services Administration (SAMHSA).[3] A consistently sampled time-series of the 21 cities from 1990 to 2002 was obtained

[2] For instance, since drug use is significantly higher among respondents who live in households considered unstable, the NHSDA's bias towards sampling stable households is likely to overlook many heavy drug users. A comparison of heavy cocaine users in the NHSDA with those in other sources shows a marked difference with respect to demographic characteristics. In the NHSDA, income is higher, unemployment is lower and fewer respondents report using more than one drug. See Rhodes et al. (2001).

[3] The DAWN cities are Atlanta, Baltimore, Boston, Buffalo, Chicago, Dallas, Denver, Detroit, Los Angeles, Miami, Minneapolis, New Orleans, New York City, Newark, Philadelphia, Phoenix, St. Louis, San Diego, San Francisco, Seattle and Washington, D.C.

from SAMHSA. DAWN collects information on patients seeking hospital emergency department (ED) treatment related to their use of an illicit drug. For the more recent years, DAWN also documents the reason for the ED admission, the majority of which are due to drug overdose, chronic effects, withdrawal, and seeking detoxification, and the rest are due to accident or injury, unexpected reaction, or other undocumented reasons. To be included in DAWN, the patient must be age 6 years or older, be treated in the hospital's emergency department, and have a problem induced by or related to drug use, regardless of when the drug ingestion occurred. Eligible hospitals in the DAWN sample are non-Federal, short-stay general hospitals that have a 24-hour emergency department. Within each participating facility, a trained reporter, usually a nurse or a member of the ED or medical records staff, is responsible for reviewing medical charts for indications noted by the treating physician that the episode was drug-related.

A drug episode is defined as an emergency department visit that is directly related to the use of an illegal drug or the non-medical use of a legal drug.[4] In addition, DAWN also identifies the substances associated with the drug abuse episodes. Up to four substances may be reported or "mentioned" for each drug-related episode; thus, the total number of mentions exceeds the number of episodes. Much of the time, however, only one drug is mentioned. Based on these data, a variable measuring the probability of a drug-related episode is defined as total drug-related ED episodes in each metropolitan statistical area (MSA) divided by population. For the sample analyzed in this study, there are 314 such episodes per 100,000 persons. Similar rates are also defined for cocaine mentions and heroin mentions. There are 119 cocaine mentions and 65 heroin mentions per 100,000 persons. DAWN medical crises occur in a small fraction of the drug abusing population. Data from the National Comorbidity Survey show that about 6% of the adult population was diagnozed with a drug abuse or dependence disorder in 1991 (Kessler et al., 1994). Applied to the mean MSA population for 1991, this translates to about 215,000 individuals with a drug disorder. The mean number of drug-related episodes for the same year was 9574. This means that about 22 additional serious abusers are required to generate one extra DAWN drug episode. Thus, these outcomes defined from DAWN are intended to capture serious health consequences related to hardcore drug use. Means for the DAWN sample are presented in Table 1.

Since the outcomes are measured at the metropolitan level, additional MSA-level socioeconomic variables are included in all models to capture time-varying trends within cities. Personal income per capita is derived from the Bureau of Economic Analysis website and deflated by the national consumer price index reported by the Bureau of Labor Statistics. Total MSA population is obtained from the U.S. Bureau of Census. Indicators measuring the percentage of MSA population that is male, black, other race, Hispanic, ages 16–24, ages 25–54, high school graduate and college graduate are constructed from the Current Population Survey March supplements. In order to capture local labor market conditions, the unemployment rate in each MSA is also included in all models. Data on unemployment are obtained from the Bureau of Labor Statistics, and in some cases also calculated from the March supplements of the Current Population Survey.

Indicators of local enforcement efforts are also appended. Variables measuring the probability of arrest for drug possession and drug sale are computed from the FBI's Uniform Crime Reporting System. Ideally, the probability of arrest is constructed by dividing the total number of arrests in each category by the total number of drug users and dealers in the MSA or some proxy for total drug activity. However, as there are no reliable estimates of the number of drug users and

[4] Since one person may make repeated visits, the number of ED episodes reported in DAWN is not synonymous with the number of individuals seeking such treatment.

Table 1
Sample means

Variable	Definition	Mean
Drug episode rate	Total drug-related emergency department episodes in each MSA divided by MSA population	0.00314 (0.0013)
Logistic drug episodes	log of the odds of drug episode rate	−5.83725 (0.3939)
Cocaine mention rate	Total number of times cocaine was mentioned in the emergency department drug episodes in each MSA divided by MSA population	0.00119 (0.0007)
Logistic cocaine mentions	log of the odds of cocaine mention rate	−6.95386 (0.7111)
Heroin mention rate	Total number of times heroin was mentioned in the emergency department drug episodes in each MSA divided by MSA population	0.00065 (0.0007)
Logistic heroin mentions	log of the odds of heroin mention rate	−7.88686 (1.1038)
Cocaine price	Price of one pure gram of cocaine, based on all purchases, divided by the annual national consumer price index	79.44819 (24.8081)
Heroin price	Price of one pure gram of heroin, based on all purchases, divided by the annual national consumer price index	421.81320 (369.0345)
Personal income	Per capita personal income in each MSA, divided by the annual national consumer price index	17.97189 (2.9212)
Unemployment	Unemployment rate in each MSA	0.05684 (0.0195)
Male	Percent of MSA population that are male	0.47808 (0.0186)
Black	Percent of MSA population that are black	0.15887 (0.1014)
Other	Percent of MSA population that are of a race other than white or black	0.05648 (0.0500)
Hispanic	Percent of MSA population that are Hispanic	0.12326 (0.1421)
Age 16–24	Percent of MSA population that are aged 16–24	0.16357 (0.0213)
Age 25–54	Percent of MSA population that are aged 25–54	0.59095 (0.0387)
High school	Percent of MSA population that are high school graduates	0.80084 (0.0544)
College	Percent of MSA population that are college graduates	0.26220 (0.0586)
Response rate	Responding sample hospitals as a fraction of total eligible hospitals	80.14469 (9.4100)
log response rate	log of response rate	4.37665 (0.1218)
Drug possession arrest rate	Total number of arrests in each MSA due to any drug possession divided by MSA population	0.00411 (0.0020)
Drug violation arrest rate	Total number of arrests in each MSA due to any drug violation divided by MSA population	0.00601 (0.0028)
Drug sale arrest rate	Total number of arrests in each MSA due to any drug sale or trafficking divided by MSA population	0.00177 (0.0013)
Cocaine sale arrest rate	Total number of arrests in each MSA due to cocaine sale or trafficking divided by MSA population	0.00112 (0.0012)
Marijuana sale arrest rate	Total number of arrests in each MSA due to marijuana sale or trafficking divided by MSA population	0.00034 (0.0003)
Population	Total MSA Population	3755332 (2373686)
Observations		273

Notes: Standard deviations are in parentheses. Number of observations listed represents the maximum number. For some variables, the actual sample size is slightly less due to missing information.

dealers by MSA, the denominator is proxied by total MSA population. Variables measuring the total number of arrests in each MSA due to any drug possession, any drug sale or trafficking, any drug-related violation, sale or trafficking in cocaine or opiates and sale or trafficking in marijuana are used to create the corresponding arrest rates.

Data on cocaine and heroin prices are computed from purchases made by undercover drug enforcement agents. Information on these purchases including cost, weight and purity is recorded by the Drug Enforcement Agency (DEA) in their System to Retrieve Information from Drug Evidence (STRIDE). The advantage of STRIDE's transaction-level data is that they directly reflect prices on the street. These prices are expected to be relatively accurate because any unreasonable price offer by a DEA agent may raise suspicion on the dealer's part and endanger the agent. However, because the transactions are of varying size and quality, the cost of each drug must be standardized.[5]

Standardized prices of one pure gram of cocaine and heroin in a given metropolitan area for a given year are derived in the following manner:

$$\log \mathrm{cost}_{ijt} = \pi_0 + \pi_1(\log \text{predicted purity}_{ijt} + \log \mathrm{weight}_{ijt}) + \pi_{2j} \sum \mathrm{MSA}_j + \pi_{3t} \sum \mathrm{year}_t + \pi_{4jt} \sum \mathrm{MSA}_j \times \mathrm{year}_t + \upsilon_{ijt} \quad (1)$$

The subscripts denote the *i*th transaction in the *j*th MSA for year *t*. Cost refers to the total cost of the purchase, weight is the total gram weight of the purchase, and purity is the weight of the pure drug found in the purchase as a fraction of the total purchase weight. MSA and year refer to dichotomous indicators of each, and MSA × year refers to indicators of the interaction between the two. Predicted purity is obtained from a first-stage regression of actual purity on all of these other explanatory variables.[6] The price of one pure gram of the drug in MSA j for year *t* is then imputed as

$$\exp\,(\pi_0 + \pi_{2j} + \pi_{3t} + \pi_{4jt}) \quad (2)$$

In the above procedure, purity is treated as endogenous because purchases may depend on expected rather than actual purity (Caulkins, 1996). Identification is achieved by constraining the coefficient on predicted purity to equal that on weight in the second-stage regression (see Footnote 6). In this study, price series based on purity treated as exogenous and estimating (1) with the coefficients unconstrained were experimented with in all models. There are no material changes in the results or conclusions. STRIDE data are available from 1974 to 2003, and all years are used to impute the price series for the periods represented in DAWN. There are 93,004 usable cocaine transactions and 41,088 usable heroin transactions.[7] All price series are deflated by the national CPI. The mean

[5] For instance, Caulkins and Padman (1993) and Rhodes et al. (1994) show that there are sizable discounts for "wholesale" or large quantity purchases of cocaine.

[6] Eq. (1) can be justified by defining the price of one pure gram of drug as: price = cost/(pure quantity of drug)$^{\pi_1}$, where pure quantity is purity times total weight. Here π_1 captures any non-linear effects of quantity on price, for example due to quantity discounts. In log-linear form, this is log price = log cost − π_1 log purity − π_1 log weight. It is assumed that the standardized price varies between cities and over time. Thus, log price = *a* + *b* MSA + *c* year + *d* MSA × year. Substituting this expression in the log-linear formulation results in an estimable form, Eq. (1).

[7] In order to maximize the sample size in subsequent estimation, heroin prices that are missing in any given MSA for any given year are imputed by the weighted mean of the prices for all other available MSA's in that particular state. About 3% of the DAWN sample are affected by this imputation. Results are not sensitive to alternately omitting the missing values.

real price (in 1982–1984 dollars) of one pure gram of cocaine is $79.45. The mean real heroin price is $421.81.

One of the advantages of this study is that the drug prices are computed and merged at the city level. Many prior studies relying on national self-reported survey data used state-average prices despite the fact that drug prices seem to vary widely from city to city. The variation in drug prices across cities and within cities can be related to cost and supply-side factors. For example in the DAWN sample, cocaine prices are lowest in port-of-entry cities like San Diego, Los Angeles, Miami, and New York, and highest in interior cities like Minneapolis, Saint Louis, and Detroit. Kuziemko and Levitt (2004) find that even within a given city, STRIDE cocaine prices from 1986 through 1996 are positively related to state-level indicators of the certainty of punishment, measured by the per capita number of drug arrests, and the severity of punishment, measured by the fraction of drug arrests resulting in imprisonment. Basov et al. (2001) argue that due to the illicit, secretive nature of the drug trade, both production and sales are more labor intensive compared to legal markets. Most of these jobs are also likely to be filled by low-skilled employees, youths, or others with fewer outside opportunities. Their study shows that cocaine and heroin prices from STRIDE are positively related to the state-specific relative unskilled wage in a time series of states from 1974 to 1999. These two studies further confirm that DEA drug prices do indeed reflect costs of retailing including expected penalties and labor costs.[8]

The underlying assumption is that drug prices vary across cities and over time as a result of changes in distribution and shipping costs, labor costs, resources expended towards enforcement and apprehension of dealers, and severity of penalties. In this case, the supply curve for cocaine and heroin is infinitely elastic. If the supply curve is instead positively sloped, then estimates of the demand price elasticity are biased downwards in absolute magnitude and may be regarded as conservative lower-bound estimates. As the supply curve becomes more elastic, the bias decreases, ceteris paribus. Supply of drugs are likely to be relatively price elastic since the marginal cost of actual production is a small component of the observed street price; most of the money price reflects enforcement and penalties aimed at sellers.[9] Miron's (2003) detailed analysis indicates that the price of cocaine and heroin are as much as four times and 19 times larger, respectively, compared to a legal market. Even if simultaneity bias is mitigated, there may still be policy endogeneity wherein drug policy, which in turn affects drug prices, is itself a function of drug use. First-differenced instrumental variables models are estimated, which account for both simultaneity and policy endogeneity.

4. Empirical framework

The objective of this study is to assess the extent to which outcomes related to cocaine and heroin consumption respond to cocaine and heroin prices. Since illicit drugs are ultimately consumer goods, this question can be framed within the context of consumer theory. Maximizing a utility function in every period subject to a basic budget constraint yields the following demand

[8] A report by the National Research Council (Manski et al., 2001) and Horowitz (2001) note that because purchases in STRIDE are motivated by criminal investigations, they do not represent a random sample of drug prices in the U.S. Nonetheless, as long as the sampling limitations are stable over time, these data can still accurately capture changes in the cost of drugs. Also see Caulkins (2001a) for a discussion of the utility in using STRIDE.

[9] The observed drug price consists of the marginal cost of production plus expected penalties for suppliers. The supply-money price elasticity can be shown to equal the elasticity of supply with respect to the marginal production cost times the ratio of the full price to the marginal production cost.

function[10]:

$$D_{1t} = \alpha_1 P_{1t} + \alpha_2 P_{2t} + \delta_1 S_{1t} + \delta_2 S_{2t} + \beta_1 I_t + \beta_2 Y_t + \varepsilon_t \quad (3)$$

Eq. (3) states that the demand for any illicit drug (D_1) depends on its own price (P_1), the price of the other drug (P_2), the addictive stocks of the own drug and the other drug (S_1 and S_2), income (I), and other characteristics (Y) such as the individual's age, gender, race, and education. The parameter of interest, α_1, is hypothesized to be negative under the law of the downward sloping demand function. The cross-price effect α_2 is positive if the two drugs are economic substitutes, negative if they are economic complements, and zero if independent. The parameter δ_1 is hypothesized to be greater than zero due to the positive reinforcement of past addictive consumption on current consumption. This intertemporal complementarity between past and current consumption is the hallmark of economic models of addiction. The cross-reinforcement effect δ_2 may be zero or positive. Since the accumulated addictive stocks of each drug are unobserved, they can be proxied by past consumption, which in turn can be proxied by the past prices of drugs.

The set of outcomes employed from DAWN is the number of times cocaine and heroin are cited in drug-related ED episodes, divided by total MSA population. DAWN does not sample all eligible hospitals. Ideally, the probability of having a cocaine or heroin induced ED episode should be measured relative to the "potential" population, that is individuals living in an area within a sampled MSA that directs medical crises to a participating DAWN ED (Model, 1993). This probability can be written as

$$\text{prob}(\text{mention}|\text{total pop}) = \text{prob}(\text{mention}|\text{potential pop}) \times \text{prob}(\text{potential pop}|\text{total pop}) \quad (4)$$

The probability of a drug mention relative to the appropriate potential population can be further expressed as

$$\begin{aligned}&\text{prob}(\text{mention}|\text{potential pop})\\ &\quad = \text{prob}(\text{report}|\text{potential pop, ED, crisis, use})\\ &\qquad \times \text{prob}(\text{ED}|\text{potential pop, crisis, use}) \times \text{prob}(\text{crisis}|\text{potential pop, use})\\ &\qquad \times \text{prob}(\text{use}|\text{potential pop}) \quad (5)\end{aligned}$$

Substituting (5) into (4) and taking the log of both sides results in

$$\begin{aligned}&\log \text{prob}(\text{mention}|\text{total pop})\\ &\quad = \log \text{prob}(\text{report}|\text{potential pop,ED,crisis,use}) + \log \text{prob}(\text{ED}|\text{potential pop,crisis,use})\end{aligned}$$

[10] The individual's current utility depends on current consumption of the addictive goods (D_1 and D_2), the non-addictive good (X), and also on the stock of the addictive goods (S_1 and S_2) accumulated through past consumption. In addition to positive and diminishing marginal utility in A and X, the utility function also satisfies other restrictions. First is the reinforcement effect, wherein the stocks of addictive consumption positively affect current marginal utility of the addictive goods: $U_{D_i S_i} = \partial_2 U_t / D_{it} S_{it} > 0$, $i = 1, 2$. Second is the tolerance effect, wherein the addictive stocks negatively affect current utility: $U_{S_i} = \partial U_t / \partial S_{it} < 0$, $i = 1, 2$. This can also reflect harmful addiction since past consumption of drugs can lower current utility due to detrimental health effects. There may also be cross-reinforcement effects so that the addictive stock of one drug may affect the current consumption of the other by affecting its current marginal utility: $U_{D_i S_i} = \partial_2 U_t / \partial D_{it} S_{jt} \geq 0$, $i \neq$ j.

$$+\log \text{prob}(\text{crisis}|\text{potential pop,use}) + \log \text{prob}(\text{use}|\text{potential pop})$$
$$+\log \text{prob}(\text{potential pop}|\text{total pop}) \quad (6)$$

This identity stresses that many factors contribute to a DAWN drug mention. First, an individual must be part of the potential population and using drugs. He must then experience some crisis or medical emergency, which results in a visit to a participating ED. Finally, hospital personnel must identify this episode as drug-related. The probability of drug use and the probability of crisis (which are a monotonic function of the intensity or chronicity of use) depend on the demand factors derived earlier in Eq. (3). The probability of being part of the potential population relative to the total population is proxied by the number of hospitals participating in DAWN as a fraction of total eligible hospitals. The conditional probabilities of an ED visit and a drug report are related to emergency room visitation practices and any non-reporting or misreporting by the ED staff. There is no a priori reason to believe that these probabilities have systematically varied over time within cities; thus, they may be modeled as part of the unobserved area and year effects. These substitutions yield the following estimable specification, which can be interpreted as a reduced-form relationship of the demand and cost factors affecting drug-related emergency department visits

$$\log\left(\frac{A_{1it}}{1-A_{1it}}\right) = \alpha_1 P_{1it} + \alpha_2 P_{2it} + \lambda_1 P_{1it-1} + \lambda_2 P_{2it-1} + \beta_1 I_{it} + \beta_2 Y_{it} + \beta_3 R_{it} + \varepsilon_{it}, \quad \text{where } \varepsilon_{it} = \mu_i + \eta_t + \nu_{it} \quad (7)$$

The subscripts denote the *i*th MSA for year *t*. *A* is the probability of a drug episode, and *Y* represents the vector of observable determinants of use, besides price and income, and is proxied by the unemployment rate, various MSA-level socioeconomic characteristics, and drug-related arrest rates. All models also include the log of the hospital response rate, R_{it}. The disturbance is modeled with two-way error components where μ_i denotes the unobservable area fixed effects, η_t denotes the unobservable time fixed effects, and ν_{it} is the remainder stochastic error term. All regressions are estimated in logistic form, where the dependent variable is measured as the log of the odds ratio. Since the original outcomes are rates between zero and one, the logistic transformation ensures that the predicted rate or probability also lies in this range.[11] Estimated standard errors are adjusted for autocorrelation within each city. Under an addiction paradigm, current drug-related outcomes will be a function of contemporaneous and past drug prices. An alternative rationale for (7) is that drug-related health emergencies are produced not just by current use but also by the cumulative effects of past use, which is a function of past prices.

This fixed effects procedure is inconsistent if city drug prices or the policies that determine them might depend on outcomes related to substance use, or as is more likely the lagged drug-related outcomes. This possibility is sometimes referred to as policy endogeneity. There are two critical issues. The first is that there is an unmeasured fixed effect that is correlated with right-hand-side variables. In the context of this research, the fixed effect may be city or state sentiment (e.g., religiosity) towards drug use that also influences drug prices and enforcement. The second issue is that price may be predetermined and not strictly exogenous because past shocks to drug use or drug-related health emergencies may be correlated with current prices. Thus, current price

[11] The elasticity of the probability of a drug-related ED visit with respect to price is calculated as α_1 $(1-A)P$. The marginal effect of price on this probability is α_1 $(1-A)A$.

is predetermined in that it is correlated with all past disturbances

$$E(P_{it}\,\nu_{is}) \neq 0 \quad \text{for} \quad s < t \quad \text{and} \quad E(P_{it}\nu_{is}) = 0 \quad \text{for} \quad s = t \tag{8}$$

Consider a simple version of (7). For convenience, LO_{it} refers to $\log(A_{it}/1 - A_{it})$ and the year effects are ignored. The area fixed effects can be removed by first differencing

$$\begin{aligned}\text{LO}_{it} - \text{LO}_{it-1} = {} & \alpha_1(P_{it} - P_{it-1}) + \beta_1(I_{it} - I_{it-1}) + \beta_2(Y_{it} - Y_{it-1}) \\ & + \beta_3(R_{it} - R_{it-1}) + (\nu_{it} - \nu_{it-1})\end{aligned} \tag{9}$$

If price is a predetermined variable then the orthogonality assumption is violated since P_{it} is correlated with ν_{it-1}. The fixed effects or first-differenced specification is no longer consistent.

In order to check for potential policy endogeneity, two informal tests are performed. First, following Model (1993), specifications with a series of lagged and leading prices are estimated. If changes in drug outcomes are caused by changes in enforcement or prices as opposed to changes in prices being caused by these outcomes, then larger outcomes should not occur until after any decreases in price and vice versa. In specifications with lagged and leading price series, only the coefficients on contemporaneous and lagged prices should be significant. The lead prices should be insignificant. If the leading prices are significant, however, this could be evidence of policy endogeneity.[12]

A second test estimates specifications with various lagged enforcement variables to proxy for past shocks to demand that may also be affecting current prices. Consider the baseline equation again, where the disturbance term ν_{it} is divided into two components ω_{it} and φ_{it}

$$\begin{aligned}\text{LO}_{it} - \text{LO}_{it-1} = {} & \alpha_1(P_{it} - P_{it-1}) + \beta_1(I_{it} - I_{it-1}) + \beta_2(Y_{it} - Y_{it-1}) \\ & + \beta_3(R_{it} - R_{it-1}) + (\omega_{it} - \omega_{it\,-1}) + (\varphi_{it} - \varphi_{it-1})\end{aligned} \tag{9a}$$

Here, φ_{it} is a pure stochastic disturbance term that is uncorrelated with all past, current, and future values of the explanatory variables. However, ω_{it} represents unobserved shocks to past use that may also affect current prices, making price predetermined and statistically endogenous. This endogeneity is similar to omitted variables bias in an intertemporal context. Conditional on ω, price is strictly exogenous with respect to the remainder disturbance term. Therefore, if variables measuring such shocks can be included in the models, then the coefficients on price can be analyzed to gauge the extent of such endogeneity. Past enforcement efforts may proxy for these shocks to some extent. For instance, higher arrest rates related to drug violations or sales may affect current drug consumption and also influence future drug prices. If the price effects are robust in specifications that control for these lagged enforcement variables, then it is likely that price is not predetermined.

The possibility that price is not strictly exogenous is also treated explicitly by applying the Arellano–Bond estimator. Arellano and Bond (1991) show that the orthogonality conditions in a dynamic panel data model can be exploited to obtain valid instruments for $(P_{it} - P_{it-1})$. If price is predetermined, all lagged levels (P_{it-1} and older) can be used to instrument for the difference

[12] Significant lead prices may also be construed as evidence of rational addiction (Becker and Murphy, 1988). However in the present context, it is unlikely that users are able to forecast drug prices far in advance, as much as 1 year. See Gruber and Köszegi (2001).

as long as the ν_{it} are not serially correlated.[13] If the drug price is not just predetermined but also purely endogenous (for instance due to simultaneity between supply and demand) such that $E(P_{it}\nu_{is}) \neq 0$ for $s \leq t$, then the orthogonality conditions allow levels of drug prices lagged two or more periods to serve as instruments. Levels of the other exogenous variables in the model can also enter the instrumental matrix.

The elasticity of drug mentions with respect to drug use is unambiguously positive, since the negative health consequences of addictive consumption are well documented.[14] Also, by definition, the majority of the ED episodes and mentions in the DAWN sample are causally related to dependent drug use. Thus, the sign and significance of the estimated elasticity of a drug mention with respect to price informs on the unobserved price elasticity of problematic drug use. The price elasticity of drug episodes and mentions is also relevant because it measures the direct "reduced-form" effect of drug prices, an instrument of enforcement and public policy, on health.

5. Results

Before turning to the results, Fig. 1 visually depicts the strong negative relationship between drug-related ED episodes and drug prices. The series reveal that total ED drug episodes increased by about 55% from 1990 to 2002 as the prices of cocaine and heroin declined.[15] The sharpest increase occurred in heroin mentions, by over 160%, which coincides with the steepest drop in heroin price of around 72%. Cocaine price declined by about 42% over this period, coinciding with a 72% increase in cocaine-related ED mentions. This is only suggestive since these figures do not control for time trends or other confounders. The multivariate models address this possibility.

Table 2 presents estimation of Eq. (7) excluding the lagged and cross-prices. All specifications include the drug price, MSA-level socioeconomic covariates, the DAWN response rate, the drug possession arrest rate, year effects, and then progressively add MSA effects and MSA-specific linear trends. Cocaine price is negative and statistically significant in all specifications, and the elasticity of the probability of a cocaine mention with respect to own price ranges from −0.20 to −0.41. Specification 2, which includes both year and MSA effects, yields a price elasticity of −0.32. The next specification adds indicators of an MSA-specific linear trend, where only deviations around a linear trend, within each city, are used for identification. The price effect remains marginally significant, and the elasticity decreases in value to −0.20. The addition of MSA-specific linear trends causes the MSA-level covariates to lose joint significance. These covariates may already be controlling for trends within MSA's to a large extent. The largest gain in adjusted R^2 results from the addition of MSA effects; including MSA-linear trends raises the adjusted R^2 by a relatively small amount. In subsequent analyses, fixed effects specifications without city-specific trends are emphasized. The estimated price elasticity of heroin mentions is

[13] If the ν_{it} are not serially correlated, there is still first-order autocorrelation between the first-differenced errors. Thus, a test of no autocorrelation in ν_{it} translates to testing whether there is second-order or higher degree autocorrelation in the differenced errors. These tests are presented in the results (Baltagi, 2002).

[14] See *The Economic Costs of Alcohol and Drug Abuse in the United States 1992* (Harwood et al., 1992).

[15] The decline in the real cocaine price has been attributed to the development of a production sector and the learning-by-doing that followed the reintroduction of cocaine into the U.S. market in the 1970s after prolonged absence. There was also vertical integration in the chain of distribution, which reduced the costs of retailing and wholesaling. Costs also declined from a shift to low-cost labor as unemployed residents of urban ghettos replaced the professionals who dealt drugs during the 1970s and 1980s. See Grossman et al. (1998, 2002). Heroin prices declined due to a shift in the heroin marketplace in the U.S. as drug cartels in Mexico and Colombia began to eclipse the southeast Asian suppliers. Most of the heroin now entering the U.S. originates from these two countries.

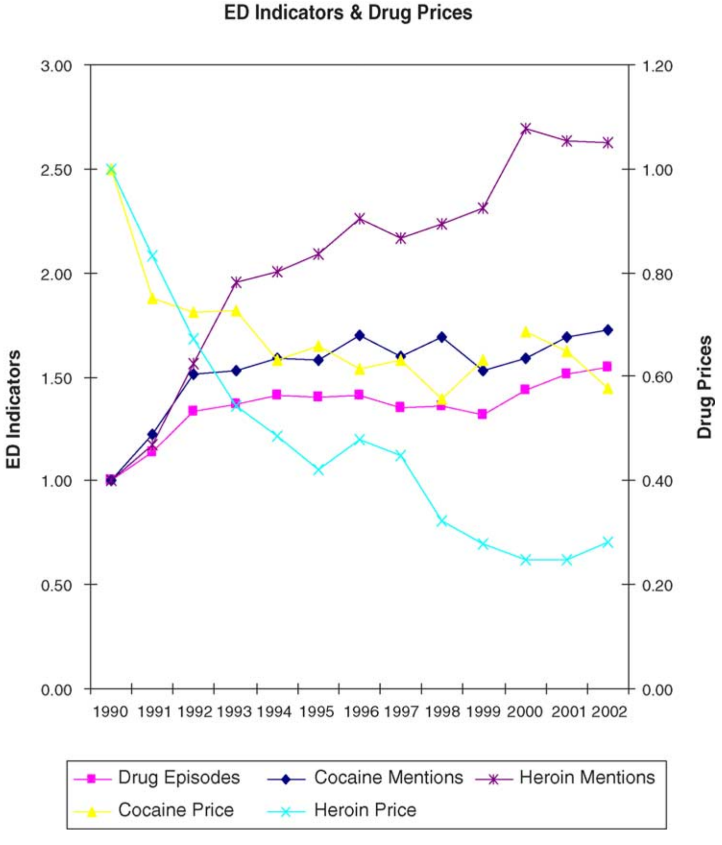

Fig. 1. ED indicators and drug prices. *Note:* Underlying values are based on population-weighted means. All values are normalized to 1990 levels.

estimated at −0.12 in the fixed effects model. The sign of the sample response rate in DAWN is positive, as expected from Eq. (6).

The estimates in Table 2 are based on all hospital ED admissions where cocaine or heroin is mentioned. DAWN provides the reasons for the ED admission from 1995 onwards, including drug overdose, chronic effects, withdrawal, seeking detoxification, accidental injury, unexpected reaction, or other. Models were also estimated for alternative measures of dependent use that included only those admissions resulting form drug overdose, chronic effects, withdrawal, or detoxification, which make up the vast majority of admissions. The elasticities for cocaine and heroin mentions were somewhat smaller in magnitude, by about 30–50%, but still remain statistically significant at conventional levels. The smaller elasticities do not qualitatively affect the conclusions and are expected if these alternative measures are capturing the heaviest of the heavy users. Subsequent analyses are based on all ED admissions in order to maximize the sample period and precision. In addition, there may be greater errors in classification over time due to differential administrative and reporting policies. Focusing on all drug-related ED admissions also underscores the fact that these individuals' drug use has resulted in a hospital ED admission, which by definition makes the drug use more serious regardless of cause.

Table 2
Cocaine and heroin mentions: baseline models

Dependent variable	log odds cocaine mentions			log odds heroin mentions		
Specification	1	2	3	1	2	3
Own price	−0.00513** (0.0026), $\varepsilon = -0.407$	−0.00398** (0.0017), $\varepsilon = -0.320$	−0.00247* (0.0016), $\varepsilon = -0.198$	−0.00074** (0.0003), $\varepsilon = -0.313$	−0.00027** (0.0002), $\varepsilon = -0.115$	−0.00011 (0.0001)
Personal Income	0.06697 (0.0411)			0.16451** (0.0745)		
Unemployment	3.56396 (2.5276)			12.17676*** (4.0358)		
Male	2.53753 (3.0867)			10.74876** (4.6255)		
Black	4.00984*** (1.0921)			2.25873* (1.2975)		
Other	2.37712 (1.8089)			6.15829** (2.3488)		
Hispanic	−1.93802 (1.1598)	Yes**	Yes	−2.52806* (1.2900)	Yes**	Yes
Age 16–24	−8.41799*** (2.3412)			−11.95997*** (3.4645)		
Age 25–54	−3.67671* (2.0033)			−9.96767** (3.6032)		
High school graduate	−1.55271 (2.2835)			0.84417 (3.3771)		
College graduate	−2.42837 (2.7653)			−3.40195 (3.7541)		
log response rate	0.46621 (0.5438)			1.15312* (0.6277)		
Drug possession arrest rate	−8.41054 (60.3450)	−28.2408 (32.2418)	−8.6202 (22.5635)	85.26097 (78.5505)	1.2135 (27.8102)	−40.7445 (24.4650)
Year effects	Yes*	Yes***	Yes***	Yes**	Yes*	Yes**
MSA effects	No	Yes***	Yes***	No	Yes***	Yes***
MSA-linear trend	No	No	Yes***	No	No	Yes***
R^2	0.587	0.911	0.954	0.639	0.945	0.971
Observations	257	257	257	250	250	250

Notes: Dependent variable is $\log(A/1-A)$ where A is the total number of cocaine or heroin mentions in each MSA divided by population. Standard errors are adjusted for MSA-specific serial correlation and are reported in parentheses. Elasticities are reported where the own-price coefficient is significant at 10% or less in a one-tailed test.

* Significant at 10%.

** Significant at 5%.

*** Significant at 1%.

Similar to self-reports, but for different reasons, there may also be underreporting in the DAWN data. Several states have adopted statutes that allow health insurers to legally deny coverage for an injury caused by alcohol or illicit drug use. Hospital administrators in such states may have an incentive to not report the ED admission as drug-related for reimbursement purposes. Rivara et al. (2000) conducted a survey of insurance commissioners in the 50 states plus D.C. to determine the prevalence of such statutes. Of the 18 states represented in DAWN, 12 states plus D.C. had such exclusions, two states allowed such exclusions with certain additional restrictions, and three states did not have any such statutes. Restricting the sample to the 13 states with strong statutes or the 15 states with any statute does not substantially affect the magnitudes or significance of the elasticity estimates. Pooled models with an interaction between the drug price and a dichotomous indicator for a strong statute or any statute were also estimated. The interaction term was insignificant in all such models. This suggests that while there may be underreporting in DAWN, the underreporting does not appear to systematically vary over time across states in a way that is correlated with drug prices. This is not the case in survey-based data, where the underreporting is positively correlated with intensity of use and negatively correlated with price leading to biased estimates of the elasticity (Dave, 2004).

Table 3 expands the baseline model by including the contemporaneous and 1- and 2-year lagged prices. The current prices are negative and significant for both cocaine and heroin in the fixed effects specifications. Adding these lagged prices does not substantially reduce the magnitude of the current price elasticity for either drug. The cocaine elasticity is very similar to those from the baseline models, and ranges from −0.21 to −0.29. The 1-year lagged cocaine price elasticity is −0.28, not much weaker than the effect of contemporaneous price. The coefficients of the contemporaneous and lagged prices can be used to calculate the long-run price elasticity of the probability of a cocaine mention, which measures the full current and future effects of a change in current price. It is about twice the magnitude of the short-run elasticity, and is estimated at −0.54. The contemporaneous heroin price elasticity ranges from −0.11 to −0.15. The range is tighter than before since the upper bound estimates obtained from the year-effects models are more in line with the other specifications. Thus, adding lagged prices makes some difference when MSA indicators are not present to capture some of their effect. The 1-year lagged price elasticity is about −0.09, and the 2-year lagged price elasticity is −0.12. The effects of past heroin prices on the current likelihood of a heroin related ED visit are also relatively substantial and of a similar magnitude to the effect of current price. The long-run elasticity is −0.29. Negative and significant lagged price effects are consistent with the addictive properties of cocaine and heroin and the ensuing positive intertemporal reinforcement effect. Since the dependent variable is a proxy for health, it is also consistent with the addictive substance having cumulative detrimental effects on health.

Specifications 4 and 5 in Table 3 provide a check for policy endogeneity. These models are similar to those discussed above except that they add 1-year leading prices in addition to the current and lagged prices. Significantly negative lead price-effects may indirectly inform on the presence of policy endogeneity. All specifications include the 1-year lagged and leading own prices.[16] The evidence does not point to the presence of policy endogeneity. The contemporaneous and long-run price elasticities remain relatively robust to the inclusion of the leads, and current cocaine or heroin related ED episodes do not seem to be affected by future prices.

Table 4 presents specifications that include lagged enforcement variables in order to control for any unobserved shocks to past drug-related outcomes and current prices. One set of lagged

[16] Other leading and lagging structures yielded similar results.

Table 3
Cocaine and heroin mentions: lagged and leading prices

Specification	1	2	3	4	5
log odds cocaine mentions					
Own price	−0.00236* (0.0017), $\varepsilon = -0.212$	−0.00334*** (0.0013), $\varepsilon = -0.268$	−0.00300** (0.0016), $\varepsilon = -0.242$	−0.00346*** (0.0013), $\varepsilon = -0.278$	−0.00333** (0.0014), $\varepsilon = -0.268$
1 Year lagged own price	−0.00368* (0.0022), $\varepsilon = -0.301$	−0.00337** (0.0015), $\varepsilon = -0.276$	−0.00281* (0.0017), $\varepsilon = -0.230$	−0.00317** (0.0016), $\varepsilon = -0.260$	−0.00303** (0.0015), $\varepsilon = -0.248$
2 Year lagged own price	−0.00061 (0.0018)	−0.00069 (0.0011)	−0.00099 (0.0009)	–	−0.00074 (0.0011)
1 Year leading own price	–	–	–	−0.00138 (0.0011)	−0.00143 (0.0371)
Long run elasticity	$\varepsilon = -0.507$	$\varepsilon = -0.539$	$\varepsilon = -0.467$	$\varepsilon = -0.533$	$\varepsilon = -0.512$
MSA covariates	Yes***	Yes***	Yes***	Yes	Yes**
Year effects	Yes***	Yes***	Yes***	Yes	Yes***
MSA effects	No	Yes***	Yes***	Yes	Yes***
MSA-linear trend	No	No	Yes***	No	No
R^2	0.579	0.914	0.956	0.952	0.914
Observations	255	255	255	243	254
log odds heroin mentions					
Own price	−0.00035** (0.0002), $\varepsilon = -0.152$	−0.00025* (0.0002), $\varepsilon = -0.107$	−0.00011 (0.0001)	−0.00031** (0.0001), $\varepsilon = -0.133$	−0.00024** (0.0001), $\varepsilon = -0.103$
1 Year lagged Own Price	−0.00048*** (0.0001), $\varepsilon = -0.222$	−0.00020** (0.0001), $\varepsilon = -0.093$	−0.00006 (0.0001)	−0.00015* (0.0001), $\varepsilon = -0.70$	−0.00019** (0.0001), $\varepsilon = -0.088$
2 Year lagged own price	−0.00061*** (0.0001), $\varepsilon = -0.319$	−0.00023*** (0.0001), $\varepsilon = -0.121$	−0.00010* (0.0001), $\varepsilon = -0.048$	–	−0.00023*** (0.0001), $\varepsilon = -0.120$
1 Year leading own price	–	–	–	−0.00016 (0.0002)	−0.00021 (0.0002)
Long run elasticity	$\varepsilon = -0.619$	$\varepsilon = -0.293$	$\varepsilon = -0.048$	$\varepsilon = -0.198$	$\varepsilon = -0.283$
MSA covariates	Yes***	Yes***	Yes	Yes**	Yes***
Year effects	Yes	Yes*	Yes***	Yes**	Yes**
MSA effects	No	Yes***	Yes***	Yes***	Yes***
MSA-linear trend	No	No	Yes***	No	Yes
R^2	0.693	0.952	0.975	0.952	0.956
Observations	243	243	243	242	239

Notes: Dependent variable is $\log(A/1-A)$ where A is the total number of cocaine or heroin mentions in each MSA divided by population. Own price refers to cocaine price in the logistic cocaine mention models, and heroin price in the logistic heroin mention models. Standard errors are adjusted for MSA-specific serial correlation and are reported in parentheses. MSA socioeconomic covariates include: personal income, unemployment, male, black, other, Hispanic, age 16–24, age 25–54, high school graduate, college graduate, log response rate, and arrest rate for drug possession. Elasticities are reported where the own-price coefficient is significant at 10% or less in a one-tailed test.

* Significant at 10%.

** Significant at 5%.

*** Significant at 1%.

Table 4
Cocaine and heroin mentions: lagged enforcement measures

Specification	1	2	3	4	5
log odds cocaine mentions					
Cocaine price	−0.00398** (0.0017), ε = −0.316	−0.00333** (0.0015), ε = −0.265	−0.00330** (0.0014), ε = −0.262	−0.00333** (0.0014), ε = −0.265	−0.00312** (0.0014), ε = −0.248
MSA covariates	Yes***	Yes	Yes	Yes**	Yes
Lagged drug enforcement	No	Group 1	Group 2*	Group3	Group 4***
Year effects	Yes***	Yes***	Yes***	Yes***	Yes***
MSA effects	Yes***	Yes***	Yes***	Yes***	Yes***
R^2	0.911	0.920	0.921	0.920	0.923
Observations	257	256	256	256	255
log odds heroin mentions					
Heroin price	−0.00027** (0.0002), ε = −0.114	−0.00020* (0.0001), ε = −0.084	−0.00019* (0.0001), ε = −0.080	−0.00020* (0.0001), ε = −0.084	−0.00019* (0.0001), ε = −0.080
MSA covariates	Yes***	Yes***	Yes***	Yes***	Yes***
Lagged drug enforcement	No	Group 1**	Group 2***	Group3*	Group 4**
Year effects	Yes*	Yes***	Yes***	Yes***	Yes***
MSA effects	Yes***	Yes***	Yes***	Yes***	Yes***
R^2	0.945	0.950	0.951	0.950	0.952
Observations	250	249	249	249	248

Notes: Dependent variable is $\log(A/1-A)$ where A is the total number of cocaine or heroin mentions in each MSA divided by population. Standard errors are adjusted for MSA-specific serial correlation and are reported in parentheses. MSA covariates include: personal income, unemployment, male, black, other, Hispanic, age 16–24, age 25–54, high school graduate, college graduate, log response rate, and arrest rate for drug possession. Elasticities are reported where the own-price coefficient is significant at 10% or less in a one-tailed test. Group 1 enforcement variables are: lagged 1 year drug violation arrest rate and drug sale arrest rate. Group 2 enforcement variables are: lagged 1 year drug violation arrest rate and cocaine/heroin sale arrest rate. Group 3 enforcement variables are: lagged 1 year drug violation arrest rate and marijuana sale arrest rate. Group 4 enforcement variables are: one and 2 year lagged drug violation arrest rate and cocaine/heroin sale arrest rate.

* Significant at 10%.
** Significant at 5%.
*** Significant at 1%.

enforcement variables includes 1-year lags of the arrest rate for any drug violation and the arrest rate for selling or trafficking in any drugs. The second set includes 1-year lags of the arrest rate for any drug violation and the arrest rate for selling cocaine and opiates. The third set includes 1-year lags of the arrest rate for any drug violation and the arrest rate for selling marijuana. The final set includes both 1- and 2-year lags of the arrest rate for any drug violation and the arrest rate for selling or trafficking in any drugs.

The top panel of Table 4 presents these results for cocaine mentions. The lagged enforcement variables as a group are generally significant. The cocaine price elasticity is significantly negative in all specifications and is robust to the inclusion of the lagged arrest rates. It decreases only marginally and ranges from −0.25 to −0.27. The bottom panel presents the same models for heroin mentions. Heroin price is negative and significant in all specifications, as are the lagged enforcement variables. The price elasticity diminishes slightly in magnitude to −0.08. Overall, the elasticity for the probability of a cocaine or heroin related ED episode with respect to own-price is not sensitive to the addition of lagged arrest rates, which may be capturing to some extent unobserved shocks that cause policy endogeneity.

All of the models presented thus far have included only the relevant drug's own price. Table 5 estimates the full cross-price model derived in Eq. (7). In specifications 1 and 2, the dependent variable measures the log of the odds ratio of the probability of any drug-related ED episode. Since drug-related emergency room visits can be induced by one or more illicit drugs, it is appropriate to include the price of both cocaine and heroin in these specifications. Cocaine is the most frequently mentioned illicit substance, present in about 40% of ED episodes for 2002. Heroin is the third most frequently cited, after marijuana, mentioned in about 22% of the ED episodes. Specification 1 includes only contemporaneous cocaine and heroin prices, and specification 2 includes current and 1-year lags of both drug prices. Current cocaine price is significantly negative, and the elasticity of the probability of a drug-related episode with respect to current cocaine price ranges from −0.17 to −0.20. The corresponding elasticity for heroin is much lower at around −0.03. The 1-year lagged cocaine price is also significantly negative, with an elasticity of −0.12. The elasticity with respect to the 1-year lagged heroin price is imprecisely estimated. Overall, increases in the price of both drugs reduce the likelihood of a drug-related health emergency, as proxied by an ED visit. The cocaine price elasticities are generally larger in magnitude than the heroin price elasticities; this may be due to the fact that cocaine is the most frequently cited in all drug-related episodes. Hence, the cocaine price would be expected to have a stronger effect. These results suggest that the negative health effects of cocaine and heroin use are positively related to current consumption and also positively related to the accumulated addictive stock.

Specifications 3 and 4 show the results for cocaine mentions. The current cocaine price is significant and negative, and estimates of the current own-price elasticity lie between −0.25 and −0.31. The corresponding lagged own-price elasticity is estimated at around −0.26. These magnitudes are very similar to those estimated from models that exclude the cross prices. The current heroin price is negative but insignificant.

Specifications 5 and 6 present these cross-price models for the probability of a heroin mention. The current own-price elasticity is negative and significant, and is estimated between −0.10 and −0.12. The current price of cocaine is also significant and negative. Its corresponding elasticity lies between −0.28 and −0.36. The relatively large magnitude of this elasticity may have to do with the fact that an ED drug episode can involve multiple mentions. Since more heroin users are polydrug users, the likelihood for multiple mentions is stronger for a heroin-related episode. For instance, data on arrestees, who are likely to be hardcore users, show that 69% of all heroin users also use cocaine, compared to only 15% of all cocaine users who use heroin. A larger cross-price

Table 5
Drug episodes, cocaine mentions, heroin mentions: cross-price effects

Dependent variable	log odds drug episodes		log odds cocaine mentions		log odds heroin mentions	
Specification	1	2	3	4	5	6
Cocaine price	−0.00248*** (0.0009), $\varepsilon = -0.196$	−0.00217*** (0.0006), $\varepsilon = -0.172$	−0.00389** (0.0019), $\varepsilon = 0.309$	−0.00316** (0.0013), $\varepsilon = 0.251$	−0.00454*** (0.0015), $\varepsilon = 0.360$	−0.00356*** (0.0011), $\varepsilon = 0.283$
Heroin price	−0.00006* (0.00003), $\varepsilon = -0.025$	−0.00008*** (0.00003), $\varepsilon = -0.034$	−0.00003 (0.0001)	−0.00007 (0.0001)	−0.00024** (0.0002), $\varepsilon = -0.101$	−0.00029** (0.0002), $\varepsilon = 0.122$
1 Year lagged cocaine price	–	−0.00154** (0.0009), $\varepsilon = -0.124$	–	−0.00326** (0.0017), $\varepsilon = -0.263$	–	0.00214 (0.0014)
1 Year lagged heroin price	–	−0.00003 (0.00004)	–	−0.00006 (0.0001)	–	−.00014 (0.0001)
MSA covariates	Yes	Yes	Yes**	Yes**	Yes**	Yes**
Year EFFECTS	Yes**	Yes**	Yes***	Yes***	Yes*	Yes**
MSA effects	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***
R^2	0.888	0.896	0.912	0.921	0.947	0.951
Observations	249	244	249	244	249	244

Notes: Dependent variable is log ($A/1 - A$) where A is the total number of drug-related ED episodes, cocaine mentions, or heroin mentions in each MSA divided by population. Standard errors are adjusted for MSA-specific serial correlation and are reported in parentheses. MSA covariates include: personal income, unemployment, male, black, other, Hispanic, age 16–24, age 25–54, high school graduate, college graduate, log response rate, and the drug possession arrest rate. Elasticities are reported where the price coefficient is significant at 10% or less in a one-tailed test.

* Significant at 10%.

** Significant at 5%.

*** Significant at 1%.

Table 6
Cocaine and heroin mentions: Arellano–Bond estimator

Specification	1	2	3	4	5	6
log odds cocaine mentions						
Own drug price	−0.00288** (0.0017), $\varepsilon = -0.229$	−0.00344** (0.0018), $\varepsilon = -0.273$	−0.00291** (0.0013), $\varepsilon = -0.231$	−0.00303** (0.0012), $\varepsilon = -0.240$	−0.00275** (0.0013), $\varepsilon = -0.218$	−0.00314*** (0.0011), $\varepsilon = -0.249$
1 Year lagged own price	–	–	−0.00293** (0.0016)	−0.00264* (0.0017)	−0.00274** (0.0015)	−0.00250* (0.0016)
2 Year lagged own price	–	–	–	–	−0.00034 (0.0010)	−0.00016 (0.0009)
Long run elasticity	–	–	$\varepsilon = -0.463$	$\varepsilon = -0.450$	$\varepsilon = -0.436$	$\varepsilon = -0.447$
AR(1)	0.096	0.079	0.106	0.140	0.155	0.173
AR(2)	0.335	0.426	0.102	0.117	0.099	0.097
Contemporaneous price treatment	Predetermined	Endogenous	Predetermined	Endogenous	Predetermined	Endogenous
log odds heroin mentions						
Own drug price	−0.00018** (0.0001), $\varepsilon = -0.076$	−0.00025** (0.0001), $\varepsilon = -0.105$	−0.00027*** (0.0001), $\varepsilon = -0.114$	−0.00028** (0.0001), $\varepsilon = -0.118$	−0.00019** (0.0001), $\varepsilon = -0.080$	−0.00020* (0.0001), $\varepsilon = -0.084$
1 Year lagged own drug price	–	–	−0.00016** (0.0001)	−0.00014** (0.0001)	−0.00023*** (0.0001)	−0.00019** (0.0001)
2 Year lagged own drug price	–	–	–	–	−0.00039*** (0.0001)	−0.00035*** (0.0001)
Long run elasticity	–	–	$\varepsilon = -0.181$	$\varepsilon = -0.177$	$\varepsilon = -0.341$	$\varepsilon = -0.312$
AR(1)	0.035	0.023	0.007	0.007	0.007	0.006
AR(2)	0.911	0.949	0.574	0.598	0.415	0.545
Contemporaneous price treatment	Predetermined	Endogenous	Predetermined	Endogenous	Predetermined	Endogenous

Notes: Dependent variable is $\log(A/1 - A)$ where A is the total number of cocaine or heroin mentions in each MSA divided by population. Own price refers to cocaine price in the logistic cocaine mention models, and heroin price in the logistic heroin mention models. Standard errors are adjusted for MSA-specific serial correlation and are reported in parentheses. MSA socioeconomic covariates include: personal income, unemployment, male, black, other, Hispanic, age 16–24, age 25–54, high school graduate, college graduate, log response rate, and arrest rate for drug possession. Elasticities are reported where the own-price coefficient is significant at 10% or less in a one-tailed test. In all models, lagged drug prices are tsreated as predetermined.

* Significant at 10%.
** Significant at 5%.
*** Significant at 1%.

elasticity of cocaine price with respect to a heroin mention may just be reflecting a larger own-price elasticity of cocaine price with respect to a cocaine mention for those heroin mentions that also involve cocaine. The lagged prices are insignificant. While the negative sign suggests that cocaine and heroin are complements, caution must be exercised in such an interpretation. Since up to four drugs can be mentioned for any given ED drug episode, a cocaine mention does not indicate that only cocaine was used. In fact, for the year 2002 only 28% of cocaine mentions involved solely cocaine.[17] Nevertheless, these cross-price elasticities do not contradict prior studies, which also suggest a complementary relationship between these two drugs (Saffer and Chaloupka, 1999; Dave, 2004).

The models with leading prices and lagged enforcement rates did not substantially alter the estimates of the price elasticity, suggesting that the results are robust to policy endogeneity. Table 6 directly accounts for the possibility that drug prices may be predetermined or structurally endogenous by applying the Arellano-Bond estimator. The top panel presents the results for cocaine use. Specifications 1, 3, and 5 treat the current drug price as predetermined, where it is correlated with all past disturbances due to policy endogeneity. Specifications 2, 4, and 6 treat the current price as endogenous, where it is also correlated with the current disturbance due to simultaneity between supply and demand. Alternative specifications add lagged price effects. The contemporaneous cocaine price elasticity is only slightly diminished in magnitude, ranging from −0.22 to −0.27. As before, the long-run elasticity is about twice this magnitude. The bottom panel presents similar estimation for heroin mentions. The short-run heroin price elasticity is estimated to be between −0.08 and −0.12, and the long-run elasticity is between −0.31 and −0.34.

Treating the cocaine and heroin prices as predetermined or endogenous and instrumenting for them does not substantially alter the results. It should also be noted that there is no evidence of autocorrelation in any of the models; no autocorrelation in non-differenced errors is equivalent to no autocorrelation beyond the first order in first-differenced errors. This is a necessary condition for the validity of past levels as instruments for current differences in the A–B procedure. As such, the instrumental set "passes" the test of overidentifying restrictions in all cases. If policy endogeneity is interpreted as an intertemporal omitted variables bias, then it will lead to impure serial correlation in the disturbance term. The lack of serial correlation suggests that policy endogeneity is not likely. This is consistent with the inferences drawn from the prior checks for such specification bias.

6. Conclusions

The persons sampled in DAWN constitute an important subgroup of hardcore drug users, which is often not captured by national surveys. Since these persons are more likely to be serious users, impose the heaviest costs on society, and are the targets of much illegal drug policy, studying outcomes related to their addictive consumption behavior is important from a public policy stance. Results indicate that the elasticity of the probability of a cocaine mention with respect to own price is about −0.27, and the own-price elasticity of the probability of a heroin mention is about −0.10. These elasticities are robust to various specification checks and controls for unobservables and endogeneity.

[17] From 1995 onwards, DAWN disaggregates the cocaine and heroin mentions into single drug mentions and multiple drug mentions. Cross-price effects are theoretically better estimated with the single drug mentions. In models, which employed admissions where only cocaine and only heroin are mentioned, the own-price effects are not substantially different. The cross-price effects however are imprecise.

Serious drug-related health problems as proxied by ED visits are more likely correlated with hardcore or heavy drug use than with casual use. The Drug Use Forecasting (DUF) system, maintained by the National Institute of Justice, samples and administers urine tests to arrestees in major metropolitan areas in the U.S. This subpopulation, representative of all arrestees, characterizes heavy, hardcore drug users (Dave, 2004). Using an overlapping sample of 16 cities from 1990 through 2000, the structural elasticity of the probability of drug-related ED visits with respect to the probability of drug use for heavy users can be estimated: 1.39 for cocaine and 0.91 for heroin.[18] The price elasticity of heavy or hardcore drug use can then be imputed by dividing the DAWN elasticities from this study by the above structural elasticities. This yields a cocaine use elasticity of about −0.20 and a heroin use elasticity of −0.11. These estimates are consistent with Dave (2004), which used objective drug use indicators based on urinalysis from the Drug Use Forecasting system to estimate cocaine and heroin participation elasticities for hardcore users of −0.23 and −0.08, respectively.

The analyses from DAWN indicate that drug prices directly affect the “bottom line”, that is higher prices improve health outcomes. The contemporaneous elasticity understates the full effect by a magnitude of about one-half. In a fixed population, the elasticity estimates from this study imply that a 10% increase in the current price of cocaine will prevent about 4687 cocaine-related ED visits nationwide this year and an additional 4739 ED visits in the future. A corresponding increase in heroin price will prevent about 1014 heroin-related ED visits nationwide this year and an additional 1763 ED visits subsequently.[19] Hospital and ambulatory costs attributed to drug abuse were estimated at $1.04 billion for 2000 (ONDCP, 2001). About 45% of all hospital emergency department drug-related episodes involved cocaine or heroin in 2000.[20] Applying this proxy share, cocaine and heroin-related hospital and ambulatory costs are approximately $466 million or higher. A 10% increase in cocaine and heroin price will prevent about 10,723 cocaine and heroin-related hospital emergency room episodes, which translates into direct hospital cost savings of $21.1 million.[21] On the other extreme, if one assumes that cocaine and heroin are responsible for all of the hospital costs, the savings amount to $47.1 million. Since studies (Kuziemko and Levitt, 2004; Grossman and Chaloupka, 1998) have shown that drug prices are positively related to enforcement efforts, they represent a tool by which the public sector can exercise control over the market for illicit, addictive, unhealthy substances and related outcomes. However, solely based on hospital cost savings, the enforcement resources necessary to drive a 10% increase in cocaine and heroin prices are most likely not cost-effective.[22] Even if other costs of drug abuse are brought into play, it is not readily apparent that further enforcement and interdiction driven increases in drug prices are necessarily cost-effective (see Dave, 2004). While the share of law enforcement has risen from 36 to 53% over the past 15 years, resources aimed at shifting demand, such as treatment and prevention, have remained at about one-third of the drug

[18] While these structural elasticities indicate a strong correlation between heavy drug use and drug-related ED visits, they should be interpreted with care since they do not account for the level or intensity of consumption.

[19] These estimates are based on the elasticity estimates in Table 3 and nationwide drug related ED visits in 2000. If the cross-price effects are negative, then more drug-related ED visits will be prevented.

[20] This is likely an overestimate because episodes may involve multiple drugs. However, cocaine and heroin are also likely to comprise a disproportionately larger component of hospital costs than the other drugs.

[21] This is a net reduction in episodes after accounting for multiple drug mentions. In the drug use forecasting system, about 13.8% of arrestees who use cocaine or heroin consume both drugs.

[22] Estimates suggest that such an increase in drug prices requires an increase in drug control spending of at least $2–$3 billion, to which must be added other external costs of enforcement such as productivity losses from imprisonment and the cost of resources expended by suppliers to evade detection.

control budget. The low magnitudes of the drug outcome-price response suggest that additional increases in the drug control budget should consider a larger role for demand-driven interventions.

Acknowledgements

Funding for this research was provided by a grant from the Robert Wood Johnson Foundation's Substance Abuse Research Program to the National Opinion Research Center, University of Chicago. I would like to thank Michael Grossman, Gary Becker, Erdal Tekin, and two anonymous referees for valuable comments and suggestions. I am indebted to Judy Ball and the Substance Abuse and Mental Health Services Administration for providing the DAWN data. I am very grateful to the John M. Olin Foundation for providing post-doctoral research support at the Wharton School, University of Pennsylvania.

References

Arellano, M., Bond, S., 1991. Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations. Review of Economic Studies 58, 277–297.

Baltagi, B.H., 2002. Econometric Analysis of Panel Data. John Wiley and Sons, New York.

Basov, S., Jacobson, M., Miron, J.A., 2001. Prohibition and the market for illegal drugs: an overview of recent history. World Economics 2 (4), 133–158.

Becker, G.S., Murphy, K.M., 1988. A theory of rational addiction. Journal of Political Economy 96 (4), 675–700.

Bureau of Census website: www.census.gov.

Bureau of Economic Analysis website: www.bea.gov.

Bureau of Labor Statistics website: www.bls.gov.

Caulkins, J.P., 2001a. Should the DEA's STRIDE data be used for economic analyses of markets for illegal drugs: comment. Journal of the American Statistical Association 96, 1263–1264.

Caulkins, J.P., 2001b. Drug prices and emergency department mentions for cocaine and heroin. American Journal of Public Health 91 (9), 1446–1448.

Caulkins, J.P., 1996. Estimating elasticities of demand for cocaine and heroin with duf data, Working Paper (Pittsburgh: Heinz School of Public Policy, Carnegie Mellon University).

Caulkins, J.P., Padman, R., 1993. Quantity discounts and quality premia for illicit drugs. Journal of the American Statistical Association 88, 748–757.

Crane, B.D., Rivolo, A.R., Comfort, G.C., 1997. An Empirical Examination of Counterdrug Interdiction Program Effectiveness. Institute for Defense Analysis, Alexandria, Virginia.

Dave, D., 2004. Illicit drug use among arrestees and drug prices, NBER Working Paper 10648.

Grossman, M., Chaloupka, F.J., 1998. The demand for cocaine by young adults: a rational addiction approach. Journal of Health Economics 17 (4), 427–474.

Grossman, M., Chaloupka, F.J., Shim, K., 2002. Illegal drug use and public policy. Health Affairs 21, 134–144.

Gruber, J., Köszegi, B., 2001. Is addiction rational? Theory and evidence. Quarterly Journal of Economics 116 (4), 1261–1303.

Harwood, H., Fountain D., Livermore, G., 1992. The economic costs of alcohol and drug abuse in the United States (Rockville, MD: National Institutes of Health, 1998).

Horowitz, J.L., 2001. Should the DEA's STRIDE data be used for economic analyses of markets for illegal drugs. Journal of the American Statistical Association 96, 1254–1262.

Hyatt Jr., R.R., Rhodes, W., 1995. The Price and purity of cocaine: the relationship to emergency room visits and death, and to drug use among arrestees. Statistics in Medicine 14, 655–668.

Kessler, R.C., McGonagle, K.A., Zhao, S., Nelson, C.B., Hughes, M., Eshleman, S., Wittchen, H.U., Kendler, K.S., 1994. Lifetime and 12-month prevalence of DSM-III-R psychiatric disorders in the United States: Results from the National Comorbidity Survey. Archives of General Psychiatry 51, 8–19.

Kuziemko, I., Levitt, S., 2004. An empirical analysis of imprisoning drug offenders. Journal of Public Economics 88, 2043–2066.

Manski C.F., Pepper. J.V., Petrie, C.V. (Eds.), 2001. Informing America's policy on illegal drugs: what we do not know keeps hurting us, Committee on Data and Research for Policy on Illegal Drugs, National Research Council (Washington, DC: National Academy Press).

Miron, J., 2003. The effect of drug prohibition on drug prices: evidence from the markets for cocaine and heroin. Review of Economics and Statistics 85 (3), 522–530.

Model, K.E., 1993. The effect of marijuana decriminalization on hospital emergency room drug episodes: 1975–1978. Journal of the American Statistical Association 88 (423), 737–747.

Office of National Drug Control Policy, 2003. Drug policy information clearing house fact sheet (Washington, DC: Office of National Drug Control Policy).

Office of National Drug Control Policy, 2001. The economic costs of drug abuse in the United States: 1992–1998 (Washington, DC: Office of National Drug Control Policy).

Office of National Drug Control Policy, 2001. The National Drug Control Strategy: 2001 Annual Report (Washington, DC: Office of National Drug Control Policy).

Rhodes, W., Hyatt, R., Scheiman, P., 1994. The price of cocaine, heroin, and marijuana, 1981–1983. The Journal of Drug Issues 24, 383–402.

Rhodes, W., Johnston, P., Han, S., McMullen, Q., Hozik, L., 2001. Illicit Drugs: Price Elasticity of Demand and Supply. ABT Associates.

Rivara, F., Tollefson, S., Tesh, E., Gentilello, L., 2000. Screening trauma patients for alcohol problems: are insurance companies barriers? The Journal of Traum: Injury, Infection and Critical Care 48, 115–118.

Saffer, H., Chaloupka, F.J., 1999. The Demand for illicit drugs. Economic Inquiry 37 (3), 401–411.