

# Impacts of federal ephedrine and pseudoephedrine regulations on methamphetamine-related hospital admissions

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Submitted 22 August 2002;  
initial review completed 15 January 2003;  
final version accepted 18 March 2003

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## ABSTRACT

**Aims** To determine whether the federal regulation of ephedrine and pseudoephedrine, precursors used in illicit methamphetamine production, reduced methamphetamine-related acute care hospital admissions.

**Design** ARIMA-intervention time-series analysis.

**Setting** California (1983–2000), Arizona and Nevada (1991–2000), USA.

**Measurements** Monthly counts of methamphetamine-related acute care hospital admissions.

**Interventions** Bulk powder ephedrine and pseudoephedrine: regulated November 1989. Products containing ephedrine as the single active medicinal ingredient: regulated August 1995. Products containing pseudoephedrine: regulated October 1997. Large-scale producers used ephedrine and pseudoephedrine in these forms. Ephedrine combined with other active medicinal ingredients (e.g. various cold medicines), used mainly by small-scale producers: regulated October 1996.

**Findings** In California, the bulk powder regulation stopped a 7-year rise in admissions (1983–89) and reduced them by 35% ( $P < 0.01$ ). The single ingredient ephedrine regulation stopped a 4-year rise (1992–95) in California, Arizona and Nevada, with 48% ( $P < 0.01$ ), 71% ( $P < 0.01$ ) and 52% ( $P < 0.01$ ) reductions, respectively. The pseudoephedrine products regulation stopped a 2-year rise (1996–97) in California, Arizona and Nevada, with 38% ( $P < 0.01$ ), 41% ( $P < 0.05$ ) and 61% ( $P < 0.01$ ) reductions, respectively. Admissions rose at the end of the study period but were still well below peak 1990s levels. The regulation of ephedrine combined with other active medicinal ingredients had no significant impact in any of the three states.

**Conclusions** Regulations targeting precursors used by large-scale producers reduced admissions substantially during the study period. However, the regulation of precursors used primarily by small-scale producers had little, if any, effect.

**KEYWORDS** ARIMA model, ephedrine, hospital admissions, intervention time-series analysis, methamphetamine, precursor regulation, pseudoephedrine.

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## INTRODUCTION

The US federal government has regulated dozens of chemicals used in illicit drug production (Implementation of the Domestic Chemical Diversion Control Act

1995). This policy, deemed effective by the Drug Enforcement Administration (Drug Enforcement Administration 1992; New Challenges Facing the DEA 1995), is a cornerstone of America's war on drugs (Sevick 1993), but its actual impact on drug problems has not been analyzed.

The federal government's most concerted chemical regulatory effort has been directed at methamphetamine (street names include meth, speed and crystal), a highly addictive, widely abused stimulant and the most prevalent controlled substance synthesized illicitly in the United States (Exemption of Chemical Mixtures 1998; Castro *et al.* 2000). Four regulations controlling methamphetamine precursor chemicals have been implemented in the past 12 years. In November 1989, the Chemical Diversion and Trafficking Act regulated ephedrine and pseudoephedrine—the two precursors used most often by illicit methamphetamine producers—in bulk powder form (Records 1989; Haislip 1996). The regulation required distributors of these bulk powder chemicals to register with the Drug Enforcement Administration and keep records of sales and customers. It also empowered the Drug Enforcement Administration to revoke the licenses of distributors that placed public health and safety at risk.

The regulation had a loophole, however—tablets, capsules and other products containing methamphetamine precursors could still be purchased unregulated in mass quantities. In August 1995, the Domestic Chemical Diversion and Control Act addressed this partly by regulating the distribution of products that contained ephedrine as the only active medicinal ingredient (Implementation of the Domestic Chemical Diversion Control Act 1995). In October 1997, the Comprehensive Methamphetamine Control Act regulated products that included pseudoephedrine, regardless of whether the products contained other active medicinal ingredients (Temporary Exemption 1997).

The above three regulations targeted ephedrine and pseudoephedrine in forms used commonly in large-scale clandestine laboratories, the source of most methamphetamine in the United States (Haislip 1996; Drug Enforcement Administration 1999). In October 1996, the Comprehensive Methamphetamine Control Act regulated the distribution of products (e.g. various sinus and cold medicines) that included ephedrine in combination with other active medicinal ingredients (Comprehensive 1996). There is little evidence that these products were used by large-scale producers (Glover & Carter 1996; Office of Advocacy 1997).

This study uses ARIMA (autoregressive-integrated moving average)-intervention time-series analysis (Box & Tiao 1975) to examine the impacts of all four precursor regulations on monthly methamphetamine-related hospital admissions in California (1983–2000), the nation's leading state for methamphetamine production (New Challenges Facing the DEA 1995; Office of the Attorney General 1997). Impacts of the three regulations enacted in the 1990s are also examined in Arizona and Nevada (1991–2000), both of which border

California and have pronounced methamphetamine problems.

## METHODS

Methamphetamine-related acute care hospital admissions were identified using ICD-9-CM codes: 304.4 (amphetamine and other psychostimulant dependence), 305.7 (amphetamine or related acting sympathomimetic abuse), 969.7 (psychostimulant poisoning) and E854.2 (accidental psychostimulant poisoning) (International Classification 1980). ICD-9-CM codes do not distinguish between methamphetamine and other amphetamines, but methamphetamine accounts for the bulk of admissions related to amphetamines (Puder, Kagan & Morgan 1988; Office of Applied Studies 2000).

All diagnostic codes (up to 25) and external cause of injury and poisoning codes (up to five) in the California discharge system were examined (Discharge Data 1997). The Arizona and Nevada discharge systems included five diagnostic codes through 1994 and nine codes thereafter (Magnetic Tape 1997; Nevada 1997). For continuity in measurement in these two systems, five codes were examined through 1994, and the first five were examined thereafter. Two external cause of injury and poisoning codes available in the Arizona discharge system were also examined.

Admissions were compiled into monthly totals. To avoid artificial seasonality, months with fewer than 31 days were adjusted (weighted) to be equivalent to 31 days. This was particularly important for February, as it has only 28–29 days and falls between January and March, both of which have 31 days.

The impacts of all four regulations on admissions in California were assessed. Impacts of the three regulations implemented in the 1990s were examined in Arizona and Nevada. These two states lacked sufficient preintervention data to examine the impact of the regulation implemented in 1989. The end dates for the time-series in each state (June 2000 for California and December 2000 for Arizona and Nevada) were the most recent data available at the time of the study.

The ARIMA-intervention analysis was conducted with the SCA Statistical System (Liu *et al.* 1992). The analysis considered each regulation for three possible impact patterns: (1) a gradual shift to a new level of the admissions series; (2) an abrupt shift in the level of the admissions series; and (3) an abrupt change that diminishes gradually. All three series were non-stationary as indicated by the following: none of the series exhibited a fixed mean level; all had high, positive autocorrelations that decreased slowly; and the Dickey–Fuller test for unit roots confirmed that a unit root existed for each of the

series. To help achieve stationarity, each of the series was first order differenced (McCleary & Hay 1980). The autocorrelation function (ACF), partial correlation function (PACF) and extended autocorrelation function (EACF) of the differenced series were used to identify the ARIMA model for each series. The MA(1) model was found to be appropriate for all three series. Dummy coding was used to represent the regulations: each was coded 0 prior to its onset and 1 thereafter.

ARIMA-intervention models were obtained using the joint estimation of model parameters and outlier effects as described by Liu & Chen (1991). This estimation procedure starts with an ARIMA-intervention model developed according to the guidelines described in Box & Jenkins (1970) and Box & Tiao (1975). It follows with a procedure consisting of outlier detection, outlier adjustment and re-estimation of model parameters. This procedure is iterated until the estimates of model parameters and outlier effects are converged. The resulting estimates are equivalent to those estimates obtained by performing joint estimation of model parameters and outlier effects. More details of this iterative estimation procedure can be found in Chen & Liu (1993). Outlier adjustment is critical in intervention analysis and must be an integral part of such analysis (see the examples shown in Liu & Chen (1991)). Outliers can be viewed as unknown interventions a priori. Depending upon the location of outliers, they can have pronounced direct impact on the estimates of intervention effects. In addition, the presence of outliers in a time-series inflates the estimate of residual standard error, making the *t*-statistics of intervention effects biased toward insignificant. This bias is particularly serious for intervention effects because interventions typically are step or pulse functions, which contain very limited information (therefore the standard errors of intervention effect estimates tend to be large). Without outlier adjustment in intervention analysis, some intervention effects may become statistically insignificant when, in fact, they should be significant.

This study uses a quasi-experimental research design—time-series with multiple interventions. The design controls confounding effects in general by examining multiple interventions over time: it is unlikely that unidentified variables would produce effects consistently at the specific times the precursor interventions under study were implemented. As such, the design is more powerful for inferring causation than are correlational studies (Cook & Campbell 1979). This study also controls for confounding effects specific to a locality (i.e. local history effects) by examining series from three separate states: it is unlikely that a local variable such as a state government intervention or changes in a data system would produce an effect in all three states.

Two statistical control variables (correlates) were examined—monthly state-wide average ambient temperature and monthly state-wide unemployment. Rises in ambient temperature can exacerbate the health consequences associated with cocaine (Marzuk *et al.* 1998). Methamphetamine is similar in effect to cocaine (including the production of hyperthermia) (Beebe & Walley 1995), making ambient temperature a concern for methamphetamine users as well. This is a salient issue for California, Arizona and Nevada, as all three states have heavily populated desert areas that experience high temperatures. The ambient temperature indicator used was a monthly measure of average temperature weighted to reflect the more populous sections of each state (National Oceanic 2002). Monthly state-wide unemployment (US Bureau 2002) was examined, as several studies indicate its association with drug abuse (e.g. Khan, Murray & Barnes 2002; Lundborg 2002; Zlotnick, Robertson & Tam 2002).

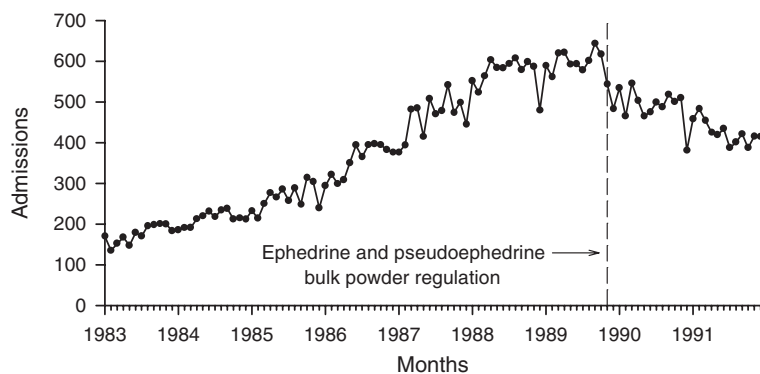
The regulation of precursors in powder form implemented in 1989 included phenylpropanolamine in addition to ephedrine and pseudoephedrine (Haislip 1996). Also, the regulation of pseudoephedrine products in 1997 included phenylpropanolamine products (Comprehensive Methamphetamine Control Act 1996). Phenylpropanolamine is a precursor used to produce amphetamine, which is sometimes marketed on the street as methamphetamine (Kypridakas 1999). At the times these regulations were implemented, there was little evidence of widespread use of this precursor to produce amphetamine illicitly.

## RESULTS

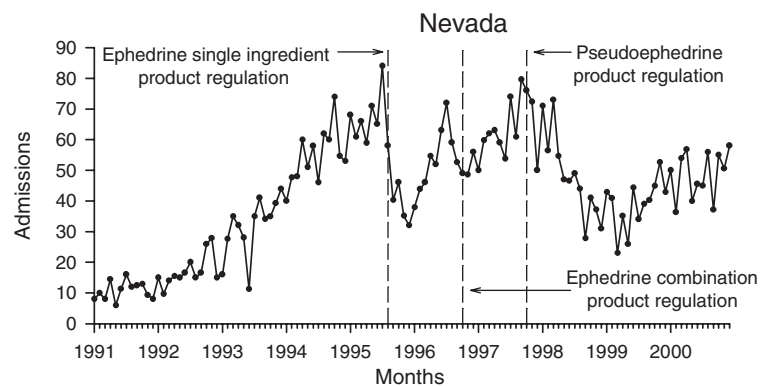
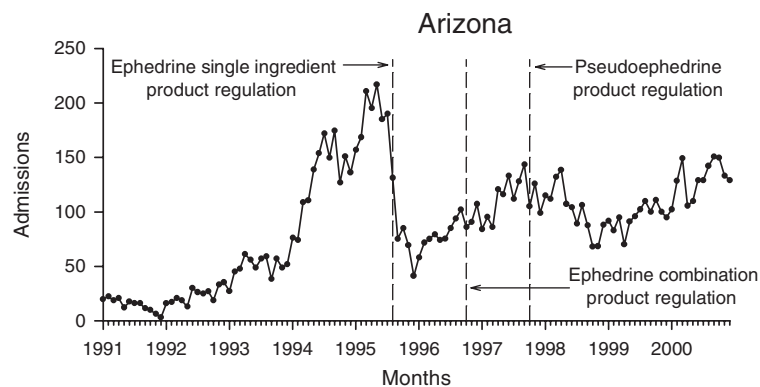
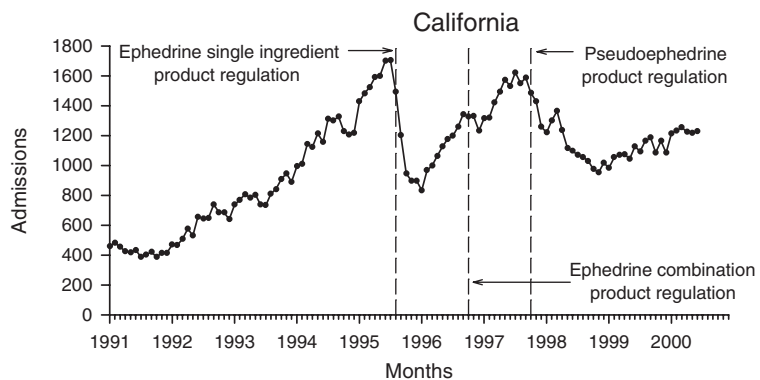
After rising steadily for approximately 7 years, methamphetamine-related hospital admissions in California began a visually striking decline in November 1989, the month methamphetamine precursors in bulk powder form were regulated (Fig. 1). The decline continued for approximately 2 years.

In 1992, admissions in California resurged and surpassed their peak preintervention counts, and continued rising throughout much of 1995 (Fig. 2). Admissions in Arizona and Nevada also rose sharply during the same period. In August 1995, the month that single ingredient ephedrine products were regulated, admissions in all three states dropped sharply for a period of approximately 6 months.

In 1996, admissions resurged in all three states. In October 1997, however, the pseudoephedrine product regulation was implemented, and admissions began another sharp decline in all three states, this one lasting approximately 1 year. In late 1998, admissions started



**Figure 1** Methamphetamine-related admissions to acute care hospitals in California (1983–1991)



**Figure 2** Methamphetamine-related admissions to acute care hospitals in California, Arizona and Nevada (1991–2000). California to June 2000; Arizona and Nevada to December 2000.

rising again. Despite this return to an upward trend, admissions at the end of the study period were still well below those preceding the 1995 regulation of single ingredient ephedrine products. In contrast with the other three regulations, the ephedrine combination

regulation, implemented in October 1996, was not associated with a visually striking decline in any of the states.

Using the procedures described earlier, ARIMA models were developed to assess the possible impact patterns of the precursor regulations. All three impact patterns dis-

cussed previously were considered. Only patterns with statistically significant parameter estimates were retained in the final models.

The final model for California is:

$$(1-B)Y_t = C + \frac{\omega_0}{1-\delta_0 B}(1-B)I_{0t} + \frac{\omega_1}{1-\delta_1 B}(1-B)I_{1t} + \frac{\omega_2}{1-\delta_2 B}(1-B)I_{2t} + (1-\theta_1 B)a_t,$$

where  $B$  is the backshift operator such that  $BY_t = Y_t - 1$ ;  $C$  is a constant term which represents the overall trend of the series (with adjustments for intervention effects);  $a_t$ 's are independent random errors following a normal distribution;  $\omega$  represents the initial effect of an intervention;  $\delta$  represents the impact rate of the intervention effect;  $\theta_1$  is a moving average parameter; and  $I_{0t}$ ,  $I_{1t}$  and  $I_{2t}$  are step functions for, respectively (1) the ephedrine and pseudoephedrine bulk powder regulation (November 1989); (2) the ephedrine single ingredient product regulation (August 1995); and (3) the pseudoephedrine product regulation (October 1997). The response patterns (with respect to  $Y_t$ ) associated with  $I_{0t}$ ,  $I_{1t}$  and  $I_{2t}$  were found to be gradual shifts in level as indicated by their statistically significant impact ( $\omega$ ) and rate ( $\delta$ ) estimates shown in Table 1. The ephedrine combina-

tion product regulation was not found to be statistically significant and thus not included in the final model. The model also does not include ambient temperature and unemployment as neither was found to be statistically significant. Sample autocorrelations and the Box-Ljung  $Q$ -test ( $Q$  statistic at lag 12 was not significant at the 5% level, where  $Q = 15.4$  with  $df = 11$ ) showed that the model's residuals were consistent with white noise. The Shapiro-Wilk  $W$ -test for normality ( $V = 1.75$ , not significant at the 5% level) indicated that the residuals followed a normal distribution.

The final model for Arizona is:

$$(1-B)Y_t = C + \frac{\omega_1}{1-\delta_1 B}(1-B)I_{1t} + \omega_2(1-B)I_{2t} + (1-\theta_1 B)a_t,$$

and the final model for Nevada is:

$$(1-B)Y_t = C + \frac{\omega_1}{1-\delta_1 B}(1-B)I_{1t} + \frac{\omega_2}{1-\delta_2 B}(1-B)I_{2t} + (1-\theta_1 B)a_t,$$

where  $I_{1t}$  is a step function for the ephedrine single ingredient product regulation intervention, modeled as a gradual shift in level for both states.  $I_{2t}$  is a step function for the pseudoephedrine product regulation intervention. The response associated with  $I_{2t}$  is approximated as an

**Table 1** Impact of precursor chemical regulations on methamphetamine-related admissions to acute care hospitals in California, Arizona and Nevada: model parameter estimates.

Parameter	Estimate	Standard error
California		
$C$	12.82*	2.17
$\theta_1$	0.30*	0.07
Regulation		
$\omega_0$ (ephedrine/pseudoephedrine powder)	-89.64*	32.98
$\delta_0$	0.59*	0.19
$\omega_1$ (ephedrine single ingredient products)	-336.37*	33.72
$\delta_1$	0.57*	0.05
$\omega_2$ (pseudoephedrine products)	-137.90*	21.91
$\delta_2$	0.84*	0.03
Arizona		
$C$	2.42*	0.85
$\theta_1$	0.34*	0.09
Regulation		
$\omega_1$ (ephedrine single ingredient products)	-67.10*	11.55
$\delta_1$	0.52*	0.10
$\omega_2$ (pseudoephedrine products)	-32.29†	12.84
Nevada		
$C$	1.21*	0.12
$\theta_1$	0.81*	0.05
Regulation		
$\omega_1$ (ephedrine single ingredient products)	-24.59*	4.07
$\delta_1$	0.35*	0.11
$\omega_2$ (pseudoephedrine products)	-4.09*	0.66
$\delta_2$	0.93*	0.01

\* $P$ -value < 0.01, † $P$ -value < 0.05.

abrupt shift in level for Arizona and modeled as a gradual shift in level for Nevada. In a preliminary model for Arizona the response for  $I_{2t}$  was modeled as a gradual shift. However, the resultant rate parameter estimate was negative which, in combination with a negative impact parameter estimate, is not readily interpretable. To address this,  $I_{2t}$  was approximated as an abrupt shift function in the final Arizona model, as this function does not include a rate parameter. The ephedrine combination product regulation was not found to be statistically significant in Arizona or Nevada and thus was not included in the final models. These models also do not include ambient temperature and unemployment, as neither was found to be statistically significant in either state. Sample autocorrelations and Box–Ljung  $Q$ -tests ( $Q$  statistics at lag 12 were not significant at the 5% level in Arizona or Nevada, where  $Q = 8.8$  and  $13.3$ , respectively, with  $df = 11$ ) showed that the models' residuals were consistent with white noise. For each state, the Shapiro–Wilk  $W$ -test ( $V = 0.69$  for Arizona and  $V = 1.07$  for Nevada, neither was significant at the 5% level) indicated that the residuals followed a normal distribution.

Parameter estimates for the final California model are shown in Table 1. Eventual intervention effects can be computed using  $\omega/(1 - \delta)$  (Box & Tiao 1975; McCleary & Hay 1980). Doing so indicates that the regulation of ephedrine and pseudoephedrine bulk powder reduced the admissions level in California by 219 admissions per month (where  $\omega = -89.64$  and  $\delta = 0.59$ ; therefore  $\omega/(1 - \delta) = -89.64/(1 - 0.59) = -219$ ). Using the same formula,

the ephedrine single ingredient product regulation and the pseudoephedrine product regulation were associated with level reductions of 782 and 862 admissions per month, respectively. Parameter estimates for the final Arizona and Nevada models are also shown in Table 1. These estimates indicate that the ephedrine single ingredient product regulation reduced admission levels in Arizona and Nevada by 140 and 38 admissions per month, respectively. The pseudoephedrine product regulation was associated with level reductions of 32 admissions per month in Arizona and 58 in Nevada.

Descriptive estimates of percentage reductions in admissions associated with the regulations were computed by comparing the average of the 3 months preceding each regulation to the average of the 3 months at the low point following the regulation (Table 2, first column). The estimated reductions are substantial, ranging from  $-35\%$  for the ephedrine and pseudoephedrine powder regulation in California to  $-71\%$  for the ephedrine single ingredient product regulation in Arizona.

Another set of reduction estimates was produced by comparing the average of the 3 months preceding each intervention to the change in admissions indicated by the model parameter estimates (Table 2, second column). These reduction estimates and those just discussed are consistent for the ephedrine and pseudoephedrine powder regulation and for the ephedrine single ingredient product regulation. They differ only regarding the final regulation, the pseudoephedrine product regulation, with the model-based estimates exceeding the descriptive

**Table 2** Impact of precursor chemical regulations on methamphetamine-related admissions to acute care hospitals in California, Arizona and Nevada: percentage reduction.

	Pre-intervention 3-month average compared with post-intervention 3-month average <sup>a</sup> % Reduction	Pre-intervention 3-month average compared with change in admissions level indicated by ARIMA-intervention model <sup>b</sup> % Reduction
California		
Regulation		
Ephedrine/pseudoephedrine powder	-35	-35
Ephedrine single ingredient products	-48	-48
Pseudoephedrine products	-38	-53
Arizona		
Regulation		
Ephedrine single ingredient products	-71	-71
Pseudoephedrine products	-41	-25
Nevada		
Regulation		
Ephedrine single ingredient products	-52	-52
Pseudoephedrine products	-61	-77

<sup>a</sup>Percentage reduction between the average of admissions during the 3 months immediately preceding the regulation and the average of admissions at lowest point following the regulation.

<sup>b</sup>Average of the 3 months immediately preceding the regulation is used as the baseline for comparison with level change indicated by model.



estimates for California and Nevada and the reverse for Arizona. The model-based reduction estimates use a rigorous statistical procedure to obtain the potential long-term change in level due to an intervention. However, if sufficient time is not available to realize that potential fully, due possibly to the occurrence of intervening events, model-based reduction estimates may differ from descriptive reduction estimates.

For Arizona, the smaller model-based percentage reduction estimate is probably an artifact of using an abrupt rather than gradual shift function for the pseudoephedrine product regulation (discussed earlier). To help assess whether a gradual function would have resulted in a larger reduction estimate, a rate parameter estimate set equal to 0.63 (the average of the rate parameter estimates in Table 1) was used to model the pseudoephedrine regulation as a gradual shift function in Arizona. The model (not shown here) indicated a reduction of 36%, which is larger than that indicated by the model with the abrupt shift function and is more in keeping with the 41% descriptive reduction estimate shown in the first column of Table 2. (Note: to avoid confusion, when the percentage reduction in admissions is discussed elsewhere in this report, the descriptive percentage reduction estimates are used.)

## DISCUSSION

The findings in this study show that ephedrine and pseudoephedrine regulations stopped the rise in and substantially reduced (−35% to −71%) methamphetamine-related hospital admissions three times during the study period. However, these effects occurred only when the precursor chemicals were regulated in forms used by large-scale producers; specifically, ephedrine and pseudoephedrine powder (regulated November 1989), ephedrine single ingredient products (regulated August 1995) and pseudoephedrine products (regulated October 1997). In contrast, the regulation of ephedrine combination products in October 1996—products that were not used widely by large-scale producers—had little or no effect on admissions.

Ephedrine and pseudoephedrine powder, single ingredient ephedrine products and pseudoephedrine products were precursors of choice among large-scale producers when regulated (Haislip 1996; Drugs and Crime Clearinghouse 1997; Office of the Attorney General 1997). Ephedrine combination products were not (Comprehensive Methamphetamine Control Act Hearing 1997). Moreover, producers had unregulated access to pseudoephedrine products (including single ingredient pseudoephedrine tablets) when ephedrine combination products were regulated. The fact that ephedrine

combination products were not preferred or needed by large-scale producers probably explains why their regulation had little impact on methamphetamine-related admissions. Notwithstanding this, the regulation, which limited unregulated purchases of ephedrine combination products to 24 g (Comprehensive 1996), may have had other effects not examined here. For example, it may have reduced ‘shelf sweeping’ of over-the-counter ephedrine combination products (such as cold and sinus medicines) at retail outlets, a practice more prevalent among small-scale (‘mom and pop’) producers. Note, however, that such producers account for a relatively small amount of the methamphetamine supply (Drug Enforcement Administration 1999).

While precursor regulations reduced admissions substantially three times, each reduction was followed by a resurgence in admissions beginning 6–24 months later. These resurgences were probably due in large part to producers accessing alternative supplies of precursor chemicals. Following the first intervention (regulation of bulk powder ephedrine and pseudoephedrine) admissions eventually began rising again, ostensibly because producers turned to single ingredient ephedrine products. Following the second intervention (regulation of single ingredient ephedrine products), admissions began rising again ostensibly because producers turned to pseudoephedrine products. By the end of the study period, and despite a third reduction associated with the regulation of pseudoephedrine products, admissions were again trending upward. According to government reports producers are now importing precursors from foreign nations, particularly Canada, in efforts to circumvent the regulations (Drug Enforcement Administration 2001; US Customs 2002). This notwithstanding, at the end of the study period admissions in California, Arizona and Nevada were still well below those preceding the 1995 regulation of single ingredient ephedrine products.

The repeated rise and fall of methamphetamine-related hospital admissions speaks to producers’ ingenuity and adaptability regarding precursor regulations: traits motivated in whole or part by a desire to capitalize on ongoing demand for methamphetamine (cf. Ghodse 1999; Reuter 2001). This points to the need for a comprehensive methamphetamine policy, one that not only reduces methamphetamine availability (supply) through precursor regulations but also reduces demand for the drug through treatment and prevention programs. If such a policy were implemented effectively the incentive to circumvent precursor regulations would be lessened, and in turn the impacts of future precursor regulations may prove longer-lasting. Moreover, such a policy would be consistent with the United Nations’ declaration that there should be a balanced approach between supply reduction and demand reduction, each reinforcing the

other, in an integrated strategy to solving drug problems (United Nations 1998).

This study examined the impacts of methamphetamine precursor regulations using time-series with multiple interventions, a powerful quasi-experimental design for inferring causality (Cook & Campbell 1979). The primary threat to its interpretation is cyclic maturation—the possibility that a series rises and falls due to a cyclic process and the falls coincide with the interventions. If a cyclical process accounted for the declines that started in August 1995 and again in October 1997, cycles of approximately 2 years should have occurred elsewhere in the study's time-series. If a cyclic process accounted for the declines starting in November 1989 and again in August 1995, cycles of approximately 6 years should have occurred elsewhere. In fact, however, no such 2-year or 6-year cycles were evident. Substantial decreases in admissions occurred only at the three points when precursor regulations targeting large-scale producers were implemented, making cyclic maturation an unlikely confounding factor.

Another possible threat to interpretation is that events other than the posited interventions accounted for reductions in admissions. While this can be a serious issue for a time-series design with a single intervention, it is generally considered a minor threat to time-series designs with multiple interventions, primarily because other events consistently occurring precisely at the times the multiple interventions are implemented is unlikely (for a discussion and examples of recent uses of time-series analysis in drug abuse research, see Edwards 2001 and Norstrom (2001)).

Hospital discharge data systems often under-report drug-related admissions (Blanc, Jones & Olson 1993). Accordingly, the number of methamphetamine-related admissions examined in this report may approximate a lower bound of the number of admissions that actually occurred. Moreover, hospital admissions are only the tip of the iceberg, so to speak, as many if not most people suffering from drug-related illnesses do not obtain hospital treatment.

Methamphetamine-related hospital admissions were reduced at the end of the study period, but additional research will be needed to determine how long this reduction will last, particularly in light of producers' ongoing efforts to circumvent precursor regulations (Drug Enforcement Administration 2001; US Customs 2002). Whether the findings of this study generalize to states other than California, Arizona and Nevada, and whether precursor chemical regulations would have comparable effects in other countries experiencing pronounced methamphetamine problems (e.g. China, Japan and Thailand; Farrell *et al.* 2002; Matsumoto *et al.* 2002; Sattah *et al.* 2002) also needs to be determined through additional research.

Despite its importance to American drug policy, the impact of federal precursor chemical regulations on drug-related health consequences has not been previously studied, possibly because drug enforcement has only recently emerged as a research focus (Manski *et al.* 2001; Reuter 2002). The findings in this study show that methamphetamine precursor chemical regulations have significant strengths and limitations. In order to direct the nation's response to methamphetamine-related problems effectively, policy makers need to use this information and demand more such information—the alternative is policy based largely on speculation.

## ACKNOWLEDGEMENTS

We wish to thank Margaret Thielemeir for helpful comments on an earlier draft of this article.

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