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Assessing Correlates of the Growth and Extent of Methamphetamine Abuse and Dependence in California

Paul J. Gruenewald, Ph.D., **Fred W. Johnson, Ph.D.**, **William R. Ponicki, M.S.**, **Lillian G. Remer, M.A.**, and **Elizabeth A. LaScala, Ph.D.**
Prevention Research Center, 1995 University Ave., Suite 450, Berkeley, CA 94704

Abstract

Using aggregate-level data, this study performed cross-sectional analyses on all 1,628 populated California zip code areas and longitudinal analyses on 581 consistently defined zip codes over six years (1995– 2000), relating place and population characteristics of these areas to rates of hospital discharges for amphetamine dependence/abuse using linear spatial models. Analyzing the data in two ways, spatial time series cross-sections and spatial difference models, amphetamine dependence/abuse were greatest in rural areas with more young low-income whites, larger numbers of retail and alcohol outlets, and smaller numbers of restaurants. Growth rates of these problems were greater in areas with higher income and larger non-White and Hispanic populations. This suggests that there was some change in the penetration of the methamphetamine epidemic into different population groups during this time. Study implications and limitations are discussed.

Keywords

Methamphetamine; amphetamine; drug dependence; drug abuse

Introduction

Since the advent of the “War on Drugs” in the 1980's, much attention has been given to policing both drug sales and trafficking in an effort to reduce the escalation of illegal drug-related problems in our nation's communities. The most widely implemented interventions that target a reduction in drug supply are increased enforcement efforts and tougher sentencing for convicted felons (Harrison and Backenheimer, 1998). However, it has been evident for some time that the market for illegal drugs responds efficiently to changes in patterns of enforcement. Generally, drug markets tend to rebound following heightened enforcement efforts or displace to adjacent neighborhoods (Caulkins, 2000) reducing the impact of enforcement efforts. The limited effects of drug enforcement are due to two main factors: 1) continued demand for drugs and 2) the existence of private and relatively closed markets for drug sales that support the rebound of public markets upon the relaxation or cessation of enforcement activities (Hunt et al., 2008). While researchers have been able to document the demand for illegal drugs using survey methods at the national and more local levels (National Institute on Drug Abuse, 2002; Kadushin et al., 1998), work that illuminates the growth and development of drug markets has been limited by the lack of available data.

For obvious reasons, when drug markets are viewed with the interests of drug sellers in mind they look quite different than they do to enforcement agents. From the drug seller's

Corresponding Author: Fred W. Johnson, Prevention Research Center, 1995 University Ave., Suite 450, Berkeley, CA 94704, Phone: (510) 883-5751, Fax: (510) 644-0594, fred@prev.org.

perspective, drug markets take one of two forms, public or private (Eck, 1995). Public markets are characterized by drug exchanges that occur in areas where individuals naturally congregate and where the threat of detection by enforcement agents is low (for example, around shopping malls, public schools, rapid transit hubs, and liquor and convenience stores). As noted by Wittman (2007), drug markets in urban areas tend to map onto retail alcohol outlets that provide places where buyers and dealers will find each other easily without interference from law enforcement or outlet management. Despite this, these markets are based upon exchanges between relative strangers and are, therefore, the markets most often uncovered by enforcement agents. Private markets rely on the social networks of current consumers to facilitate the development of new clientele. These markets are based upon exchanges between friends and more distal but connected members of drug users' social networks. Private markets are for this reason more closed to public scrutiny, less likely to be identified by enforcement agents, and persist when public markets are disrupted. While fine distinctions between public and private markets are unwarranted, differences between these markets being a matter of degree, the importance of privacy to the maintenance of these markets is clear. This privacy also precludes direct empirical investigation.

Given the needs for suppliers, distributors, retailers and consumers to remain invisible to enforcement efforts, population survey methods have proven successful at measuring drug demand (National Institute on Drug Abuse, 2002; Kadushin, et al., 1998), but have proven unsuccessful at illuminating drug supply. Ethnographic and other qualitative research approaches have been more successful in the study of local drug markets (e.g., Eck and Gersh, 2000). Although these studies have been an invaluable source of information about local drug markets accessible through the social networks of drug users, they present only a fragmented and incomplete view of any market within any city or state in the nation (Goldstein, 1998). Since these markets span city, county, state and national boundaries, and remain largely private by intent, the majority of drug market activities remains invisible. For these reasons Caulkins and Pacula (2006) observe that much more is known about drug sales and demand than about markets and supply. Regrettably, efforts by social scientists to elucidate the ecological correlates of drug markets through the examination of arrest data (e.g., Banerjee et al., 2008) do not ameliorate this situation. The limitations of arrest data are notoriously severe. Arrests are a function of enforcement, but drug market activities and changes in arrest rates reflect changes in either enforcement or market activities and, very often, both.

An Epidemiological Approach

There is a pressing need to begin characterizing community and neighborhood risk factors that lead to or accelerate the growth of illegal drug market activities and related problems. In the absence of direct indicators of drug market activity, how can we learn more about the growth and spread of drug markets so that intervention efforts can be proactive rather than reactive in nature? In recent years, greater consideration has been given to the developing dynamics of drug markets and their relationships to broader community characteristics (Curtis and Wendel, 2000). The current study takes a geographic epidemiological approach and considers the degree to which one well-understood outcome of methamphetamine use, diagnoses of abuse/dependence, varies spatially across many areas of California and over a short period of time, 1995 – 2000. The goal of the study is not to completely characterize growth and change in methamphetamine abuse/dependence over the full course of growth in use in California. Indeed, that is not possible at this time. Rather, the goal of this study is to demonstrate feasible strategies for elucidating growth and change in the methamphetamine market using measurable outputs from some medical sequelae of use. In prior studies, these outcomes have been shown responsive to implementation of methamphetamine precursor laws (Cunningham and Liu, 2003). Here we entertain the possibility that these measures may reflect differential growth and change over space and time, providing a first look at the larger picture of growth and change in the methamphetamine market in California.

Our approach to understanding the growth of methamphetamine use in California is founded on the availability of hospital discharge data. But it is also supported by the value of these data when considered in light of the scope and magnitude of the methamphetamine problem in the state. Across cities in the US, the number of emergency department discharges that involved amphetamine or methamphetamine increased by 54% between 1995 and 2002 (SAMHSA, 2004). The typical methamphetamine user has been identified as young, white, and male; often unemployed, impoverished, and living in his own residence (Yacoubian, 2007; Iritani et al., 2007). Iritani et al. also found that 12.8% of Native Americans had used crystal methamphetamine in the past year, 4.2 times the rate of whites. Considering rates of growth in use across different populations, Yacoubian suggests that although methamphetamine use is lower among Hispanics, rates of use are increasing in this group. There are also strong regional patterns to methamphetamine use. Methamphetamine use among arrestees has been much greater in western US cities (30% to 37% percent across Honolulu, San Jose, San Diego, and Sacramento) than eastern cities (1% or less across Washington, D.C., New York City, and Philadelphia; Yacoubian, 2007). Iritani et al. (2007) found crystal methamphetamine use to be 5.4 times higher in the west than in the northeast.

These regional patterns of methamphetamine abuse are reflected at local levels within the state of California. As shown in Figure 1, incidence rates of methamphetamine abuse/ dependence discharges from hospitals in California increased between 1983 and 2005, with dependence admissions per 10,000 population increasing 5-fold and abuse admissions increasing 18-fold over this period. Although the popular literature that characterizes levels of methamphetamine abuse as “epidemic” often uses this term to refer to high levels of use rather than epidemic growth, rates of increase in hospital discharges related to abuse in California do in fact reflect epidemic growth; exponential increases of about 13% per year over this time. Importantly, this growth has not been continuous nor homogeneous over time across the state. Dependence admissions show a lesser increase, though still exponential, of about 5% per year and, as Figure 1 shows, there were declines from 1997 to 1999, largely in response to changing market conditions related to the introduction of precursor laws (Cunningham and Liu, 2003). These declines were not long lasting, however, and by 2003 dependence rates reached and thereafter exceeded the previous 1997 high. As further shown in Figure 2, the geographic distribution of rates of amphetamine use and abuse discharges per 10,000 population grew rapidly from 1990 to 1995, spreading into the northern, southern, and central parts of the state. The years 1995 through 2000 showed the pattern of decline just noted, followed by substantial increases across zip codes in the state through 2005. In each year, rates across zip codes differed by up to three orders of magnitude; and within specific areas, such as relatively isolated rural zip codes, but also neighborhoods in the Bay Area and the Los Angeles basin, increases by a factor of three or more were observed. These data indicate substantial geographic variation in both levels and rates of growth of methamphetamine and amphetamine abuse across the state.

In this study, we present regression analyses relating indicators of amphetamine-involved hospital discharges within defined geographic areas, zip codes, to various local factors that might affect an area's likelihood of fostering amphetamine use and developing amphetamine-related problems. These factors include the demographic characteristics of local residents, their income, and the physical availability of alcohol and other retail goods. As Banerjee et al. (2008) have suggested, dense markets for retail goods, and especially alcohol outlets, are markers for areas where drug market activities (indicated by sales, possession, and use arrests) are prevalent. Three sets of linear spatial regression models were used to relate rates of hospital discharges to these demographic and place characteristics using (1) a comprehensive cross-section of data available for the year 2000 including all zip codes in the state of California, (2) longitudinal panel data from a limited subset of zip codes over 6 years from 1995 to 2000, and (3) the same panel data with the outcome measure expressed as year-to-year rates of change. The last analysis represents a convenient way to identify demographic and place characteristics that may be related to greater rates of growth in methamphetamine/amphetamine use over time. We restrict our consideration to the years 1995 through 2000 for two reasons: First, this was an important transition period during which domestic production declined and the market substantively changed. Second, there were too few consistently defined area units (zip codes) over longer periods of follow-up (further discussed below).

Method

This study takes a population-based ecological approach to the examination of rates of amphetamine dependence/abuse across community areas using two distinct data sets. The first set was cross-sectional data from all 1,628 populated California zip codes in the year 2000. The second set contained panel data covering the years 1995 through 2000 collected for 581 index zip codes the boundaries of which were unchanged during the entire six-year study period. The main advantages of the cross-sectional data are complete geographic coverage of the state and a relatively comprehensive array of population and place characteristics that could be related to hospital discharges, relying among other sources on Census 2000 data. The panel data set had less geographic coverage and included a more limited collection of covariates, restricted by the need to identify common measures over the six years of observation. Although the geographically comprehensive, cross-sectional data can help identify ecological correlates between community characteristics and amphetamine-related problems at a single point in time, no causal inferences can be drawn because there are any number of reasons that one place might exhibit more problems than another. The geographically less-complete panel data provide some ability to infer causation by differentiating between communities that are experiencing dissimilar changes in discharges over a period of years.

Geographic basis

The geographic basis for the study was regions defined using electronic maps of the state obtained from Claritas (Ithaca, NY) and Environmental Systems Research Institute, Inc. (ESRI, 2001, 2002) of Redlands, CA. These maps were developed by GDT (Geographic Data Technology, Lebanon, NH) by geocoding U.S. postal route zip code information and estimating unspecified areas based on topology. The resulting electronic zip code base maps have 100 percent coverage of the state, but include synthetic zip codes for areas with extremely low population density such as national forests and state parks, and include some zip codes such as post offices and government buildings with negligible geographic area. Considering only zip codes with some geographic extent, 1,646 zip codes from the year 2000 served as the source of the 581 “stable” zip codes for the panel analyses. “Stable” areas were defined as those zip codes that maintained a consistent area definition over the six years of the study (adjudicated by reference to Census 2000 block internal points). These areas, by definition, maintained consistent boundaries over time, thus obviating the severe interpretive problems that arise in analyzing data from continuously modifiable area units (Openshaw, 1984). Although the 581 zip codes cannot be claimed as representative, they included a broad selection of urban and rural, coastal and inland regions of California, covering much of the demographic and geographic diversity of the state.

Dependent and independent measures

Information on amphetamine dependence/abuse was obtained from patient discharge data (PDD) collected by the California Office of Statewide Health Planning and Development (OSHPD). Each case was geocoded to the residential zip code of the person discharged. PDD records provide information on all discharges that result in at least one overnight hospital stay including up to 24 ICD-9-CM (diagnostic) codes. Code 304.4 indicates amphetamine dependence and code 305.7 indicates amphetamine abuse (ICD-9- CM, 1992). These two classifications by definition include use of a variety of psychostimulant drugs, for example, amphetamine, Dexedrine, methamphetamine, and whatever drugs may be covered by “street” names such as “speed.” In only 8.7 percent of cases is amphetamine dependence/ abuse the primary diagnosis; in the other 91.3 percent of cases the dependence abuse diagnosis is secondary to hospital discharge for some other medical or injury condition. The validity of discharge diagnoses is good. In 1989, OSHPD conducted a major reabstracting project to test the validity of various components of the patient discharge record including primary and other diagnoses. Overall, a sensitivity and specificity of better than 90 percent in record check and patient follow-up studies was observed (Abellara et al., 2005; Meux, 1993; Meux et al., 1990). Over 99 percent of all hospital discharge records were successfully geocoded to zip codes in the state. Rates of amphetamine abuse and dependence were calculated per 1,000 population, and a logarithmic transformation applied to reduce substantial skewing due to very high discharge rates observed in some areas, then multiplied by 1,000 to rescale model coefficients for ease of presentation.

Data on the locations of alcohol outlets were obtained from California Alcohol Beverage Control. Outlet locations were geocoded to their zip code based on the street address of the establishment. Numbers of active alcohol outlets by zip code were tabulated for off-premise establishments, restaurants, and bars plus pubs. Geocoding rates exceeded 99 percent, a rate comparable with those obtained in previous studies (Gruenewald et al., 2006) and by earlier investigators using other data at this level of geographic resolution (Alaniz et al., 1998; Gorman et al., 2001). Alcohol outlet density was indexed in units of roadway miles for cross-sectional analyses of zip code data (see also Gruenewald et al. 1996; Lipton and Gruenewald, 2002). Alcohol outlet density was indexed in counts per area for the panel analyses because the units of analysis remained unchanged over time.

County business pattern data on all retail establishments are collected annually by the U.S. Department of Commerce and published electronically as Zip Code Business Patterns by the U.S. Census Bureau. The data include counts of retail establishments within zip codes by type (NAICS, North American Industry Classification System codes), although counts may be low because the census is voluntary for small businesses that have no paid employees. Numbers of all retail establishments were tabulated for one broad category, termed “Total Retail” (NAICS 44, 45, and 72). Converting nonspatial zip codes (P.O. boxes and single-building zip codes) to the surrounding zip code, geocoding rates exceeded 99 percent. Densities for all retail establishments were calculated in parallel to those for alcohol outlets.

Variables that characterized populations living in zip code areas were obtained from annual estimates reported by Sourcebook America (CACI Marketing Systems, 1995, 1996, 1997, 1998, 1999, and 2000) for each of the six panel-model years, 1995 through 2000. At the zip-code level, these estimates are available for a limited number of measures that represent changes in core population characteristics previously shown to be associated with substance dependence or abuse: population expressed in thousands (×1000), average household size, percent male population, median household income expressed in thousands (×1000), median age, and percents of population that are white, black, or Hispanic. Both population and income were expressed in thousands to place them on a scale similar to the other exogenous variables, and like the outcome measure, for ease of presentation. For the year 2000 cross section, additional zip-code-level measures were available from the U.S. Census for that year only. These included four measures of poverty and social disorganization: percent of families having a female head of household with children, percent of population in poverty, percent unemployed, and percent high school graduates. Three measures of residential stability, known to be related to crime and therefore possibly to substance abuse, were also included: percent vacant housing, percent of households that moved in the last five years, and percent foreign born population (Morenoff, Sampson, and Raudenbush, 2001).

Statistical approach

Simultaneous autoregressive (SAR) spatial models were used to estimate statistical associations between covariates and rates of hospital discharges for patients with any amphetamine use or abuse diagnostic codes. SAR models correct for spatial autocorrelation of model residuals, which would induce bias in uncorrected regression models. This is important in analyses such as these because zip codes that are physically near each other may exhibit similar characteristics related to drug use, yet data for many of these characteristics are not available at the zip code level. All analyses were weighted by population size, a procedure that reduces the influence of small population effects in estimates of statistical associations. The panel models included spatial random effects because they can help avoid bias in two ways. First, random effects address the fact that nesting of annual observations within spatial units violates the standard regression assumption that errors are independent across all observations. Second, random effects help to avoid parameter bias resulting from excluded variables. By creating zip-code-specific error terms, spatial random effects account for time-invariant place differences related to causal variables which are not available for inclusion in these analyses.

The panel analyses were run using both undifferenced and differenced versions of the outcome measure. The undifferenced analysis relates the level of each covariate to the level of the hospital discharge rate in the same year for each zip code. The differenced version of the analysis relates the level of each covariate in a given zip code in time t to the change in the hospital discharge rate for that zip code between time t and t+1. The year 2000 is excluded from the panel analysis using the differenced outcome measure, reducing the total number of cases from 3,486 (581 zip codes times 6 years) to 2,905 (581 times 5 years). A linear time trend was included in the undifferenced model to account for state-level changes over time between 1995, the base year, and 2000. The constant term in the differenced model serves the same purpose. Whereas the undifferenced analysis is designed to test whether each community characteristic is associated with higher or lower expected discharge rates for amphetamine dependence/abuse, the differenced analysis investigates whether community characteristics are associated with temporal growth or decline in these discharge rates.

Given the above review, what hypotheses can be generated with some degree of confidence? First, we would expect hospital discharge rates to be greater in areas with more bars and off-premise alcohol outlets, but perhaps lesser in areas with more restaurants, which are likely to be in more affluent areas and patronized by more affluent clientele and families. Secondly, as suggested by the maps in Figure 2, where the increases noted above in 1995 and 2005 appear to be greater in rural areas, we might expect hospital discharge rates to be greater in areas with lower population densities, the best measure of rurality in the data. Finally, based on Yacoubian's (2007) work, we expect hospital discharge rates be to higher in zip code areas with greater numbers (densities) of young, white, unemployed, males living in households of one.

Results

Table 1 shows the zero-order correlations for the year 2000 among the predictors used in the panel models, permitting an overall assessment of the degree of interrelatedness among the exogenous measures included in the panel models (and most of the predictors in the cross-sectional models as well). Although only the correlations for the final panel model year are shown (2000), obtaining the correlations for the preceding five years showed that they changed little over time as would be expected from aggregate data based on large Ns and population proportions. All four retail measures (total retail, off-premise, restaurants, bars) are highly intercorrelated. These high correlations are due in part to spurious correlation because all three outlet types are included in the total retail measure and in part to the tendency for commercial businesses to cluster together in downtown or shopping areas such as malls. Total retail was included in the analysis as a statistical control to absorb variance due to the presence of retail businesses that might otherwise be attributed to the three outlet types. The other high correlations, reflect either the structure of urban areas, for example, the high positive correlation between population in thousands and off-premise outlets (large numbers of liquor stores are found in densely populated inner-city areas); demographics, for instance, the high negative correlation between median age and household size (older people have few or no children); or residential self-segregation, for example, the high negative correlations of percent white with percents black and Hispanic (people of similar racial or ethnic background tend to live in the same area). What is most important regarding the models is that the correlations among these measures did not result in collinearity, which can inflate standard error estimates, and result in Type II errors. Although not presented in the tables here, the standard errors were reasonable in magnitude, similar to those in other analyses we've performed using the same techniques, and did not appear to affect the validity of the results (standard errors for all models available upon request).

Table 2 presents descriptive statistics for the dependent and independent measures for all 1,628 zip codes in the cross-sectional analyses. The first four columns of Table 3 present analogous year 2000 descriptive statistics for the 581 consistently defined zip codes included in the panel analyses. The last two columns of Table 3 present average percent change and its standard deviation from 1995 to 2000 for the consistently defined zip codes. Comparison of the descriptive statistics from the two sets of zip codes for the year 2000 shows that the 581 consistently defined zip codes were about 50 percent more populous than the statewide average, with the mean count of hospital discharges in the stable subset of zip codes exceeding the statewide average by a similar proportion. The consistent zip codes also have higher average proportions of black and Hispanic populations. The consistently defined zip codes were more likely to include urban and rural areas with relatively stable populations but tend to exclude rapidly growing suburban areas. In addition, of great importance to the estimation of effects in the panel models, average percent changes over time were small across zip code areas but varied substantially within zip code areas over time. For example, average total population per zip code changed only −0.5% over the six years, but changes within zip codes had a standard deviation of 8.4%.

Cross-sectional models

Table 4 presents two analyses of the cross-sectional data for the year 2000. The base model included measures of retail density and population characteristics that paralleled covariates available for the subsequent panel models (discussed below). The one important exception was inclusion of the percent Native American population in each zip code; this measure was unavailable for the panel analyses but of substantial importance given the high rates of amphetamine abuse/dependence recently observed in the Native American population. The full model included the four additional poverty and three residential stability measures noted above.

As shown in Table 4, a number of predictors were significantly associated with amphetamine abuse/dependence. In the base model, residents of zip code areas with greater numbers of bars, larger populations, greater proportions of females and whites, lower median household incomes, and greater proportions of Native Americans had higher rates of hospital discharges for amphetamine abuse/dependence. In the full model, effects related to bar and population densities, proportion female population, and median household income were retained. Percent African American residents and percent foreign born residents were related to lower rates of amphetamine abuse/dependence. Percent female-headed households was positively related to amphetamine abuse/dependence. Note that in both analyses spatial autocorrelated error was substantial and significant.

Panel models

Table 5 presents the results of the undifferenced and differenced panel models. Substantive and significant spatial autocorrelation was observed in both analyses, indicating in the undifferenced model that levels of abuse/dependence tended to be similar between areas and, more importantly, in the differenced model that rates of change in levels of abuse/dependence across years also tended to be correlated among adjacent units.

In the undifferenced model shown in Table 5, all the retail measures, including all types of alcohol outlets, were significantly related to dependence/abuse, with geographic areas containing greater numbers of total retail, off-premise establishments, and bars having higher rates of dependence/abuse, but areas with more restaurants having lower dependence/abuse rates. Five of the eight demographic measures were significantly related to rates of dependence/abuse, with rates positively related to percent white, but negatively related to population density, median household income, median age, and percent Hispanic. In general, higher rates of abuse/dependence were found in zip code areas with greater numbers of retail establishments, excluding restaurants. The differenced model in Table 5 shows that year-to-year change in rates of abuse/dependence was unrelated to all retail characteristics, but strongly related to higher median household income, lower percent White population, and higher percent Hispanic population.

Supplementary analyses

A number of additional specification tests were conducted for the dependence/abuse outcome measure. These included models 1) examining the possible moderating effects over time of median household income, age, and percent white, 2) separately assessing the contributing effects of alcohol and non-alcohol retail establishments, and 3) examining different specifications for measures of ethnic group composition, such as controlling for percent Asian. In all these alternate models, the findings for the amphetamine dependence/abuse analyses were robust with population and place effects stable across different model specifications. Residuals from every analysis were assessed for outliers and highly leveraged cases through examination of studentized residuals, Cook/Weisberg test statistics, other leverage statistics, and Cook's distances. No high leverage cases were detected in any analysis. Outliers were detected, almost invariably related to values obtained from lightly populated areas where only a small number of dependence/abuse hospitalizations can have a disproportionate effect. Estimation biases that might have otherwise arisen from including these units in the analyses were substantially reduced by weighting the analyses by population size. There were several outliers observed in different analyses among more populous zip code areas. Supplementary analyses in which dummy codes were introduced to account for these outliers showed that results from all analyses remained largely unchanged using this approach.

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Discussion

The three analyses presented in this paper ask and answer three somewhat different questions about the growth of methamphetamine abuse/dependence in California from 1995 to 2000. Although the cross-sectional analysis is of limited value in explaining causation, it is geographically comprehensive and provides an assessment of the ecological correlates of these problems for the year 2000. These results showed that rates of hospital discharges for abuse/dependence were positively related to population size and bar density, female heads of household, and the percentages of whites and Native Americans, but were negatively associated with median household incomes and percents male and foreign born.

The panel analyses take two steps beyond these limited cross-sectional findings. The undifferenced panel model explored correlates of abuse/dependence as they were associated with varying *levels* of these problems over time within a fixed set of units. Rates of abuse/dependence were positively associated with percent white and all retail covariates other than restaurants, while being negatively related to restaurants (which tend to be concentrated in more affluent areas), population density, median household income, median age, and percent Hispanic. These results generally suggest that amphetamine abuse/dependence tends to be higher in rural areas with many poor, young, non-Hispanic whites. In general, the undifferenced panel model results largely support the hypotheses stated above.

Whereas the undifferenced panel model seeks to identify which covariates are associated with observed levels of amphetamine abuse/dependence, the differenced panel analysis investigates which exogenous measures are related to increases or decreases in localities' abuse/dependence rates. Interestingly, each of the significant coefficients in the differenced panel model is opposite in sign from its corresponding significant effect in the undifferenced panel results. Although the former analysis found that average amphetamine abuse/dependence rates were associated with low-income areas with many whites but few Hispanics, the latter analysis suggests that abuse/dependence tended to grow faster in higher-income zip codes with relatively few whites but many Hispanics. This last observation suggests that the late 1990s saw continued growth and spread of amphetamine abuse/dependence into new areas with different population characteristics than were associated with high levels of these problems prior to that time. This finding is consistent with Yacoubian's (2007) observation that methamphetamine use is increasing among Hispanics.

As argued in the introduction, activities of this illegal market are difficult to index in an unbiased way using reactive enforcement measures and more fully observable only under conditions which seriously limit generalization to all cities or other areas of the state (e.g., using ethnographic field methods). As a consequence, detailed study of the medical consequences of this developing market deserves consideration for two reasons: First, the scale of the market is not that of a single social network, neighborhood, or city, but rather that of neighborhoods within cities and communities across the state and across national boundaries (i.e., between California and Mexico). Statewide surveillance data are required to capture the full scale of the epidemic in California. Second, at the population level, consequences of methamphetamine use can be measured downstream from drug activities, thus providing a “hard” measure of the impacts of the epidemic on human populations, one that is less immediately responsive to local enforcement efforts and one that reflects the accumulated medical burden of the epidemic. Although the 581 areas examined in the panel analyses were not a representative sample of all zip code areas in the state, and inferences from the panel analyses are risky under these conditions, the panel data are useful for understanding the growth of the methamphetamine market in California. The panel analyses suggest that the California methamphetamine market was most developed in poor white areas as of 1995, but that during the late 1990s it was continuing to grow and diversifying into new areas of the state with specific population characteristics (e.g., higher income, Hispanic). The long term trajectory presented in Figure 1 suggests that this grim pattern is continuing today.

Study Implications

The chief implication of this study may be that the undifferenced panel model findings for the sociodemographic measures (significant negative coefficients for population size, household income, median age; and significant positive coefficients for proportion white population) generally support previous research showing methamphetamine dependence/ abuse to be concentrated among young, white, unemployed, impoverished males living alone (Yacoubian, 2007) and supports the popular notion that the methamphetamine epidemic is a more rural than urban problem. That the methamphetamine epidemic is a greater rural than urban problem is evident not only in the undifferenced regression analysis, but also in the Figure 2 maps. The series of California maps, particularly the concentration of methamphetamine-related hospital discharges in 2005, indicates that the growth of methamphetamine use was greatest in rural areas.

What are the implications of these findings regarding prevention, treatment, and enforcement? The increase in methamphetamine use in rural California may represent a displacement of methamphetamine markets out of areas of greater enforcement noted by (Caulkins, 2000) but on a larger rural-urban scale; or growth of methamphetamine markets in rural areas where producers believe they can better evade enforcement. In either case, effective enforcement efforts may have to supplement precursor laws by focusing on rural areas of likely manufacture although finding methamphetamine laboratories will prove challenging if they are remotely located or well hidden. If amphetamine use is greater in rural areas, then clearly both prevention and treatment programs appropriate to rural areas need to be developed, implemented, and evaluated. It is possible that the most recently enacted precursor legislation, The Combat Methamphetamine Act of 2005, which went into effect on March 9, 2006, and has stringent reporting requirements for small purchases of precursor drugs, the sort made by the average consumer with a cold, will be more effective than earlier precursor laws. If these reporting requirements were collected in a national database rather than reporting only “suspicious payments or disappearances,” the law would be significantly strengthened, and the methamphetamine epidemic might be contained if not eliminated.

Limitations and Directions for Future Research

The current study demonstrates the feasibility of using a geographic epidemiological approach to analyze changing spatial patterns of methamphetamine-related problems. The spatial autocorrelation coefficients were large, positive and highly-significant in all models, suggesting that spatially-corrected models such as these are necessary to avoid biases in the estimation of model parameters. The analyses also provide a useful demonstration of the possibility that geographic patterns of amphetamine abuse/dependence may change over time in an evolving drug market. The panel model results show that certain population and place characteristics that are positively associated with current levels of hospital discharges may also be negatively related to local growth rates in those discharges.

Although the current findings represent a substantial advance in this area of research, this study has a number of limitations that might be addressed in future research. One such limitation involves the use of zip-code data, which was chosen under the assumption that drug market activities tend to operate within fairly compact geographic areas. The main drawback of using these administratively-defined spatial units is that zip code boundaries are frequently adjusted and new zip codes are sometimes introduced, particularly in areas of rapid population growth. This inconsistency in spatial definitions creates a difficult trade-off in setting up panel models. Although long time series are important for analyzing long-term market changes, such data can only be analyzed for a relatively small and unrepresentative group of consistently-defined zip codes. Tracking growth of amphetamine abuse/ dependence over the relatively short 1995 to 2000 period reduced the number of spatial units from over 1,500 statewide zip codes to a consistently-defined group of only 581. Extending this analysis to additional spatial units within the same time frame, or to additional years using the same units, would create a situation in which highly modified area units would be introduced into the analyses. Biases that would arise are severe and difficult to control. Extending these analyses over space and time will require the development of spatial statistical methodologies that enable unbiased statistical analyses of space-time data from heterogeneously defined and changing units.

A second limitation stems from the specification of connections between spatial units used in these models. The connectivity between the zip code areas is sometimes dense (e.g., between zip codes in urban areas) and sometimes sparse (e.g., between zip code areas along the Mojave desert). Connections between units may be better represented in any of a large number of plausible spatial topologies including connectivity over roadway systems and flows along transportation networks. The degree to which the chosen representation of connections between units affects results of analysis strategies is unknown.

Another potential weakness of the current study is that it does not allow for the possibility that the effects of independent measures on outcomes observed across units may vary from-place-to-place. For example, levels of poverty may be influential with regard to the acquisition and maintenance of amphetamine abuse in some places (e.g., rural areas) but irrelevant in others (e.g., urban areas) where other drugs of abuse may be available. Spatially varying parameter models could be employed to explore the degree to which consistent or meaningfully varying relationships of this sort may be present in these data.

Other limitations arise from the use of hospital discharge data as the outcome measure. Sample-selection biases could result if some persons with amphetamine abuse/dependence problems are more likely than others to be admitted to a hospital. For example, high-income drug abusers may be more likely to be admitted due to superior medical insurance, and older abusers may be more likely to be admitted to the extent that their overall health is less robust. This problem may be complicated by the fact that these analyses count hospitalizations as amphetamine dependence/abuse if a relevant ICD-9-CM code is listed either as the primary diagnosis or among the 24 secondary diagnoses that may be recorded for each case. Over 90 percent of the cases analyzed here have amphetamine abuse/ dependence as a secondary diagnosis. This implies that an amphetamine abuser's probability of being included in this study may depend on whether they also suffer from other health problems that are the primary reason for their hospital admission. Future studies could employ sample-selection models to minimize these biases. The last and most important limitation is the fact that no adequate theoretical model of the growth and spread of the methamphetamine “epidemic” has been proposed. Descriptive epidemiological analyses such as the current study may encourage the development of adequate theory that will, in turn, suggest testable hypotheses and creative and innovative prevention strategies to reduce methamphetamine and amphetamine use, abuse and dependence.

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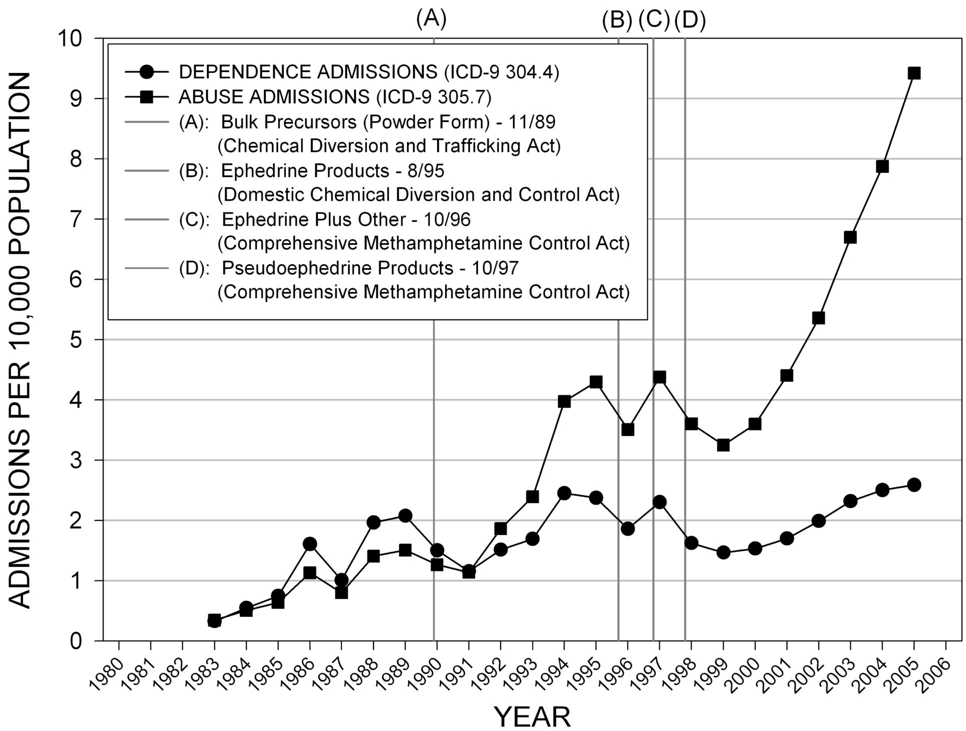

Figure 1.

Statewide methamphetamine and amphetamine related hospital discharge cases per 10,000 population from 1983 to 2005.

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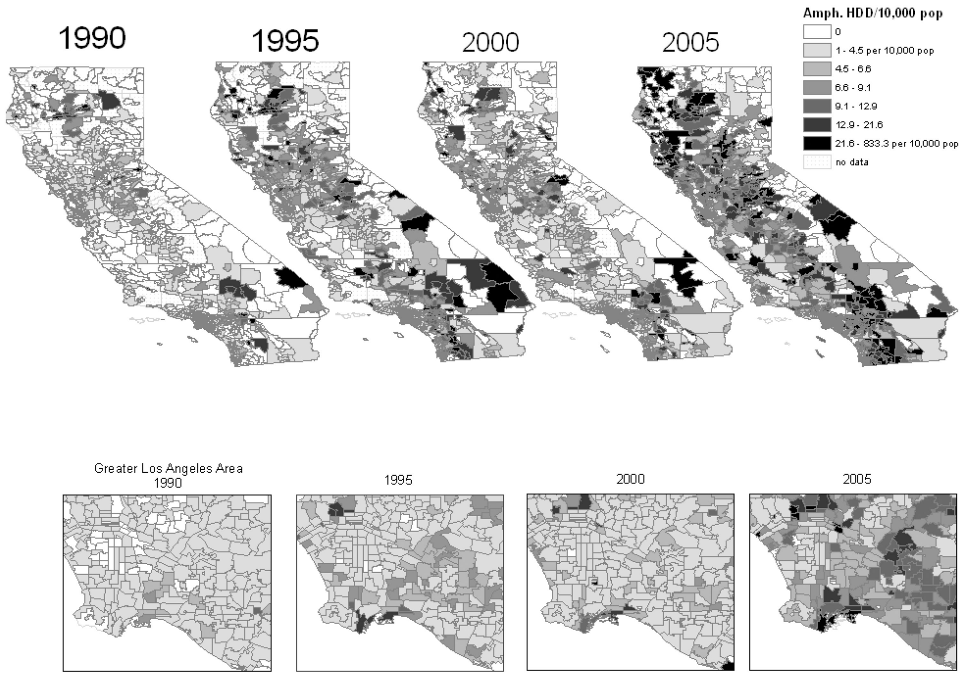

Figure 2.
Distribution of methamphetamine and amphetamine related hospital discharges per 10,000 population across zip codes within California and the Los Angeles basin for 1990, 1995, 2000, and 2005.

Table 1

Zero-order Correlations Among the Predictors Used in the Panel Models (N=3486)

	All retail[a]	Off premise	Restaurants	Bars	Population (×1000)	Household size	Precent male	Median household income (×1000)	Median age	Percent white	Percent black	Percent Hispanic
All retail	1.00											
Off premise	0.69	1.00										
Restaurants	0.88	0.57	1.00									
Bars	0.60	0.78	0.59	1.00								
Population (×1000)	0.61	0.80	0.43	0.55	1.00							
Household size	−0.14	0.25	−0.28	0.07	0.33	1.00						
% Male	−0.12	−0.10	−0.07	0.00	−0.16	0.21	1.00					
Median household income (×1000)	0.15	−0.10	0.17	−0.16	0.16	−0.11	−0.16	1.00				
Median age	−0.12	−0.41	0.03	−0.27	−0.44	−0.69	−0.24	0.25	1.00			
% White	−0.07	−0.36	0.02	−0.23	−0.41	−0.55	−0.02	0.20	0.60	1.00		
% Black	−0.03	0.15	−0.07	0.07	0.17	0.12	−0.12	−0.18	−0.24	−0.66	1.00	
% Hispanic	0.06	0.40	−0.06	0.30	0.36	0.73	0.27	−0.30	−0.69	−0.60	0.06	1.00

[a]Because of the large sample size, all correlations except the four correlations below .06 are significant beyond .001.

Table 2

Descriptive Statistics for the Year 2000 Cross Section (N=1628)

Variable Group	Variable Name	Mean	Standard Deviation	Minimum	Maximum
Endogenous measure	Amphetamine dependence/abuse	9.98	16.34	0	160
Retail markets	All retail	1.38	3.67	0	55
Alcohol outlets	Off-premise	0.18	0.30	0	4
	Restaurants	0.27	0.81	0	18
	Bars	0.05	0.18	0	6
Demographics	Population (×1000)	20.81	20.68	0	104
	Household size	2.86	0.68	0	5
	% Male	50.67	5.61	0	100
	Median household income (×1000)	48.94	21.85	0	185
	Median age	36.98	7.02	16	76
	% White	69.27	20.85	0	100
	% Black	4.66	8.75	0	88
	% Hispanic	24.13	21.90	0	100
	% Native American	1.79	4.02	0	81
Poverty	% Female head of household	6.48	5.33	0	100
	% Poverty	14.09	9.84	0	100
	% Unemployed	8.00	6.15	0	69
	% High school graduate	78.38	16.36	0	100
Residential stability	% Vacant households	11.75	15.52	0	99
	% Moved last 5 years	49.68	12.19	0	100
	% Foreign born	18.89	14.71	0	79

Table 3

Descriptive Statistics for the Final Panel Model Year (2000) and Percent Change in Measures Over Time (N=581)

						Percent Change	
Variable Group	**Variable Name**	**Mean**	**Standard Deviation**	**Minimum**	**Maximum**	**Mean**	**Standard Deviation**
Endogenous measure	Amphetamine dependence/abuse	15.09	18.84	0	152	4.11	84.08
Retail markets	All retail	150.83	122.64	0	708	4.23	29.08
Alcohol outlets	Off-premise	24.34	17.77	0	122	−0.43	24.58
	Restaurants	26.94	25.91	0	192	5.27	54.09
	Bars	5.73	5.79	0	57	−3.98	42.06
Demographics	Population (×1000)	31.19	20.85	0	100	−0.52	8.43
	Household size	2.76	0.52	2	5	−1.69	2.52
	% Male	50.04	2.70	43	72	0.20	3.14
	Median household income (×1000)	46.42	16.05	14	122	31.79	17.99
	Median age	35.31	5.96	22	68	3.02	5.43
	% White	67.18	22.20	5	99	−3.29	6.38
	% Black	6.77	12.51	0	86	−3.89	31.83
	% Hispanic	28.21	21.33	1	98	16.29	18.16

Table 4

Year 2000 Cross-Section Amphetamine Dependence/Abuse Base and Full Models

Model Component	Variable	Base N=1628 *b*	Base N=1628 *t*	Full N=1628 *b*	Full N=1628 *t*
	Constant	465.440	0.860	−162.579	−0.156
Retail establishments	Total retail	14.783	0.929	14.876	0.937
Alcohol outlets	Off-premise	−249.696	−1.862	−104.360	−0.741
	Restaurants	−27.919	−0.344	39.538	0.487
	Bars	1042.262	3.439**	882.940	2.915**
Demographics	Population (×1000)	3.817	3.958***	3.620	3.718***
	Household size	−93.130	−1.484	−40.035	−0.540
	% Male	−22.985	−3.911***	−14.097	−2.113***
	Median household income (×1000)	−15.248	−9.715***	−15.118	−8.069***
	Median age	−5.083	−0.799	6.143	0.737
	% White	8.530	4.139***	−3.037	−0.898
	% Black	3.491	1.084	−14.992	−3.411**
	% Hispanic	−0.085	−0.042	1.874	0.735
	% Native American	44.482	3.135**	23.824	1.632
	% Female head of household			44.756	3.795***
	% Poverty			−3.132	−0.616
	% Unemployed			9.667	1.212
	% High School graduate			7.052	1.445
	% Vacant households			−0.768	−0.194
	% moved last 5 years			−2.404	−0.872
	% Foreign born			−16.154	−3.830***
Spatial autocorrelation	P_s	0.639	26.335***	0.637	25.284***

[a] Two-tailed tests. Nonsignificant effects have no entry.

* ρ < .01;

** ρ < .01;

*** $\rho < .0.001$.

Table 5

Amphetamine Dependence/Abuse Undifferenced and Differenced Panel Models

		Undifferenced N=1628		Differenced N=1628	
Model Component	**Variable**	***b***	***t***	***b***	***t***
	Constant	−110.374	−0.161	86.188	0.721
	Linear time trend	14.943	1.798		
Retail establishments	Total retail	0.974	3.071**	−0.079	−1.479
Alcohol outlets	Off premise	7.040	3.381***	−0.094	−0.262
	Restaurants	−4.813	−3.245**	0.212	0.835
	Bars	14.283	3.499***	−0.287	−0.420
Demographics	Population (×1000)	−5.145	−3.025**	0.192	0.676
	Household size	−76.119	−0.912	−10.802	−0.881
	% Male	2.164	0.217	−1.953	−1.061
	Median household income (×1000)	−15.492	−6.989***	0.979	2.801**
	Median age	−24.770	−3.269**	0.539	0.422
	% White	13.001	5.945***	−0.925	−2.955**
	% Black	−0.831	−0.269	−0.302	−0.695
	% Hispanic	−8.128	−3.547***	0.751	2.299*
Spatial autocorrelation	P_s	0.334	20.097***	0.271	14.201***

[a] Two-tailed tests. Nonsignificant effects have no entry.

* ρ < .05;

** ρ < .01;

*** ρ < .001.