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Computational Neuroscience of Drug Addiction

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Chapter 11
Simulating Patterns of Heroin Addiction Within the Social Context of a Local Heroin Market

Lee Hoffer, Georgiy Bobashev, and Robert J. Morris

Abstract This study illustrates how the social structure of the heroin market can impact the physiology of heroin addiction and how heterogeneity of addiction patterns can be shaped by market dynamics. We use a novel agent-based modeling (ABM) approach to simulate possible neurophysiologic functions based on the collective self-organizing behavior of market agents. The conceptual model is based on three components: biological, behavioral, and social. Biological components are informed by mechanistic animal studies, behavioral component relies on studies of real-life human experiences with addiction, and social aspects are based on market research that describes the transactional and decision-making processes associated with the distribution of drugs within local drug markets. Using ABM, this paper unifies these three components to simulate how heroin addiction patterns are generated and shaped through heroin markets. The market model is based on data from an ethnographic study of a local heroin market and includes customers (users), street and private dealers, street brokers, police, and other potential market actors. Behavioral data is based on converting narrative descriptions and fieldwork observations into formal states and transitions, and a simple model of addiction process for the drug users is based on published peer-reviewed literature. Analysis of model-based simulations reveals "binge/crash," "stepped," and "stable" patterns in customer addiction levels.

11.1 Introduction

Substance use has both social and individual aspects. Internal pharmacological and neurobiological factors act as strong self-administration drivers (Koob and Le Moal 2005; Ahmed et al. 2007; Gutkin et al. 2006). At the same time, human substance

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use depends on drug availability (i.e., drug markets) and social environment (Hoffer 2006). Drug availability, in turn, is intertwined with drug demand and law enforcement activities. In this paper, we address a challenge of linking individual consumption patterns with both internal physiological mechanisms of addiction and external market activities. In particular, we attempt to answer the question: how do heroin markets shape users' addictions? While there is a broad body of science that tries to predict behavior based on neurobiology and physiology, our approach reverses this order by deducing physiological patterns from social behavior.

The choice of heroin for our research is based on two factors: the importance of heroin research to both basic science and public policy, and the availability of ethnographic data. Heroin, 6-monoacetyl morphine (6-MAM), is a psychoactive substance that both directly and indirectly influences the daily lives of millions of people each year. Complicating efforts to reduce the public health harms associated with its use is that addiction to heroin, like that to all psychoactive substances, involves complex biological and social/environmental factors. On one hand, the importance of the biology and addiction cannot be ignored. Clearly, addiction is a "brain disease." On the other hand, people use drugs in very specific social, cultural, and political contexts, and thereby experience addiction differently. These social environments affect drug use behaviors, as well as how harm associated with drug use is experienced by the user.

In the United States, as in most countries, an unavoidable component of heroin use is the illegal markets through which the drug is acquired. Since the Harrison Narcotic Act in 1914 making the drug illegal (Hanson et al. 2006) and Richard Nixon's inauguration of the war on drugs in 1969 (Musto 1987), more and more resources are spent each year in the United States unsuccessfully trying to undermine illegal drug distribution activities. The economic cost of this policy and its burden on our judicial system are well established (Musto 1987; Singer 2006). Research also has demonstrated how drug market activities, often framed and manipulated by this war, have negatively influenced the health behaviors of drug users (Kerr et al. 2005; Koester 1994; Zule et al. 2002).

As the hallmark method in cultural anthropology, ethnographic research entails gaining perspective on a social group's beliefs and behaviors by the researcher becoming an ad hoc member of the group under study (Bernard 1988; Patton 1980; Hammersley and Atkinson 1993; Fetterman 1998). This is an inductive and interpretive methodology. Since the 1960s, ethnography has been the primary methodology used for in-depth research studies of illegal drug distribution and dealing operations (Preble and Casey 1969; Agar 1973; Adler 1985; Bourgois 1997). Researchers take considerable time and effort with participants to overcome suspicion and develop the rapport necessary to collect credible accounts of illegal drug dealing. The method requires observing interactions and behaviors to validate findings. Because of the significant rapport necessary to collect this type of data, ethnography has been suggested as the only valid research approach in this context (Bourgois 1997).

Hoffer's ethnographic studies (Hoffer 2006) suggest that acquiring heroin through a market is highly variable and inherently promotes intense short-term fluctuations in individual addiction levels. Heroin users, however, attempt to maintain

their addictions, which engage them in a dynamic interaction between their biology and the market. Agent-based modeling techniques allow one to describe and simulate individual behavior as well as the interactions between individuals. At the same time, agent-based models (ABM) allow incorporation of the dynamic of drug effects *within* an individual. Thus, ABMs provide a link across temporal and physical scales as well as combine research findings from tangential disciplines such as the social and basic sciences. In a previous publication (Hoffer et al. 2009), we have concentrated on the market aspects of social dynamics. In this paper, we focus on the inverse relationship, that is, the individual neurophysiologic factors that are shaped by market activities.

11.1.1 Individual and Social Patterns Impacting Heroin Addiction

Despite the considerable harm associated with heroin use, some people addicted to the drug seem able to maintain stable addictions over considerable time periods. However, for most people this stability is unachievable. Many factors often conspire against heroin addicts: money runs out, the drug habit gets too unmanageable, or both. Eventually, some users willingly or unwillingly change their habits or even quit. Even dealers and others with apparently limitless access to the drug can get "tired" of using, attempt to cut back, or otherwise reduce consumption. Under societal and health pressures, users can go into drug-treatment programs, or they may be incarcerated, both of which can effect drug habits.

Because of the variety of patterns in heroin use over time and the challenges of measuring them accurately, characterizing these patterns using conventional methodologies has proven extremely difficult. Typically for behavioral studies, data are extrapolated by asking heroin users to self-report how many days in the last 30 days they used a drug[1] and how much they typically used each day/occasion. These methods are clearly inexact and do not adequately address variations in use. For example, a typical user's response to the questions above might be, "I use heroin twice a day, but there were several days last month when I only used once and a few where I used three times." Such responses do not fit formal survey question formats.

A large body of biological research focuses on the animal models of drug self-administration under controlled experimental conditions. However, human heroin users do not simply receive heroin whenever they want it. Rather, they purchase it within the context of a market and through relationships with other market participants, that is, dealers. This aspect of maintaining an addiction introduces considerable variation. In human studies, researchers are only able to capture a rough estimate of how much heroin a user consumes over a specific timeframe (i.e., 30 days),

[1] This paraphrases a question from the RBA (Risk Behavior Assessment) questionnaire (National Institute on Drug Abuse 1993), commonly administered by professional interviewers and considered the gold standard in community-based research studies funded by the National Institute on Drug Abuse. Other instruments use different questions but similarly remain oriented to a specific timeframe.

but little information concerning their overall pattern of use. Questions remain, such as: how consistently do heroin users ingest the drug? How often are such patterns disrupted? To generate answers to these questions, ABMs can simulate these behaviors by designing agents who are addicted to heroin and then allowing them to acquire and use the drug in association with other agents. In addition to building agents with heroin addictions, our model includes resources (cash and heroin) that could be exchanged by the agents, the relationships necessary to acquire the drug, and the places where users must go to facilitate transactions. This more *contextualized* version of heroin addiction is what our simulation attempts to characterize.

The heroin market modeled in the Illicit Drug Market Simulation (IDMS) project detailed below is not intended to answer all the questions about the interactions between the individual and the market; however, this is the first attempt to apply a multiscale systems approach to addiction modeling. The approach provided is experimental and could be used to generate hypotheses, as well as provide useful insights for designing prevention and treatment interventions. For example, among the agents in our model, there were critical times when their addiction became out of control. In the real world, these situations might cause users to (1) enter treatment in an effort to reduce their addiction, (2) combine their resources with other users, potentially increasing their health risks, and/or (3) commit crimes to support their increasing drug habit.

As a result, policymakers can gain a more detailed understanding of what is required to construct effective policy by looking at simulations of the patterns in heroin addiction and how these patterns are shaped and vary over time. Instead of being restricted to individual narratives of addiction, this simulation demonstrates that addictions are dynamic and patterned through the market context in which they exist.

11.1.2 Internal Components of Heroin Addiction

A large body of biological, clinical, neuropharmacologic, and ethnographic research describes heroin addiction from individual perspectives. In our study, we simulate experienced users and do not focus on heroin initiation and neurophysiologic processes associated with initial euphoria in a naïve subject. We only consider the three main features associated with repeated heroin use, such as withdrawal, tolerance, and a user's drug habit, that is, addiction.

Withdrawal is a key feature of most addiction, but is particularly relevant for those addicted to heroin. After a certain length of time of repeatedly using the substance, a person addicted to heroin must continue to use it or else become sick. This withdrawal syndrome involves intense symptoms such as chills, fever, runny nose, intense muscle pains, headaches, constipation and/or diarrhea, insomnia, anxiety, depression, and crawling flesh. Withdrawal from heroin is incapacitating and persists for approximately 2 weeks after an addict discontinues use. However, symptoms are alleviated seconds after an addict in withdrawal uses the drug. Thus, heroin addicts commonly use the terms "fixing" and "getting well" to refer to injecting heroin, implying correcting and/or returning to a state of well-being.

Tolerance is another important feature of heroin addiction, and refers to needing ever-increasing amounts of the drug to feel the euphoria it produces. After consistently using a certain amount, a user must use more (or a higher level of potency) to experience a high. Tolerance is a neuropsychological consequence of consistent use. Eventually, because achieving a high may require using amounts of heroin that have become unaffordable to the user, "staying well" or maintaining their addiction to avoid withdrawal, is often a primary motive for addicts. As a result of tolerance, people addicted to heroin often use the drug to prevent withdrawal rather than to induce euphoria. While, on balance, avoiding withdrawal might be more motivating to heroin addicts who are maintaining their drug habits, this does not mean users are not still motivated to get high, that is, overcome their tolerance. After all, the euphoria keeps heroin users wanting more.

Both tolerance and withdrawal are diagnostic terms characterizing substance dependence disorders, classified by both DSM-IV (American Psychiatric Association 2000) and ICD-10 (Isaac et al. 1994) diagnostic manuals. People who are dependent on heroin frequently report withdrawal and tolerance to the drug, as well as cross-tolerance to other opiates, and these criteria are often the two most common indicators of heroin addiction.

Another term relevant to this paper is "heroin habit." Unlike terms defined by the medical community, the term heroin habit is part of the lexicon of heroin users. In short, a heroin habit is how heroin users describe their addiction and typically refers to an amount of drug that addicts believe they need to consistently use to avoid withdrawal. Another way to understand a heroin habit is the typical dose a user reports using in one day.

Because heroin is a commodity, heroin habits are often framed monetarily. A "$20-per-day-habit" straightforwardly means the user is using approximately $20 worth of heroin per day. In the author's research (Hoffer 2006), this $20 dose corresponded to a "pill" of black tar heroin, the smallest unit of heroin sold in the market. If a heroin addict does not use equal to or more than their habit, they will eventually get sick and go into withdrawal. Maintaining a habit refers to a heroin user's ability to consistently use this baseline level of heroin. Simply, a user's habit is what heroin addicts seek to maintain, and is the subject of this paper.

Finally, we introduce a working technical term, "addiction level," which describes the amount of drug (in standard units: 1/120 of a gram) a user consumes per day. It is closely related to habit and, in the case of stable price-to-dose ratio, there is an exact one-to-one relationship. However, when price varies for the same dose depending on the market condition, addiction level becomes a better measure of use than a habit expressed in dollar amounts. Addiction level is thus a convenient measure (similar to standard drinks in alcohol research) to use in modeling and analysis.

11.1.3 Social and Market Components of Heroin Addiction

The social environment surrounding the user can be quite complex and can involve drug-use "buddies," drug dealers, friends, relatives, neighbors, co-workers, treatment professionals, and law enforcement professionals. While it is challenging to identify the main social groups and components associated with the individual's drug use, in our research we consider the closed social circle that controls the supply of the drug. A real-life heroin market differs from the controlled supply environment in animal experiments and is a product of social behavior.

The global economy of heroin involves production, sales/exchanges, and use. Local social markets are strongly impacted by both regional drug trends (Curtis and Wendel 2000; Agar et al. 1998; Agar and Reisinger 2002; Hamid 1992) and local use patterns. Because this study focuses on individual addiction patterns, we make certain assumptions about the stability of drug supply and consider a micro-level *social space* in which transactions occur in the local distribution of a drug. Unlike buying a product in a store, buying and selling heroin is not a depersonalized activity. In this context, prices, logistics, and credit are all unregulated and potentially negotiable (Johnson et al. 1985).

For this modeling project, we made decisions about the level of detail describing the market. We considered market complexity, relevance of the details to the research question, and availability of the data. For example, although people who use heroin also often use other drugs, for the purpose of this model, we only consider their heroin addiction. We also don't consider the intricacies of deal negotiation, rather, we focus on the fact that the deal was eventually made and heroin was obtained by the user.

11.2 The Data

Because heroin use and heroin dealing are illegal and stigmatizing behaviors, especially in the United States, collecting data on these activates is no simple matter. Conventional methodologies such as surveys do not accurately capture these complexities; one cannot realistically survey the participants of a heroin market.

Information on the heroin market presented in this manuscript was collected during eighteen months of ethnographic research conducted with heroin users and dealers in Denver, CO (Hoffer 2006). Because of the ethnographic nature of the study, information was obtained through narratives of and fieldwork observations with participants. One of the innovations of our study was to convert the narratives into events, transitions, and transition probabilities that allowed us to build an agent-based model. In-depth, extensive, and historical accounts of heroin users, dealers, and middlemen (i.e., brokers), and their interactions in the market over time were used for programming these groups as "agents" in the simulated market. The advantage of ethnographic research over surveys is that the data are collected on social actions linked in sequence, as well as to participant belief systems. What heroin users are describing and how they are acting are easier to interpret if the researcher is "there" when the action takes place. This perspective was essential for determining and setting simulation parameters, evaluating agent logics, debugging programs, and most important, interpreting results.

A description of the heroin user's daily activities can be transformed into model parameters in two ways. One way is the logical sequence of events related to market activities. For example, when users want to buy drugs, they can go to a private dealer, if they know one, or go to the open marketplace. At the market, users can search for a street dealer and engage in a deal if they find a dealer with heroin. Alternatively, they can go to a street broker. A broker is a drug user who connects customers and dealers.

The second way is providing distributions of numeric parameters, such as frequencies of events and conditional probabilities. Although these parameters are not measured exactly, ethnographic studies can provide ideas about the ranges and distributions of parameter values. For example, several drivers can make a user seek heroin. One driver is related to a user's withdrawal. This driver is guided by habit and heroin pharmacodynamics from the last use. Another driver could be related to the external cueing or other reasons not associated with the last dose. In the latter case, the frequency of use or the distribution of such events is difficult to assess precisely, but long-term ethnographic observations can provide reasonable insight about the range and shape of the distribution. In the case of withdrawal as the driver, we have used published pharmacokinetic data calibrated to humans. Because each individual has different metabolism and response to a drug, we used a distribution with reasonable parameter ranges.

11.3 The Model

While ethnographic description provides considerable information regarding various aspects of heroin addiction, we have selected only those elements that are relevant to market functioning and individual behaviors associated with selling, buying, and using heroin. Other components such as treatment, criminal justice processes, and family relations were not included in the model. Thus, the agent-based model developed for the Illicit Drug Market Simulation (IDMS) contains six different agent types. In particular, customers, brokers, sellers, and private dealers are the most behaviorally complex agents. These agents can learn about market, change their level of addiction based on heroin use, choose transaction partners, and modify their activities based on past experiences. Police and homeless agents are less complex. Hoffer et al. (2009) describes more specific details. In the simulation study presented here, we used 360 agents: $n = 200$ customers, $n = 25$ private dealers, $n = 20$ street dealers, 15 street brokers, and $n = 100$ homeless agents.

Agents in the IDMS function according to agent rules. These rules specify the states in which the agent can be (e.g., seeking money, seeking heroin, buying heroin, using heroin) and transitions between these states (e.g., *if* found a dealer *and* the dealer has enough heroin *then* purchase the desired amount of heroin or *if* purchased heroin can *either* use right away *or* go home, with certain probabilities of making the choice). These states, and conditional decisions and the rates of transitions between the states for an agent, are represented in a form of a state diagram (Fig. 11.1). For example, a drug user could be in a satiated state but, after a while, the withdrawal symptoms become more pronounced according to a within-agent pharmacological model. When the level of withdrawal reaches a certain point, the user changes the state to "seeking the drug."

Because of the complexity of the full market model and the space limitation of this manuscript, the authors are unable to provide complete documentation for the IDMS model here. To find a narrative description, table of parameters, and the programming code for this model, the authors invite researchers to visit http://www.case.edu/artsci/anth/Hoffer.html. Copies of the simulation also are available upon request.

In this paper, we focus only on the 200 customer agents, or the main users, of heroin. Their actions are primarily focused on (1) maintaining a drug habit (set randomly for each agent as an initial condition); (2) using more heroin than their habit when possible to get high; and (3) attempting to avoid running out of heroin and entering withdrawal. If users consistently use more heroin to feel euphoria, the increased use can reset their heroin habit to the greater amount. If users return to their previous amount, they will get sick until their body readjusts. Such increments in use are not random. Rather, they tend to be organized by the heroin units sold in the market. Using the "$20-per-day-habit" as an example, if heroin users want to feel high, they cannot simply purchase a little more heroin, that is, less than a pill. Instead, they would have to purchase two pills. Increments (and decrements) in use correspond to the heroin available.

Furthermore, the heroin-using agents in our simulation were dependent on the capacity of the market; while some would use all their resources to purchase the maximum available drug, others could be more prudent and purchase the amount they expect to need in the near future. Potency of the drug was standardized and linearly associated with heroin unit size.

Market organization shapes a user's ability to acquire the drug (Hoffer 2006; Curtis and Wendel 2000). For example, in local communities that have an open-air market in which anyone can buy heroin at any time, the features of the market (i.e., open access, constant availability) will directly influence a user's ability to maintain his or her addiction. Similarly, if no open-air markets exist, such as in many smaller, rural communities, a heroin user's personal relationship with a dealer(s) directly determines access. We consider contingencies that organize a user's ability to acquire the drug structural components of heroin markets.

A no less relevant issue concerns how heroin users navigate social relationships within these market structures. In other words, while heroin users might have biological motivations to use and knowledge about where to acquire the drug, these prerequisites are put into action only within a set of social norms and/or belief systems. In other words, there are rules customers (and dealers) must know and follow (Hoffer 2006).

While the complete model and market simulation outcomes are presented elsewhere (Hoffer et al. 2009), the findings below only concentrate on how customer

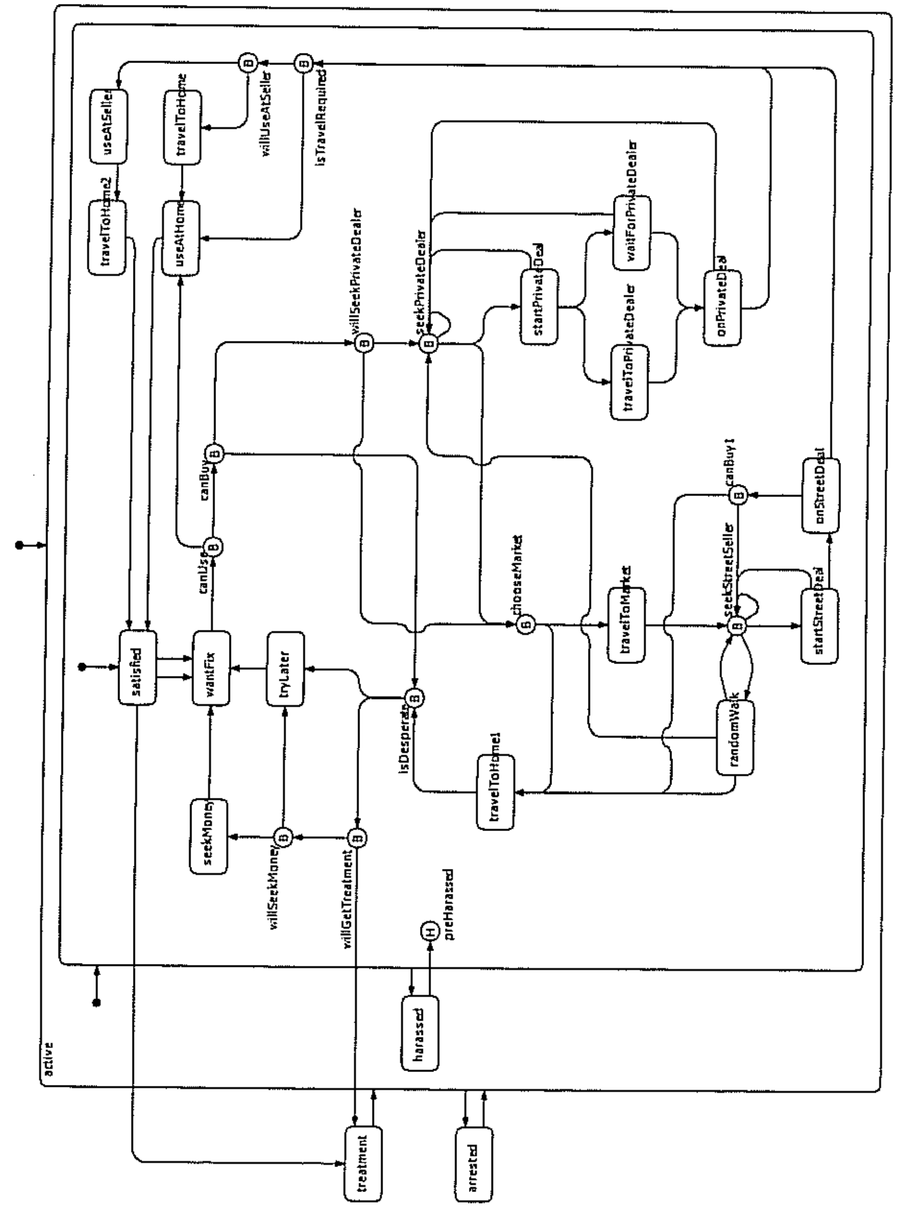

Fig. 11.1 A state diagram representing the states and potential transitions between the states for a heroin user (customer)

agents' addictions were operationalized. Each customer agent in the simulation was assigned four initial conditions, including (1) an addiction level, (2) a drug concentration level, (3) an inventory of drug, and (4) money. A customer agent's addiction level is measured in drug units the customer sought to maintain the addiction. In the model each agent was initially assigned a random number drawn from a normal distribution with the mean of 120 and a standard deviation of 55. This addiction level roughly reflects an addict's "heroin habit", as described above. The concentration level represented the current amount of drug in the agent's body. This number also was drawn from a normal distribution with a mean of 15 and a standard deviation of 45.

The processes of satiation, withdrawal, tolerance, and habit are the key features that distinguish our model from usual behavioral models. By modeling these processes, we introduce neurobiological and physiological drivers that create sustainable support for drug use. Because this is an introductory "pilot" model, we used a simple functional relation based on drug concentration in the body to describe satiation and withdrawal. Assuming that drug injection increases drug concentration very quickly, we ignore the processes of rapid increase of concentration in blood and assume that it happened instantly after the injection. The concentration C stays constant for some short period of time τ, and then gradually decreases according to the first order pharmacokinetic equation:

$$dC/dt = -\lambda Ct \quad \text{for } (t > \tau),$$

where λ is the rate at which drug concentration decreases and depends on the individual metabolism. If drug concentration is below a certain threshold, the message for seeking a fix is generated and the agent starts looking for the drug. Although this process does not represent the actual heroin concentration, it mimics the dynamics and the timing of the need for the new fix. Tolerance is introduced in an implicit way through the change in the addiction (or habit) level. The habit depends on the accumulated dose over a prolonged period and represents the change in the habit, that is, it is linearly increased as the user consumes more heroin than targeted by his or her addiction level, and linearly decreases in the event that the customer did not use heroin.

The heroin used and sold by agents in the IDMS corresponds to the units of heroin available in the market: 10-, 30-, 40-, 60-, 120-, and 360-unit bundles. These bundles parallel actual units sold in the market in both cost and proportionality, namely, $20 for a pill (10 units); $40 for 2 pills (30 units); $50 for 3 pills (40 units); $70 for a half-gram (60 units); $130 for a gram (120 units); and $330 for 3 grams (360 units). Considerable data from the ethnographic research (Isaac et al. 1994) contributed to determining this pricing scheme.

In the event that a customer agent had an addiction level occurring between these amounts, they had to select what amount to purchase and use. If they had the resources, customer agents always selected the larger amount. For instance, an agent with a 37-unit addiction level could only buy 30 or 40 units worth of heroin, and if he or she had $50 or more the customer agent purchased 40 units (3 pills). Customer agents used heroin units that best aligned with their addiction level in this manner until they ran out of inventory. If they possessed fewer units of drug than what they wanted to use, they used the remainder of their inventory. Customers also used heroin randomly, that is, when they were not otherwise motivated to do so.

After running out inventory, the customer evaluated if they could purchase heroin. Customers with money either purchased as much drug as they could or just enough to cover their addiction level. This decision was randomly determined. Customers could only purchase heroin at the full retail prices, and most customers received an income that they used for this purpose. Incomes were distributed based on one of three pay schedules: weekly, every 2 weeks, or monthly. To reflect the potential for less-organized income sources, IDMS also included times when customers randomly received money.

Customer agents could engage in the market and purchase heroin in one of three ways: going into the public (open-air) market and purchasing from a street seller, using a broker (middleman) in this market, or using a private dealer not in an open-air market. Purchases from a street seller were straightforward and direct; customers could see street sellers. If a customer agent transacted with a broker, the sales process was indirect. The customer located a broker who was visible to him or her, but the broker made the sale with a street seller or private dealer. Customer sales through private dealers required a customer knowing the location of the dealer. These locations were identified after customers used a broker for a certain number of sales with that dealer. Private dealers and customer agents transacted in two ways: either the private dealer delivered drugs to the customer or, more typically, the customer traveled to the dealer's location.

Agents selling heroin processed each transaction separately and often had competing transactions that delayed completion of sales. Street sellers and brokers also were subject to arrest from police agents roaming the open-air market and thus would change location. Customers maintained an up-to-date list of sellers and locations in which they had successful transactions, returning to locations in descending order of success the next time they needed to purchase the drug.

The agent rules directing seller and customer behaviors clearly do not include all decision-making processes or the complexity associated of heroin-market operations. Nonetheless, they do include a fairly robust and dynamic set of criteria and realistically incorporate variation in these behaviors. It was not always easy for customer agents to purchase the heroin they wanted to maintain their heroin addiction levels.

11.4 Results

The initial and final distributions of addiction levels for 200 customers in the 12-month simulation are compared in Fig. 11.2. The mean addiction level for the sample at baseline was 122 units and 156 units at 12 months. With one exception, these distributions are relatively similar. The exception was that at 12 months, considerably more customer agents had addiction levels of 250 or above ($n = 1$ vs. 25).

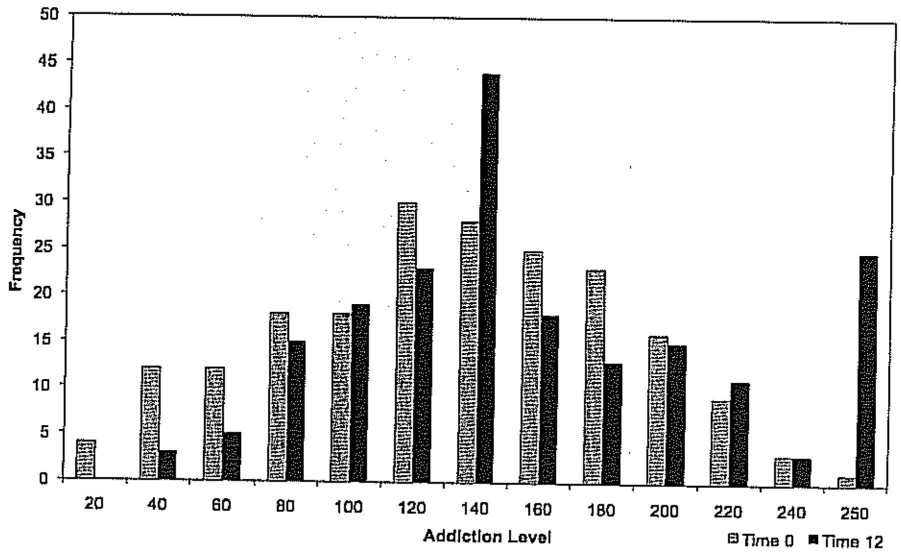

Fig. 11.2 The distribution of customer-addiction levels, in units, for the sample of $N = 200$ customers at baseline (Time 0) and 12 months postbaseline (Time 12)

However, this finding is not out of line after considering individual variations observed in the patterns of addiction over time.

Although the overall distribution of addiction levels was important and within the boundaries of what would be expected in a real sample of heroin users, the major focus of this manuscript is to identify patterns in addiction levels among agents over time. Using the initial mean addiction level as a guide, we randomly selected 15 customers around the mean, as well as two standard deviations above and below it, for more detailed investigation. Although the complete analysis of all 200 agents incorporating multiple simulation runs is ongoing, several trends in this initial random sample are reported below. Figures 11.3, 11.4, 11.5 and 11.6 show individual customer agent addiction levels over the entire 12 months of one random simulation run.

First, some customer agents exhibited an intense and brief time period in which their addiction level increased and then decreased. These long-term binges were defined when an agent's addiction doubled or more over a timeframe of 1 month. These increases were then immediately followed by a sharp decline in addiction level, usually of the same magnitude. Figures 11.3 and 11.4 show agents representing this pattern.

This pattern likely contributed significantly to the addiction level discrepancy between the initial and final distributions. Ending the simulation at 12 months was arbitrary, and addiction levels of 250 and above are likely for customers who are on the upward slope of a binge (Fig. 11.5).

Overall, this binge/crash pattern can be imagined behaviorally as customers who are trying to overcome their tolerance rapidly, but then run out of money to consistently maintain such a high addiction level. Heroin users often report these sorts

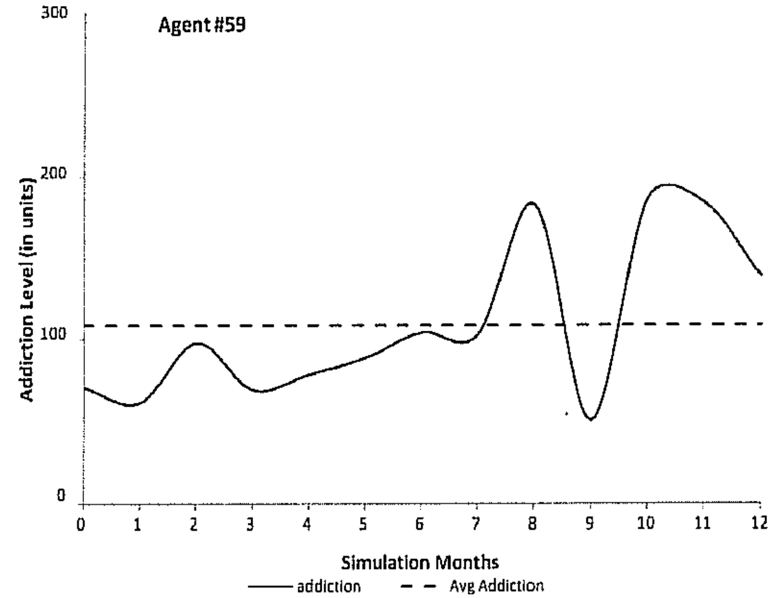

Fig. 11.3 The addiction level, in units, of agent #59 over the course of a 12-month simulation. This agent shows a binge/crash pattern in the agent's addiction level

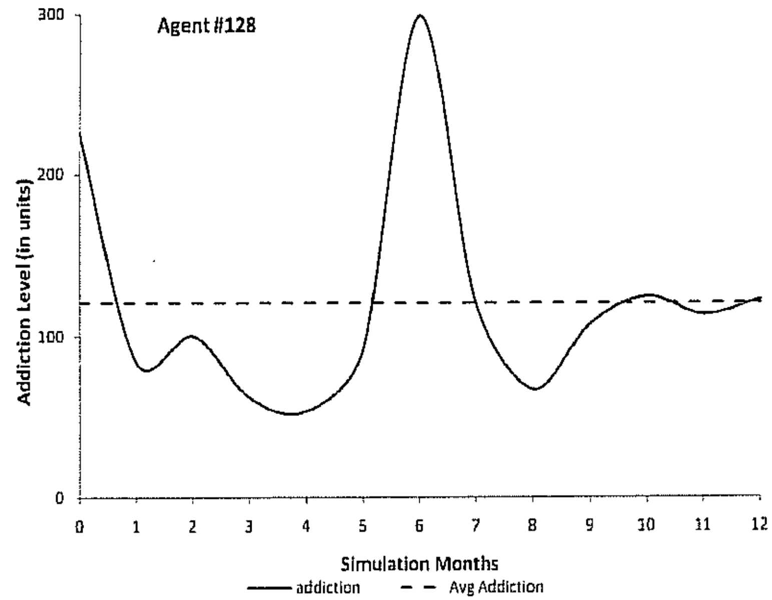

Fig. 11.4 The addiction level, in units, of agent #128 over the course of a 12-month simulation. This agent shows a binge/crash pattern in the agent's addiction level

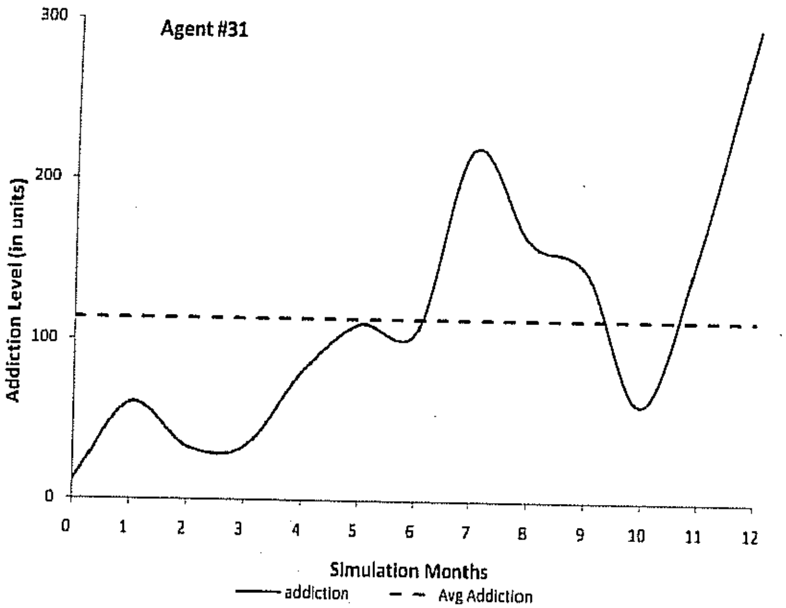

Fig. 11.5 The addiction level, in units, of agent #31 over the course of a 12-month simulation. This agent shows a stepped pattern to increasing the agent's addiction level. This agent also may be exhibiting the beginning of a binge/crash pattern at month 10

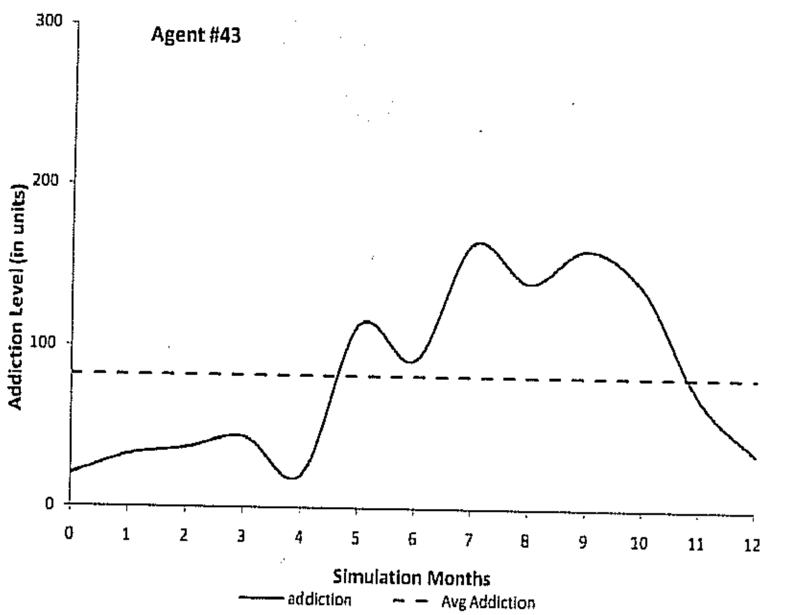

Fig. 11.6 The addiction level, in units, of agent #43 over the course of a 12-month simulation. This agent shows a stepped pattern increasing the agent's addiction level

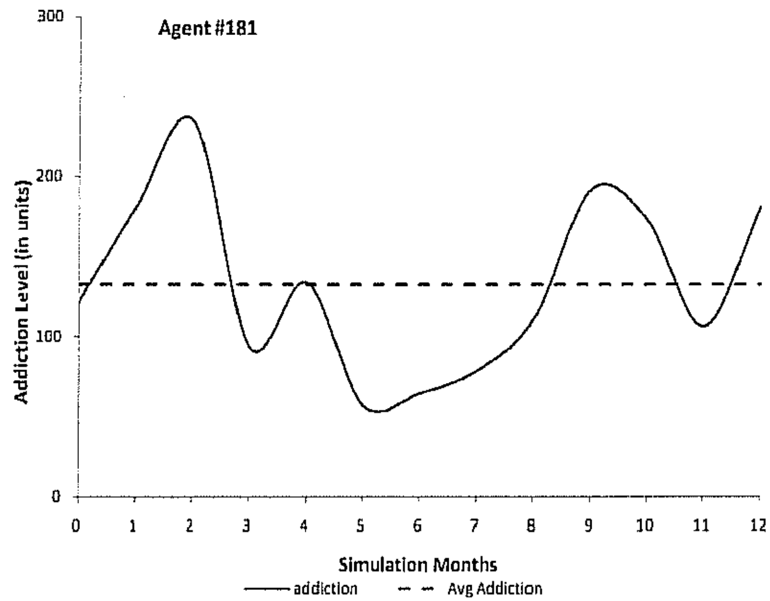

Fig. 11.7 The addiction level, in units, of agent #181 over the course of a 12-month simulation. This agent shows a stepped pattern reducing the agent's addiction level

of binge/crashes, especially when they buy heroin using money that they acquire haphazardly or unexpectedly from crime.

Contrasting this binge/crash pattern, another pattern observed was a gradual or stepped pattern of addiction levels. In this pattern, addiction levels increase for 1 month, are followed by a plateau period, and then followed by another increase. The pattern is then repeated as the addiction level decreases. As in the binge/crash pattern, the addiction level is also increasing and decreasing; however, the timeframe here is more extended. Figures 11.5 and 11.6 show agents with this pattern.

Most stepped patterns produced overall increases in addiction levels. However, in a few instances, addiction levels decreased in this manner. Overall, increases and reductions seemed to correspond to the initial addiction level of the agent. If the addiction level started low, it could increase gradually, while if it started high, it might diminish over time, as shown in Fig. 11.7.

The gradual increases in addiction levels presented in the stepped pattern correspond to a common narrative in becoming addicted. Users often report gradual increases in heroin use over several months: they might start out "chipping" (i.e., using only on the weekends) and then proceed over time to everyday use. Many heroin addicts report that often they slowly increase the amount of heroin that they use to overcome tolerance.

The final pattern of customer agent addictions is shown in Fig. 11.8. This pattern represents stability over time, meaning that the agent's addiction level remains relatively constant throughout the entire 12 months of the simulation. Our initial analysis suggests that this pattern appears less frequently than the other patterns.

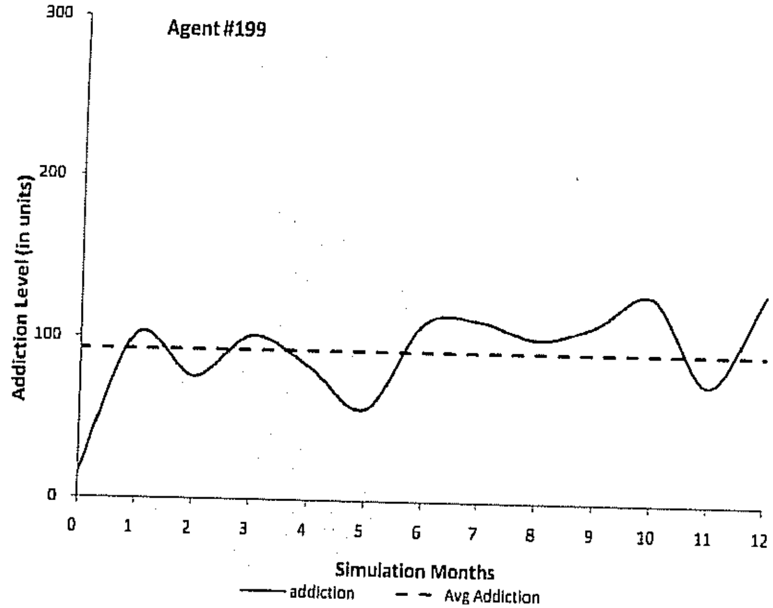

Fig. 11.8 The addiction level, in units, of agent #199 over the course of a 12-month simulation. This agent shows a stable pattern in the agent's addiction level

It also seems most dependent on an agent's initial addiction level, occurring most often at relatively lower initial addiction levels. This result has certain face validity because large addictions are inherently more expensive to maintain.

Stable patterns in addiction levels also are noted in the behavior of heroin users. Heroin users who have considerable experience with their addiction show remarkable resilience in maintaining affordable and manageable levels of use. Although rare in our initial analysis, it is important to recognize agents who have developed behaviors to meet the needs of their addiction and who could do so consistently through the contingencies of the market.

As noted, a complete analysis incorporating multiple simulation runs and investigating all 200 customer agents is in progress. Nonetheless, initial patterns identified in this preliminary analysis are promising. The authors hope to better characterize the binge/crash, stepped, and stable patterns, as well as recognize additional patterns using ABM.

11.5 Limitations

It is important to recognize that the model presented here addresses *only* a limited dimension of the market's overall influence on heroin users' addictions. One important missing component is the influence of other heroin users on a heroin user's behavior. People addicted to heroin often rely on their associates to share the cost

of drugs. This is particularly relevant when users run out of their own funds (see below). The current version of the model is focusing on the incorporation of the full range of processes associated with purchasing the drug. It also is currently unclear how factors associated with the cost or the processes of sales contribute to the patterns observed. We are currently working on the incorporation of this component into the next version of the model.

Other issues not included in the model involve how heroin users actively seek to reduce their level of addiction. Heroin users who believe their addiction is becoming out of control often enter treatment to reduce their use and/or substitute other opiate class substances to reduce their dependence on heroin (Koester et al. 1999). We model entering and leaving treatment as a random process associated with the level of addiction and availability of resources to buy the drug, however, we don't track the detailed process of relapse and reentry as was considered, for example, by Zarkin et al. (2005). Polydrug use is not currently included in the model.

In this model, the variety of alternatives for obtaining money and heroin is represented in two random processes: receiving windfalls and seeking money, when the agent is actively seeking money and can find it with some probability. In the real world, heroin addicts are much more industrious and find ways to acquire heroin in these situations. Some of the ways users acquire heroin without money include partnering with fellow heroin users (as noted above), committing crimes to get money, or getting heroin on credit from dealers (Hoffer 2006). Currently these behaviors are not included in the model, and the windfall and seeking money processes are calibrated to represent the frequency with which a user is able to acquire drugs.

Despite the limitations of IDMS, this model takes an important step toward providing a comprehensive understanding of heroin addiction by specifically incorporating individual features of a heroin addiction expressed within the context of a dynamic social environment (the market), in which heroin and cash are exchanged.

As this project remains ongoing, the authors hope to address some of these important limitations and to verify findings from this model through independent data collection. In particular, combining ethnographic research with Ecological Momentary Assessment, where the users record their daily heroin use and purchasing patterns, the authors will obtain the data to validate decisions and patterns assumed in the model.

11.6 Conclusion

This paper illustrates how the social fabric of a heroin market can impact the physiology of heroin addiction and how heterogeneity of addiction patterns can be shaped by the events in the market. Two innovations are specifically notable: first is a new conceptual use of ABMs, where the focus is on the within-agent dynamics under the influence of the surrounding social landscape. This approach complements the more traditional use of ABM, which studies self-organization of the complex system due to the interaction of its members. The second innovation is an attempt to uncover physiological trends and patterns that are generally not measurable in real life. Future studies might provide ways to measure partial components of the model such as drug concentration or craving to validate patterns. However, this research will never be able to provide an uninterrupted history of these dynamics available via ABM. This study shows the utility of the systems approach, where simple but realistic rules and equations provide insight into a real-life problem.

Using the results of this study, we would argue that heroin addiction and perhaps some other addictions, such as addiction to crack or methamphetamine, cannot be fully understood without incorporating ways in which drug users acquire the drug within these environments. Thus, as the next stage in our project, we are collecting daily drug use reports from active heroin users via interactive voice response (IVR) or smartphones. These data will greatly facilitate both setting market simulation parameters, as well as collecting the data necessary to validate simulated addiction patterns and outcomes.

Finally, the real-world application of the findings reported here are significant in a number of ways. For addicts attempting to manage their addiction, uncontrolled increases and decreases in their level of addiction are nearly unavoidable. For frontline health professionals working with addicts, being able to identify and work with specific patterns of addiction in devising strategies to minimize harm might be extremely beneficial. These patterns also may prove useful in anticipating opportunities when addicts might be more receptive to treatment alternatives. Developing ABMs that included biologically motivated and socially meaningful behavior represents an exciting and novel approach for researching the complexity of drug addiction.

References

Adler PA (1985) Wheeling and dealing: an ethnography of an upper-level drug dealing and smuggling community. Columbia University Press, New York

Agar M (1973) Ripping and running. Academic Press, New York

Agar M, Reisinger HS (2002) A heroin epidemic at the intersection of histories: the 1960s epidemic among African Americans in Baltimore. Med Anthropol 21:189–230

Agar M, Bourgois P, French J, Murdoch O (1998) Heroin addict habit size in three cities: context and variation. J Drug Issues 28:921–940

Ahmed SH, Bobashev GV, Gutkin BS (2007) The simulation of addiction: Pharmacological and neurocomputational models of drug self-administration. Drug Alcohol Depend 90:304–311

American Psychiatric Association (2000) Diagnostic and statistical manual of mental disorders: DSM-IV-TR. Author, Washington

Bernard HR (1988) Research methods in anthropology. Sage, Newbury Park

Bourgois P (1997) In search of respect: selling crack in El Barrio. Cambridge University Press, New York

Curtis R, Wendel T (2000) Toward the development of a typology of illegal drug markets. In: Natarajan M (ed) Illegal drug markets: from research to prevention policy. Criminal Justice Press, Monsey, pp 121–152

Fetterman D (1998) Ethnography: step by step. Sage, London

Gutkin BS, Dehaene S, Changeux JP (2006) A neurocomputational hypothesis for nicotine addiction. Proc Natl Acad Sci 103:1106–1111

Hamid A (1992) The development cycle of a drug epidemic: the cocaine smoking epidemic of 1981–1991. J Psychoact Drugs 24:337–348

Hammersley M, Atkinson P (1993) Ethnography: principals in practice, 2nd edn. Routledge, New York

Hanson GR, Venturelli PJ, Fleckenstein AE (2006) Drugs and society, 9th edn. Jones and Bartlett, London

Hoffer L (2006) Junkie business: The evolution and operation of a heroin dealing network. Wadsworth, Belmont

Hoffer LD, Bobashev G, Morris RJ (2009) Researching a local heroin market as a complex adaptive system. Am J Community Psychol 44:273–286. doi:10.1007/s10464-009-9268-2

Isaac M, Janca A, Sartorius N (1994) ICD-10 symptom glossary for mental disorders. Division of Mental Health, World Health Organization, Geneva

Johnson BD, Goldstein PJ, Preble E, Schmeidler J, Lipton DS, Spunt B, Miller T (1985) Taking care of business: the economics of crime by heroin abusers. D.C. Heath and Company, Lexington

Kerr T, Small W, Wood E (2005) The public health and social impacts of drug market enforcement: A review of the evidence. Int J Drug Policy 16:210–220

Koester SK (1994) Copping, running and paraphernalia laws: contextual variables and needle risk behavior among injection drug users in Denver. Human Organ 53:287–295

Koester SK, Anderson KT, Hoffer L (1999) Active heroin injectors' perceptions and use of methadone maintenance treatment: cynical performance or self-prescribed risk reduction. Subst Use Misuse 34:2135–2153

Koob GF, Le Moal M (2005) Neurobiology of addiction. Elsevier, New York

Musto D (1987) The American disease: origins of narcotic control. Oxford University Press, New York

National Institute on Drug Abuse (1993) Risk behavior assessment, 3rd edn. National Institutes of Health, Rockville

Patton MQ (1980) Qualitative evaluation and research methods, 2nd edn. Sage, London

Preble E, Casey J (1969) Taking care of business: The heroin user's life on the street. Int J Addict 4:1–24

Singer M (2006) Something dangerous: emergent and changing illicit drug use and community health. Waveland Press, Long Grove

Zarkin GA, Dunlap LJ, Hicks KA, Mamo D (2005) Benefits and costs of methadone treatment: results from a lifetime simulation model. Health Econ 14(11):1133–1150

Zule WA, Desmond DP, Neff JA (2002) Syringe type and drug injector risk for HIV infection: a case study in Texas. Soc Sci Med 55:1103–1113