A BEHAVIORAL ECONOMIC ANALYSIS OF POLYDRUG ABUSE IN HEROIN ADDICTS

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ABSTRACT

Polydrug abuse is common among substance abusers, but few empirical or theoretical methods accurately characterize this phenomenon. This chapter describes a simulation paradigm that was developed to apply a behavioral economic analysis to understanding polydrug abuse. Heroin abusers "purchased" drugs as the price of drugs or income varied. In Experiment 1, heroin price rose while prices of other drugs and income remained constant. Heroin purchases significantly decreased as heroin prices increased. As price of heroin rose, valium and cocaine purchases increased, and cross-price elasticity coefficients indicated these drugs substituted for heroin. In Experiment 2, prices of both heroin and valium increased separately to determine symmetry of the substitution effect. While valium substituted for heroin, heroin purchases were independent of valium prices. Marijuana and alcohol purchases were independent of valium price, but both these drugs were weak substitutes for heroin. In Experiment 3, income rose while prices remained constant. At some changes in income, demand for heroin and cocaine was income elastic, with purchases rising in greater proportion than income. Marijuana, alcohol, and valium purchases did not vary significantly as a function of income. Choices in this simulation were very reliable both between and within subjects. Moreover, drug choices in the simulation were correlated with drug use as determined by urinanalysis testing. These results are discussed in terms of the utility of a behavioral economics approach for characterizing polydrug abuse.

Nancy M. Petry
Department of Psychiatry
University of Connecticut
School of Medicine
263 Farmington Avenue
Farmington, CT 06030-2103

Warren K. Bickel
Department of Psychiatry
University of Vermont
38 Fletcher Place - Ira Allen School
Burlington, VT 05401

Alcoholics and illicit drug users often consume a wide variety of drugs (Ball & Ross, 1991; Hubbard et al., 1989; Hammersley, Forsyth, & Lavelle, 1990). For example, 50, 33, 47, and 69% of heroin addicts applying for methadone treatment are regular users of alcohol, benzodiazepines, cocaine, and marijuana, respectively (Ball & Ross, 1991). Prevalence of marijuana use among cocaine- and alcohol-dependent patients ranges from 25 to 70% (Higgins et al., 1991; Hubbard, 1990; Miller et al., 1989; Schmitz et al., 1991). Polydrug abuse presents a range of problems to treatment and public health initiatives. For example, the overwhelming majority of drug-related hospital emergency room visits involve combinations of alcohol and multiple illicit drug use (NIDA, 1991). Polydrug abuse also increases likelihood of overdose (Risser & Schneider, 1994; Ruttenber & Luke, 1984), HIV risk-taking behavior (Darke et al., 1994; Klee et al., 1990), and poor treatment compliance (e.g., Ball & Ross, 1991).

One problem in trying to understand polydrug abuse is that no descriptive method has been designed to characterize it. For example, polydrug abuse refers to use of two drugs together (e.g., "speedball") and use of drugs in place of one another (e.g., using barbiturates or benzodiazepines when alcohol is not available). An understanding of variables that affect use of different drugs may elucidate factors that precipitate and propagate drug abuse and dependence.

Behavioral economic analyses and its putative relationship to polydrug abuse

Price is one variable that seems intricately related to drug use. Economists are devoted to the proposition that higher prices will lower consumption of almost any good (e.g., Mansfield, 1988), and considerable evidence suggests that drug consumption responds to changes in price. For example, alcohol and nicotine use both decrease as their respective prices increase (e.g., Becker, Grossman, & Murphy, 1994; Coate & Grossman, 1988). The interrelationship between price and consumption of illicit drugs, however, has been difficult to assess. Because drugs are bought and sold in a volatile market and in varying purities, very little data exists on how prices affect polydrug abuse in natural settings. In particular, how the price of one drug may affect use of other drugs is not well understood.

Behavioral economics is an analytic research area that applies consumer demand theory to the study of behavior, and these theories have been applied successfully to drug dependence issues in laboratory experiments of drug self-administration (e.g., Bickel et al., 1990, 1991, 1995b; DeGrandpre et al., 1993). The value of behavioral economics analyses for understanding drug abuse derives from its concepts that describe relationships between price and consumption. *Cross-price elasticity* quantifies the relationship between the consumption of one good and prices of another. At one end of the spectrum, one commodity may *substitute* for another. For example, as price of Coke increases from $.50 to $2 per can and the price of Pepsi remains constant at $.50 per can, the consumption of Pepsi may increase, thereby demonstrating that Pepsi is a substitute for Coke. A reinforcer may also be a *complement* of another. As price of soup increases and soup consumption decreases, the consumption of crackers may decrease concurrently, even though the price of crackers has not changed. Between these extremes are *independents*; as the price of Coke increases, consumption of crackers is unlikely to change.

Cross-price elasticity (E_{cross}) can be determined using Equation 1 derived from Allison (1983):

$$E_{cross}=[\log (Q_{A2}) - \log (Q_{A1})] / [\log (P_{B2}) - \log (P_{B1})] \qquad \text{Equation 1}$$

where Q is quantity consumed of reinforcer A (e.g., Pepsi) at price B1 or B2 (the two prices of reinforcer B, e.g., Coke). Positive E_{cross} values indicate reinforcer A is a substitute for reinforcer B, and negative E_{cross} values indicate reinforcer B is a complement of reinforcer A. Values around 0 indicate reinforcer A is independent of reinforcer B. Using this equation, E_{cross} is simply the slope between two consecutive points when the price of one commodity (e.g., Coke) and the consumption of another commodity (e.g., Pepsi) are plotted on log-log coordinates (Bickel et al, 1995a; Green & Freed, 1993; Hursh, 1980, 1991, 1993; Samuelson & Nordhaus, 1985).

Own-price elasticity quantifies the relationship between the price of a particular good and its own consumption (e.g., DeGrandpre & Bickel, 1996; Hursh, 1980, 1993; Samuelson & Nordhaus, 1985). Increases in price may markedly decrease consumption, and this pattern is termed *elastic* demand. Demand may be elastic when the price of potato chips rises; a price increase of 50% may result in an 80% reduction in potato chip purchases. At the other extreme, price increases can result in marginal decreases in consumption, or *inelastic* demand. An example is that as price of milk increases 50%, a mere 10% reduction in purchases results. Own-price elasticity of demand (E_{own}) can be calculated using an equation from Allison (1983):

$$E_{own}=[\log (Q_{A2})- \log (Q_{A1})] / [\log (P_{A2}) - \log (P_{A1})] \qquad \text{Equation 2}$$

where Q is the quantity of reinforcer A purchased at price (P) 1 or 2. When price and consumption data are plotted on log-log coordinates, the slope between any two points represents E_{own}. If the slope between two points is less than -1, demand is elastic and consumption decreases rapidly with increases in price. Conversely, if the slope is between -1 and 0, demand is inelastic, and increases in price are associated with relatively small changes in consumption. If the slope is 0, price has no effect on consumption (e.g., DeGrandpre, et al., 1994; Hursh, 1991, 1993)..

Elasticity can also be assessed by examining consumption following income manipulations. If income increases by 5%, demand for a commodity is considered *income elastic* if purchases increase by more than 5%. For example, a 5% rise in income may result in an increase in seafood consumption of 7% in seafood lovers. Demand is considered *income inelastic* if income increases by 5% yet purchases rise by less than 5%. An example is that as income increases 5%, consumption of hamburger may increase by only 2%. Income elasticities (E_{inc}) can be determined from Equation 2, with P being income. E_{inc} values greater than 1 are indicative of elastic demand, with purchases rising in greater proportion that the rise in income. E_{inc} values less than 1 are indicative of income inelastic demand, with purchases not rising in proportion to income. When consumption and income are plotted on log-log coordinates, income elastic demand is demonstrated by a slope of ≥ 1 and income inelastic demand by a slope of < 1 (DeGrandpre et al., 1993).

These concepts of cross-price, own-price, and income elasticities have been tested empirically in laboratory experiments of drug self-administration. Bickel and colleagues

(1995a) reviewed 16 studies in which two reinforcers, one or both of which were drugs, were concurrently available and prices (usually in terms of the number of lever presses required for a unit of drug) were altered. Cross-price elasticities indicated that some drugs were substitutes for others, some served as complements, and others were independents. For example, in a group of rhesus monkeys responding for concurrently available alcohol and PCP, increases in response requirements for PCP resulted in an increase in responding for and consumption of alcohol (Carroll, 1987a). Thus, alcohol was a substitute for PCP. In terms of complements, both heroin and cigarette self-administration decreased when the price of heroin rose, indicating that cigarettes were a complement to heroin (Mello et al., 1980a). Cigarette smoking also decreased as alcohol price rose in the majority of subjects in one study (Mello et al., 1980b), but cigarette smoking was relatively independent of alcohol price in another study (Mello et al., 1987). Bickel and colleagues (1992) found that cigarette smoking and coffee consumption were independent, regardless of whether the response requirement was raised for cigarettes or coffee. The relationship between concurrently available reinforcers was not always symmetrical, however. Although ethanol substituted for PCP when the lever press requirement for PCP was raised, increases in the response requirement for ethanol did not affect PCP self administration (Carroll, 1987).

In terms of own-price elasticities, demand for alcohol was relatively inelastic compared to demand for sucrose in rats with extensive alcohol histories (Heyman & Oldfather, 1992; Petry & Heyman, 1995). Thus, responding for alcohol persisted and increased as the response requirement for alcohol rose, while responding for and consumption of sucrose rapidly diminished when its response requirements rose. Similarly, demand was inelastic for etonitazene (Carroll & Meisch, 1979), morphine (Dworkin et al., 1984), PCP (Carroll, Carmona, & May, 1991), coffee (Bickel et al., 1992) and nicotine (Bickel, et al., 1992) at some increases in price for these various drugs. However, at large price increases, demand for these drugs often became elastic, and consumption decreased proportionally greater than rises in price.

Income can be defined as the amount of funds, goods, or services available to any one individual at a given time (Pearse, 1986). In behavioral terms, income can be conceptualized as a constraint on total reinforcement possible to earn in a laboratory session. Increases in income can either increase or decrease choice of any particular good, depending on the type of good and the availability of other goods (Deaton & Muellbauer, 1980; Lea, Tarpy, & Webley, 1987). For example, choice for a large, bitter food pellet increased relative to a small, normal pellet when income was decreased (Silberberg, et al., 1987). Only one known laboratory study has examined directly the effects of income on drug self administration. DeGrandpre et al. (1993) varied the amount of money available to spend during experimental sessions, while prices remained constant. Subjects were nicotine-dependent smokers, and they could purchase puffs on their preferred brand of cigarettes or on a less preferred brand of cigarettes during the sessions. Puffs on the less preferred brand were less expensive than puffs on the preferred brand. In low income conditions, subjects purchased more puffs from the normally non-preferred brand. As income increased, puffs on the preferred brand increased, and demand for the preferred cigarettes was income elastic (DeGrandpre et al., 1993).

These economic relationships of cross price, own price, and income elasticities may be useful in describing and predicting drug use in natural situations as well as in these laboratory settings (Bickel & DeGrandpre, 1995, 1996; Hursh, 1991). For example, as heroin price increases, heroin addicts may substitute less expensive opioids (methadone) or drugs from other classes that abate opioid withdrawal symptoms (e.g., benzodiazepines). Demand for drugs that produce physical dependence may be relatively inelastic among dependent individuals, with increases in price not greatly affecting consumption. Analysis of income elasticity of demand may show that as one has more disposable money, consumption of certain drugs (e.g., heroin and cocaine) may increase markedly, while consumption of other drugs may remain relatively constant (e.g., marijuana).

Description of simulation methodology

Systematic investigation of the relationship between price and polydrug abuse in natural settings is hindered by the illicit nature of many drugs of abuse. Drugs are bought at fluctuating prices and variable purities. While these relationships can be studied in the laboratory, logistical and ethical considerations of providing drugs to drug abusers remain. Behavioral simulation experiments involve simulation of essential aspects of a situation in order to elicit the behavior in question. If behavior that emerges in the simulation is similar to that observed in natural situations, then processes responsible for the behavior have likely been identified (Epstein, 1986). Such simulations have been used successfully in experimental economics such that resultant data is predictive of behavior in the real world (Plott, 1986).

This chapter describes a behavioral simulation paradigm that was developed to apply a behavior economic analysis to the phenomena of polydrug abuse (Petry & Bickel, submitted). Polydrug abusing heroin addicts were given imitation money, and prices of drugs were indicated on paper. Subjects indicated the types and quantities of drugs they would buy, presuming they had the available amount of money to spend. Changes in drug choices were examined as a function of price and money available.

The subjects were 40 patients in our outpatient programs for opioid abuse and dependence. Of those enrolled in the clinic, 96% volunteered, and therefore the sample tested was representative of our clinic population. Fifteen subjects were female, and 25 were male. On average, subjects were in treatment for 3.8 months (range 3 weeks to 16 months). Thirty-two of the subjects were receiving buprenorphine (an alternative to methadone), five were receiving naltrexone (an opioid antagonist that prevents relapse to opioid abuse), and three were no longer receiving medication. One subject was receiving Antabuse for alcohol dependence. Average age was 35, and years of education was 12. Average legal monthly income was $750, and in the month prior to intake, subjects used an average of $350 worth of opioids each week. On average, subjects reported a 10-year history of heroin dependence, and intravenous use was the route of choice for all but six subjects, who used heroin intranasally. In the month prior to intake, 65, 68, 60, and 55% of subjects reported alcohol, benzodiazepine, cocaine, and marijuana use, respectively.

A sample of the stimuli used for these experiments is shown in the Appendix. Various drugs, in amounts typically used for a "hit," are presented. The prices are representative of Vermont street prices, as determined by informal survey. A copy of the imitation money used in these studies is shown on the bottom of the page. The experiment commenced with the Experimenter reading instructions that subjects were to presume they was not in treatment and were actively abusing drugs. Subjects were also told that they had a certain amount of "money" that they could "spend" on drugs each day, and that they could not receive drugs from any other source, other than those they "bought" with the allotted money. The subjects were further instructed to presume that the drugs they "purchased" were for their own personal consumption only, and that all drugs "purchased" in this hypothetical situation could only be used in a 24-hour period. They were told that they could not "sell" drugs that they "purchased" or save them up for later.

1. Effects of heroin price on demand for heroin, valium, cocaine, marijuana, and alcohol

In Experiment 1 (Petry & Bickel, submitted), we examined cross-price elasticities of demand for valium, cocaine, alcohol, and marijuana using Equation 1, and own-price elasticity of demand for heroin using Equation 2. Four trials were presented in which heroin prices varied between the trials; heroin was available at \$3, \$6, \$11, and \$35/bag. Income was kept constant at \$30 per trial, and prices of valium, cocaine, alcohol, and marijuana remained constant at local street prices: valium was \$1/pill, cocaine was \$15 per 1/8 ounce, alcohol was \$1/drink, and marijuana was \$5/joint.

The top panel of Figure 1 shows heroin purchases as a function of heroin price. Statistical analyses indicated that heroin purchases differed significantly across the three price conditions in which heroin could be purchased, and values significantly different from the \$3 condition are denoted by filled symbols. Note that across all conditions, subjects tended to spend a large proportion of their \$30 income on heroin. In the \$3 price condition, the mean number of bags of heroin purchased was over 8, in the $6 condition mean purchases was just under 5 bags, and in the $11 condition mean purchases was 2 bags.

Data are plotted on log-log coordinates, such that the slope between any two successive points is equal to E_{own} values shown in Table 1. As heroin increased in price from $3 to $6, the own-price elasticity of demand was -.86. This value suggests that demand for heroin was inelastic, and increases in price were associated with decreases in purchases that were proportionally smaller than the price increments. Demand for heroin became more elastic as its price increased further, from $6 to $11, with own-price elasticity of demand equal to -1.26.

The top panel of Figure 2 shows the percent of subjects demonstrating elastic and inelastic demand for heroin as its price rose. When heroin doubled in price from $3 to $6, over 85% of subjects showed inelastic demand for heroin, but as price increased further to $11 and $35, demand for heroin became elastic in the majority of subjects.

Price of heroin not only affected heroin purchases, but purchases of other drugs as well. When heroin was inexpensive, subjects tended not to purchase valium, and average number of valium pills purchased was less than 1 (Figure 1). However, as heroin price rose, valium purchases significantly increased, and the number of valium pills purchased in the $11 and $35 heroin conditions differed significantly from the number of pills purchased in the $3 heroin condition. In the $35 heroin price condition, for example, subjects purchased an average of 10 valium pills. E_{cross} values for valium were high, ranging from .38 to 1.69, with an overall slope of 1.06 indicative of a strong substitution effect (Table 2). Using a strict definition of a substitute relationship to be one in which E_{cross} values are greater than 1.0 and a complement relationship to be one in which E_{cross} values are less than –1.0, approximately fifty percent of subjects substituted valium for heroin as heroin prices rose (see Figure 2). In less than 10% of the subjects was valium ever a complement as heroin prices rose.

Average alcohol and marijuana purchases also increased, but not significantly, with heroin price. In low heroin price conditions, the average number of alcoholic drinks and marijuana joints purchased was less than 1. As heroin price rose, purchases of these drugs increased, but the mean number of drinks and joints purchased was under 3, even in the condition in which when subjects were unable to buy heroin (heroin=$35). E_{cross} values averaged about 0.5 for both marijuana and alcohol, indicative of a relatively independent or weak substitute relationship. Figure 2 shows that marijuana and alcohol purchases were independent of heroin price in the majority of subjects across all heroin price conditions.

In contrast the lack of significant effect on alcohol and marijuana purchases, cocaine purchases were significantly affected by heroin price. As denoted by filled symbols in Figure 1, the number of cocaine purchases in the $6 and $35 heroin conditions significantly different from those in the $3 heroin condition. Cocaine was a complement when heroin price increased from $3 to $6 per bag, but it became a substitute as heroin price continued to rise (Table 1). While the group mean purchases demonstrated this complement and substitution effect as heroin price rose, this effect occurred in only 23% of subjects (Figure 2). In the majority of subjects, demand for cocaine was independent of heroin price.

2. Symmetry of substitutability of heroin and valium

a. Effect of heroin price on demand for valium, alcohol, and marijuana

In Experiment 2 (Petry & Bickel, submitted), we altered prices of both heroin and valium to determine whether cross-price elasticities between these two drugs were symmetrical or asymmetrical. This experiment contained 16 conditions, presented in a random order to 18 subjects. Heroin prices varied ($3, $6, $11 and $35/bag), and at each heroin price condition, valium was available at $.33, $1, $3, and $10/ pill. Income was constant at $30, and marijuana and alcohol prices were $5 and $1, respectively. In addition to providing cross-price elasticities, this study provided estimates of the own-price elasticity of demand for valium in heroin addicts. This experiment also provided estimates of own-price elasticity of demand for heroin when cocaine was not available and in a new group of subjects, none of whom participated in Study 1.

Figure 3 shows drug purchases as heroin price increased in Experiment 2. Four panels are shown, one for each valium price condition. Statistical analyses demonstrated that valium purchases were significantly affected by heroin price. In conditions in which valium was inexpensive, subjects purchased large quantities of valium, with an average of four pills purchased even when they concurrently purchased 8 bags of heroin. As heroin price rose to

$35/bag, valium purchases increased to an average of 40 and 20 pills in the $.33 and $1 valium price conditions, respectively. While the quantities of valium purchased were lower in conditions in which valium was more expensive ($3 and $10/pill), valium purchases nevertheless increased significantly as heroin price rose (range from less than 1 to over 6 pills).

Table 2 shows cross-price elasticity values for valium as heroin price rose. Regardless of the price of valium, Ecross values indicated that demand for valium was relatively independent of heroin price when heroin price increased from $3 to $6/bag. However, as heroin prices increased further to $11 and $35, valium tended to became a strong substitute for heroin, with cross-price elasticities ranging from .23 to 1.32. Across the four heroin price conditions, the overall cross price elasticities for valium ranged from .93 to 1.02. These values are indicative of a strong substitute relationship between valium purchases and heroin prices.

Table 3 shows the percentage of subjects demonstrating a substitution, complement, or independent relationship between heroin price and valium purchases. In the majority of subjects, valium purchases were generally independent of heroin price when heroin was inexpensive ($3 to $6). However, valium became a substitute for heroin in the majority of subjects as heroin prices increased further. Over half of the subjects substituted valium for heroin at some or all of the different valium price conditions as heroin prices rose.

Heroin price also significantly affected purchases of marijuana in some conditions (Figure 3). E_{cross} values for marijuana were negative (-.325 to -1.0) as heroin rose from $3 to $6, indicating marijuana was an independent or complement to heroin when price of heroin was relatively low. As heroin prices increased further, E_{cross} values were positive, indicating marijuana became a substitute for heroin. Table 3 shows that approximately 30% of subjects substituted marijuana for heroin in high heroin price conditions, but the majority of subjects showed an independent relationship between heroin price and marijuana purchases.

Similarly to marijuana, E_{cross} values for alcohol were negative as heroin increased from $3 to $6, indicating alcohol was an independent or complement to heroin. As price of heroin increased further to $11 and $35/bag, alcohol purchases rose slightly with elasticities ranging from .223 (independent) to 1.923 (strong substitute). Only in the conditions in which valium was very inexpensive ($.33) or very expensive ($10) did alcohol purchases significantly increase with heroin price. Approximately 70% of subjects showed an independent relationship between heroin price and alcohol purchases (Table 3).

Similarly to Experiment 1, heroin purchases significantly decreased as heroin price increased (Figure 3). E_{own} values for heroin were remarkably similar regardless of valium price (Table 2). Over 75% of the subjects showed inelastic demand for heroin when its price increased from $3 to $6 (Table 3), but the majority of subjects demonstrated elastic demand for heroin as prices for heroin increased further.

b. Effect of valium price on demand for heroin, alcohol and marijuana

Figure 4 shows these same data from Experiment 2, but as a function of valium price. The four panels show number of drug purchases at each heroin price condition. Heroin purchases were not significantly affected by the price of valium. In contrast to the substitution effect of valium for heroin, Table 4 shows that E_{cross} values for heroin were extremely small (0.000 to -0.047) when valium prices rose. Thus, heroin purchases were independent of valium prices. Likewise, alcohol and marijuana purchases did not vary significantly with valium price. E_{cross} values for alcohol and marijuana were small, indicating purchases of these substances were independent of valium price as well.

Table 5 shows the percent of subjects demonstrating a substitution, complement or independent relationship between valium price and purchases of heroin, alcohol, and marijuana. Heroin purchases were independent of valium price in every subject across all conditions studied. Marijuana and alcohol purchases also tended to be independent of valium price in most subjects. Only in one condition (heroin at $11/bag, and valium increasing from $3 to $10) did one-third of the subjects demonstrate a substitution effect of alcohol for valium.

Although price of valium did not significantly affect purchases of heroin, marijuana, or alcohol, Figure 4 shows that valium price significantly affected valium purchases. As valium prices rose, valium purchases decreased. Table 4 shows that demand for valium was inelastic with initial changes in valium price ($.33 to $1/pill), but demand for valium became more elastic as its price increased further, and the slopes between price conditions tended to be less than -1. Table 5 also shows the percent of subjects demonstrating inelastic and elastic demand for valium. Across all conditions, demand for valium was inelastic in over half of subjects.

3. Effects of income on demand for drugs

In Experiment 3 (Petry & Bickel, submitted), we examined income elasticities by varying the amount of money available: $30, $100, $156, $300, and $560. Prices were constant at all conditions: heroin was $35/bag, valium was $1/pill, marijuana was $5/joint, alcohol was $1/drink, and cocaine was $15/ one-eight ounce. The same 22 subjects who participated in Experiment 1 participated in this study. Thus, a total of nine conditions (the four heroin price conditions from Experiment 1, and the five income conditions from Experiment 3) were presented in a random order to each of these subjects.

Increases in income were associated with statistically significant increases in the total number of bags of heroin purchased, as shown in Figure 5. When subjects had $100 available, they purchased an average of 1.7 bags of heroin. As income increased to $156, an average of 3 bags of heroin was purchased. In the $560 income condition, subjects purchased an average of over 10 bags of heroin. Income elasticity coefficients were high for heroin (Table 6). An increase in income from $100 to $156 was associated with a steep rise in heroin purchase (slope=1.58), indicative of income elastic demand for heroin. But as income increased further, the slope of the line between successive incomes became slightly lower, and demand for heroin became income inelastic. The slope of the best fitting line between the four conditions in which heroin could be purchased, however, was greater than 1.0 and indicative of income elastic demand for heroin.

Income did not significantly affect valium purchases. The income elasticity coefficients for valium were negative in the conditions in which subjects received a relatively low income, demonstrating a non-significant decrease in valium purchases at initial increases in income. The slope of the best fitting line across all income conditions was close to 0, indicating that overall income did not affect valium purchases. Marijuana purchases showed a similar trend, but again income did not significantly affect purchases. Alcohol purchases likewise increased marginally, but not significantly, with each successive increase in income.

Cocaine purchases, however, increased significantly with income (Figure 5), and demand for cocaine was income elastic in the two highest income conditions (Table 6). The slope of the best fitting line between the four income levels was positive (.71), but less that that of heroin. Thus, over the five income conditions tested, income significantly affected cocaine purchases, but demand for cocaine was income inelastic overall.

Figure 6 shows the percent of subjects showing income elastic or income inelastic demand for each drug across the income levels. At each successive increase in income, over 50% of the subjects demonstrated income elastic demand for heroin, suggesting heroin purchases increased proportionally greater than rises in income. Between the $156 and $560 conditions, demand for cocaine was income elastic in about 40% of the subjects. Less than 25% of the subjects showed income elastic demand for any of the other drugs across the income conditions.

Summary of findings

Three major findings emerged from these studies (Petry & Bickel, submitted). First, these data show price of heroin affects purchase of some other drugs; notably, increases in heroin price resulted in increases in valium and cocaine purchases. Second, as heroin prices increased, own-price elasticities indicated demand for heroin was relatively inelastic at low prices but elastic at higher prices. Third, as income rose, heroin and cocaine purchases increased, but other drug purchases remained unchanged.

When heroin price rose in Experiments 1 and 2, purchase of valium increased. Cross-price elasticity coefficients indicated that valium was a substitute for heroin in most subjects. Cocaine was also a substitute for heroin, but only in a minority of subjects. An independent or weak substitute relationship was found between heroin price and purchase of marijuana and alcohol.

Experiment 2 demonstrates an asymmetric substitution effect between heroin and valium. While over 50% of subjects substituted valium for heroin, no subjects substituted heroin for valium. Heroin purchases were independent of valium prices in all subjects across all conditions. Alcohol and marijuana purchases were independent of valium price as well. Together, these results suggest that increases in price for heroin may increase use of other drugs, notably valium and cocaine, but increases in price for valium are unlikely to affect other drug use in this population.

Own-price elasticity coefficients indicated that demand for valium and heroin was relatively inelastic. In Experiment 2, subjects continued purchasing valium as price increased, and demand for valium was inelastic in over half the subjects. Similarly, in the first two experiments, demand for heroin was inelastic; as heroin price doubled from $3 to $6 per bag, purchases of heroin decreased by less than half. However, as heroin price rose further to $11 and $35/bag, demand for heroin became elastic, and the near quadrupling in price from $3 to $11/bag resulted in a greater than four-fold reduction in heroin purchases.

In terms of the relationship between income and drug purchases in the third experiment, subjects consistently purchased more heroin as they had more money to spend. Income elasticity coefficients indicated that demand for heroin was income elastic as income rose from $100 to $156, and heroin purchases rose in greater proportions than incomes. At higher income conditions, demand for heroin was income inelastic, and increases in purchases were not proportionally greater than increases in income. Demand for cocaine was income elastic at high incomes ($156 to $560), and these income levels resulted in significant increases in cocaine purchases compared to the lower income conditions. Purchases of other drugs did not vary significantly with income. In summary, income was most likely to affect purchase of heroin, and to a lesser extent cocaine; purchases of valium, marijuana and alcohol were unlikely to change with increasing incomes.

Reliability and validity of the simulation

These data were reliable both between and within subjects. In Experiments 1 and 3, each subject was exposed to nine conditions in a random order. Two of the conditions were identical ($30 income and prices of all drugs at current street value), and 17 of 22 subjects made purchases from the same drug categories in the two exposures to this condition. In Experiment 2, eighteen new subjects participated. Sixteen conditions were included, and four of these ($3, $6, $11 and $35 for heroin and valium at $1 per pill) were virtually identical to a condition in Experiment 1, with the exception of cocaine being available only in Experiment 1. Own-price elasticity coefficients for heroin were virtually identical in the two groups of subjects (compare Tables 1 and 2).

To assess relationships between self-reports of drug choice in the simulation and actual drug use, we compared drug purchases during the simulation to objective indicators of drug use in real-life by these subjects. While in treatment at the clinic, urines were collected on a random basis once per week and screened for benzodiazepines, cocaine, marijuana, and opioids using Enzyme Multiplied Immunoassay Technique (Syva Corp., San Jose, CA). Percent of urines positive for benzodiazepines and marijuana was significantly correlated ($p<.001$) with the number of valium pills and marijuana purchases made during the simulation. Correlations were conducted between Michigan Alcohol Screening Test scores (MAST; a measure of severity of alcohol problems; Pokorny, Miller, & Kaplan, 1972) and units of alcohol purchased also approached levels of statistical significance ($p=.09$). While these correlations do not suggest that use of these drugs in real-life is related to demand elasticities of these drugs in this simulation, they do provide preliminary evidence that subjects who "purchase" valium, alcohol, and cocaine in large quantities in the simulation are more likely to frequently use these drugs in real life.

Correlations between opioid-positive urines and heroin purchases were not conducted because subjects were required to remain opioid abstinent during treatment. Cocaine purchases were not significantly correlated with the number of cocaine positive urines. One explanation may be that cocaine is more likely to be a complement to heroin than any of the other substances (Table 1 and Figure 2). In natural settings, heroin addicts tend to use cocaine when they are using heroin (speedball). Because subjects were required to remain opioid abstinent during treatment, their cocaine use may have decreased concurrently with their heroin use. Therefore, cocaine urine results during treatment may not have been correlated with self-reported preference for cocaine during this simulation. Further research with non-treatment seeking drug users may clarify this issue and further validate this methodology.

Although the data obtained from the simulation were reliable both between and within subjects and urine results tended to corroborate drug selections in the simulation, potential criticisms of the present findings are that all choice were between hypothetical amounts of money and drugs and all subjects were involved in drug treatment. Whether or not drug abusers actually chose these same amounts and types of drugs in natural settings is unclear. Despite the hypothetical nature of the present simulation, spontaneous verbal reports of subjects during participation in the study suggest that the simulation is related to real life experiences of these subjects. For example, one subject reported that each time he receives his pay check, he thinks back to when he was doing drugs and how he would have allocated such a sum of money to drugs prior to his entering treatment. Many subjects became excited in conditions in which heroin prices were very low or when they received large sums of money with which to buy drugs, and several made statements such as, "It's my lucky day!" Most subjects tried to "bargain" with the experimenter when heroin price exceeded income, and some actually became upset with the experimenter in these conditions. Several subjects tried to "rip off" the experimenter by not "paying" the full amount for the drugs they had verbally requested or by "stealing" the imitation money. The experimenter counted the money after each trial, and confronted some subjects, to ensure that purchases matched income in each trial.

Relationship between findings from the simulation and drug use in natural settings

One of the main findings of these simulation experiments is that valium is a strong substitute for heroin, and these results are consistent with clinical observations. Benzodiazepines are used to abate opioid withdrawal symptoms during inpatient opioid detoxifications. It is not unreasonable to assume that heroin addicts use more valium when heroin becomes too expensive or unavailable in natural settings (e.g., Woods, Katz, & Winger, 1987) and when heroin addicts are detoxifying as outpatients (e.g., Green & Jaffe, 1977; Green et al., 1978).

Only a few studies have provided an economic analysis of the substitutability of drugs in natural settings (see Saffer & Chaloupka, this volume, for review). Chaloupka and Laixuthai (1994) found that drinking frequency and heavy drinking episodes were negatively related to alcohol costs and minimum legal drinking age, but reductions in alcohol use were associated with increases in marijuana use and marijuana-related car accidents. Thus, marijuana tends to be a substitute for alcohol among adolescents.

In terms of own-price elasticity of demand, these data show that demand for heroin is inelastic during small changes in price, but demand becomes more elastic at higher prices. Naturalistic research also demonstrates demand for heroin is relatively inelastic. For example, pooled cross-sectional time-series data on 41 neighborhoods in Detroit during the 1970s found own-price elasticity of demand for heroin to be -0.26 (Silverman & Spruill, 1977). van Ours (1995) also found demand for opium in Indonesia during the Dutch colonial period to be relatively inelastic, with own-price elasticity values ranging from -.70 to -1.0. Nonetheless, the elastic demand for heroin noted at high prices suggests that if prices become high enough, use of heroin may decrease, even amongst dependent heroin addicts.

This relatively inelastic demand for heroin may have important social implications. If consumption decreases only slowly with increased price, one can expect enhanced drug-seeking behavior associated with small price increments (see also Bickel & DeGrandpre, 1996). In other words, original consumption levels may be maintained despite price increases by engaging in criminal activities and trading sex for drugs and money. Silverman and Spruill (1974) and Brown and Silverman (1974) demonstrated property crimes, as opposed to non-property crimes like rape and murder, were positively and significantly affected by heroin price. Additionally, one can hypothesize that the use of more efficient modes of drug taking, such as intravenous injection, may assist in maintaining consumption levels against price increases.

Participation elasticity (effect of price on probability of using a substance) may also be responsive to drug prices and/or income levels. For example, using data form the National Household Survey of Drug Abuse and the Drug Enforcement Agency, Saffer and Chaloupka (1995) found that participation elasticity is about -.90 to -.80 for heroin and about -.55 to -.36

for cocaine. Thus, given a 60% decrease in drug prices with legatization, a 100 percent increase in the quantity of heroin consumed and a 50 percent increase in the quantity of cocaine consumed is predicted. Decriminalization of marijuana was estimated to increase the probability of marijuana participation by only about 5 percent. The relationship between demand elasticities derived from these statistical estimates and those obtained in simulation paradigms employing non-dependent, recreational drug users may be of interest.

Conclusions and future applications

In summary, this simulation paradigm appears to be useful for examining the relationship between drug prices and consumption. The data were reliable between and within subjects, consistent with clinical observations of polydrug abuse, and compatible with the limited amount of data relating drug prices to consumption in natural settings. Further examination of the relationships between drug price and consumption using this simulation may elucidate prevention and treatment strategies for drug abuse. In terms of prevention, this procedure may serve as a gauge for at-risk recreational users. Non-dependent recreational users may demonstrate lower own-price demand elasticities than dependent users, and individual differences in demand elasticities may be related to risk for dependency and/or response to treatment.

In terms of treatment, drug prices may be strongly associated with entry into treatment. For example, Dupont & Greene (1973) demonstrated that methadone acceptability, as indicated by treatment entry, increases with rises in the retail price of heroin. Similarly, in a series of questionnaires, Vermont heroin addicts were asked to indicate whether they would use heroin, enter into treatment, and withdraw from treatment as the price of heroin varied from $1/bag to $100/bag; price was strongly associated with self-reported use and entry to treatment. Interestingly, once in treatment, these patients reported that they were *not* likely to drop out of treatment, although they were more likely to use while in treatment when heroin price was low (Petry & Bickel, unpublished data). Given the strong negative relationship between treatment for drug use and HIV infection (e.g., Metzger, et al., 1993), further exploration of the relationship between drug prices and treatment entry is warranted.

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Figure Captions

Figure 1. Mean units of heroin, valium, alcohol, marijuana, and cocaine purchased as heroin increases in price from $3 to $35 per bag. Data are plotted in log-log coordinates such that the slope between any two successive points is equal to the E_{own} or E_{cross} values listed in Table 1. Purchases that differ significantly from the $3 heroin price condition are denoted by filled symbols. No heroin purchases were made in the $35 heroin price condition since price exceeded income, and therefore no symbol is plotted for heroin in this condition. See text for further details.

Figure 2. Percent of subjects demonstrating inelastic or elastic demand for heroin as price of heroin increased in Experiment 1. Percent of subjects demonstrating a complement, independent or substitution relationship between valium, marijuana, alcohol, and cocaine purchases as heroin price increased in Experiment 1. See text for further details.

Figure 3. Mean units of heroin, valium, alcohol and marijuana purchased as heroin price increases from $3 to $35 per bag. The top, left panel shows this data for the $0.33 valium price condition, the top, right panel for the $1 valium price condition, the bottom, left panel for the $3 valium price condition, and the bottom, right panel for the $10 valium price condition. Purchases that differ significantly from the $3 heroin price condition are denoted by filled symbols. No heroin purchases were made in the $35 heroin price condition since price exceeded income, and therefore no symbol is plotted for heroin in this condition. See text for further details.

Figure 4. Mean units of heroin, valium, alcohol and marijuana purchased as valium price increases from \$0.33 to \$10 per pill. The top, left panel shows this data for the \$3 heroin price condition, the top, right panel for the \$6 heroin price condition, the bottom, left panel for the \$11 heroin price condition, and the bottom, right panel for the \$35 heroin price condition. Purchases that differ significantly from the \$0.33 valium price condition are denoted by filled symbols. No heroin purchases were made in the \$35 heroin price condition since price exceeded income, and therefore no symbol is plotted for heroin in this condition. See text for further details.

Figure 5. Mean units of heroin, valium, alcohol, marijuana, and cocaine purchased as income increases from \$30 to \$560. Data are plotted in log-log coordinates such that the slope between any two successive points is equal to the E_{income} values listed in Table 4. Purchases that differ significantly from the \$30 income condition (or \$100 income condition for heroin only) are denoted by filled symbols. No heroin purchases were made in the \$30 income condition since price exceeded income, and therefore no symbol is plotted for heroin in this condition. See text for further details.

Figure 6: Percent of subjects demonstrating income elastic or income inelastic demand for heroin, valium, marijuana, alcohol, and cocaine as income rose in Experiment 3. See text for further details.

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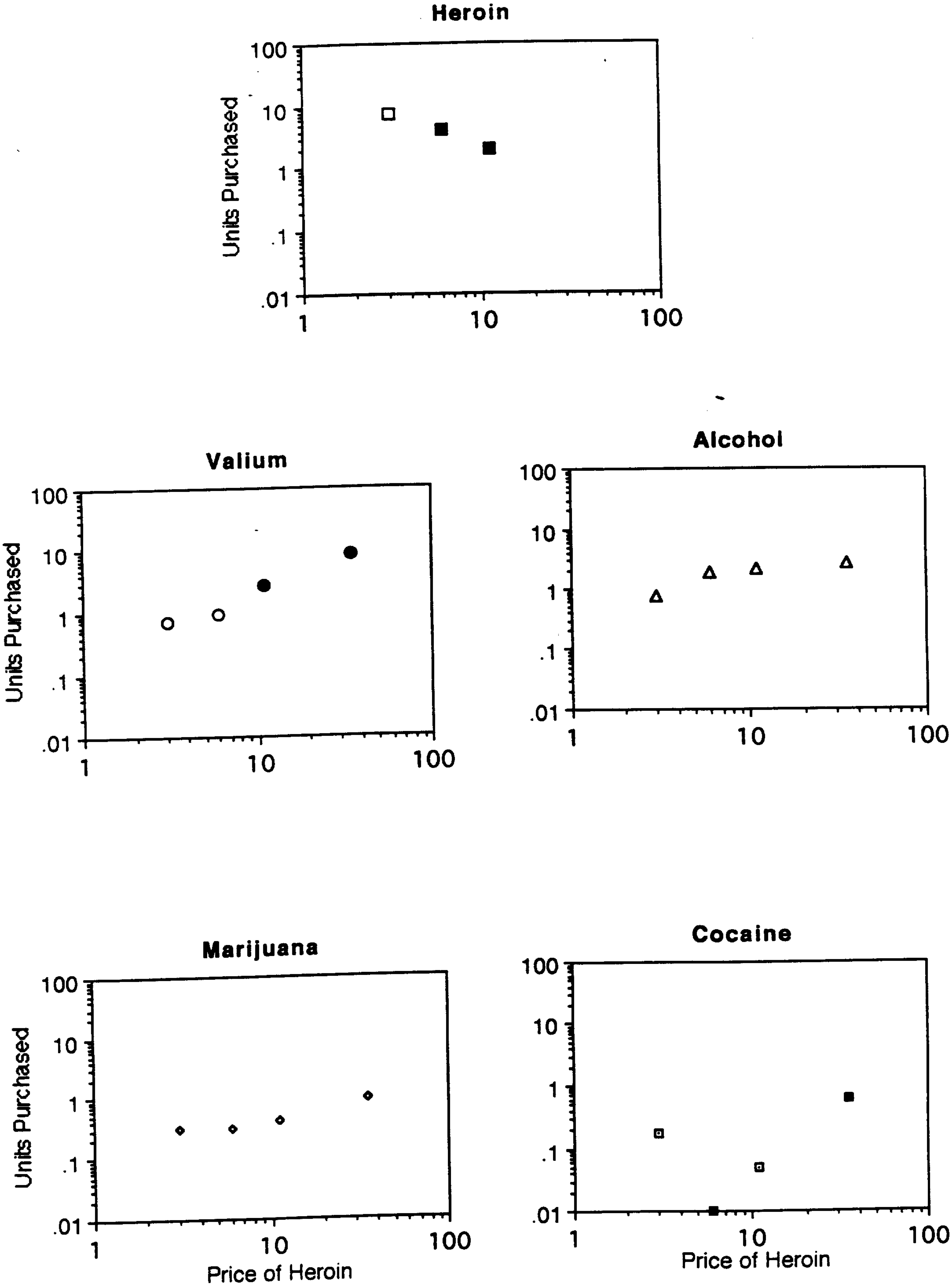
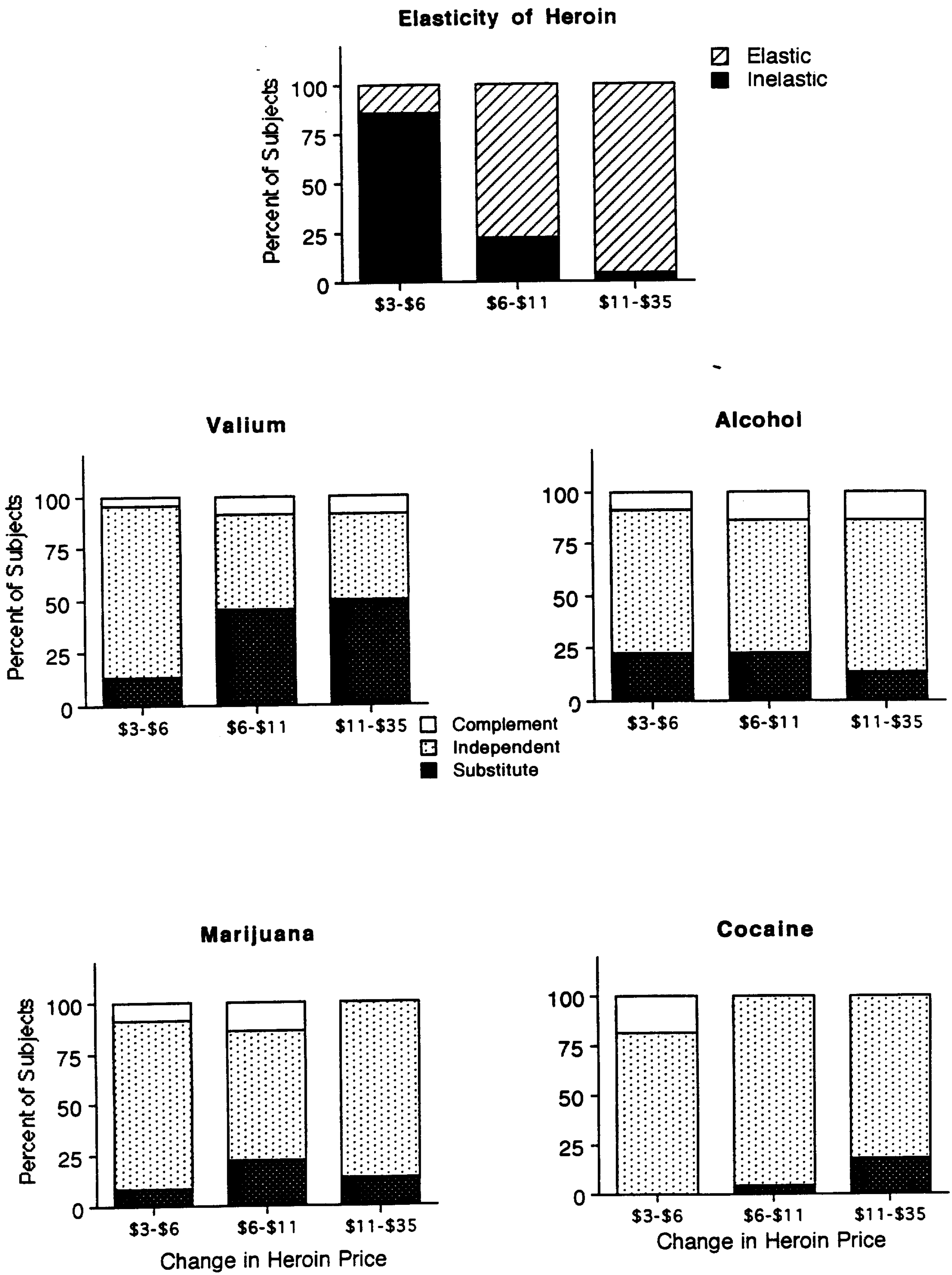
Fig 1

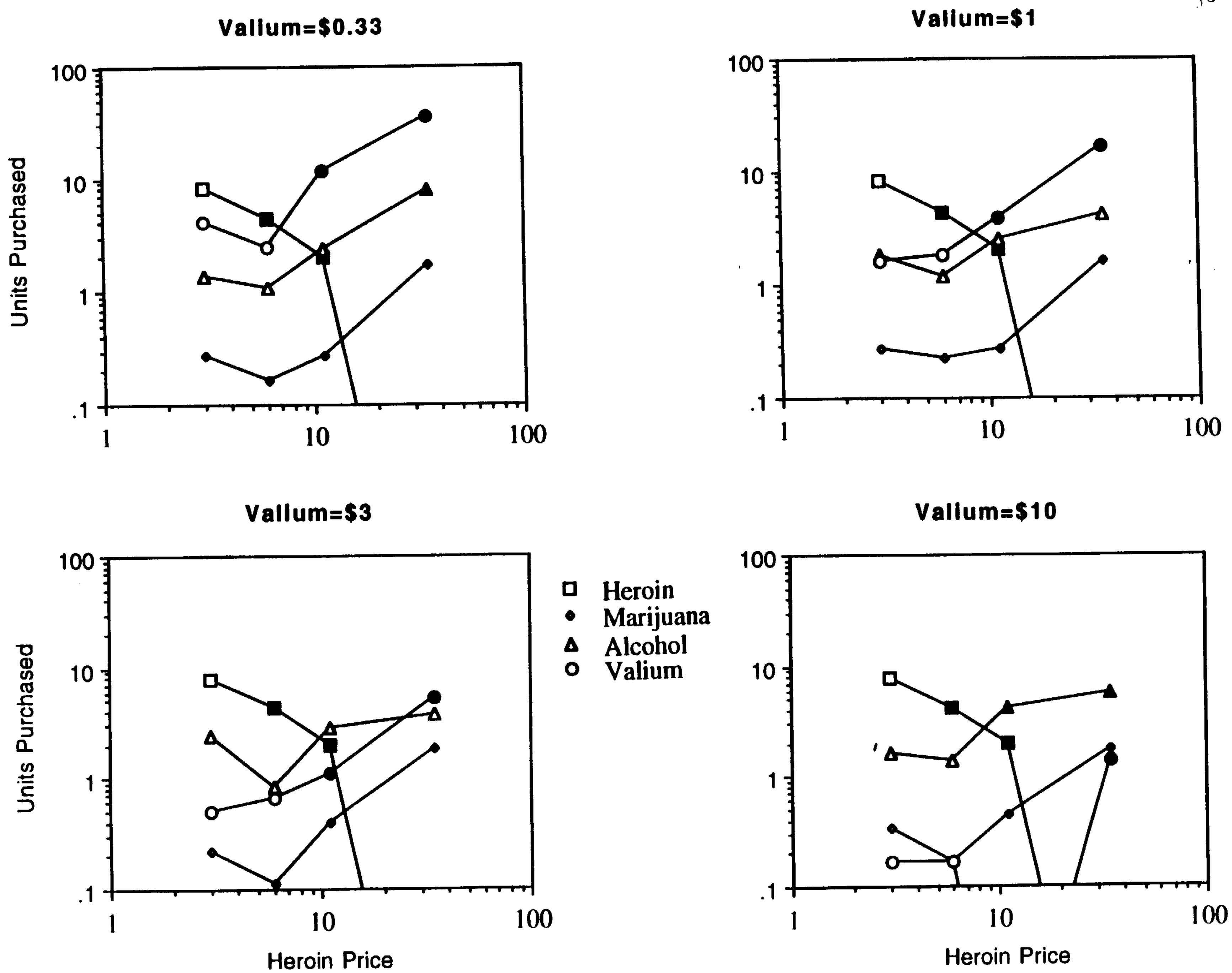


Heroin
Valium
Alcohol
Marijuana
Cocaine
Units Purchased
100
10
1
.1
.01
1
10
100
Price of Heroin

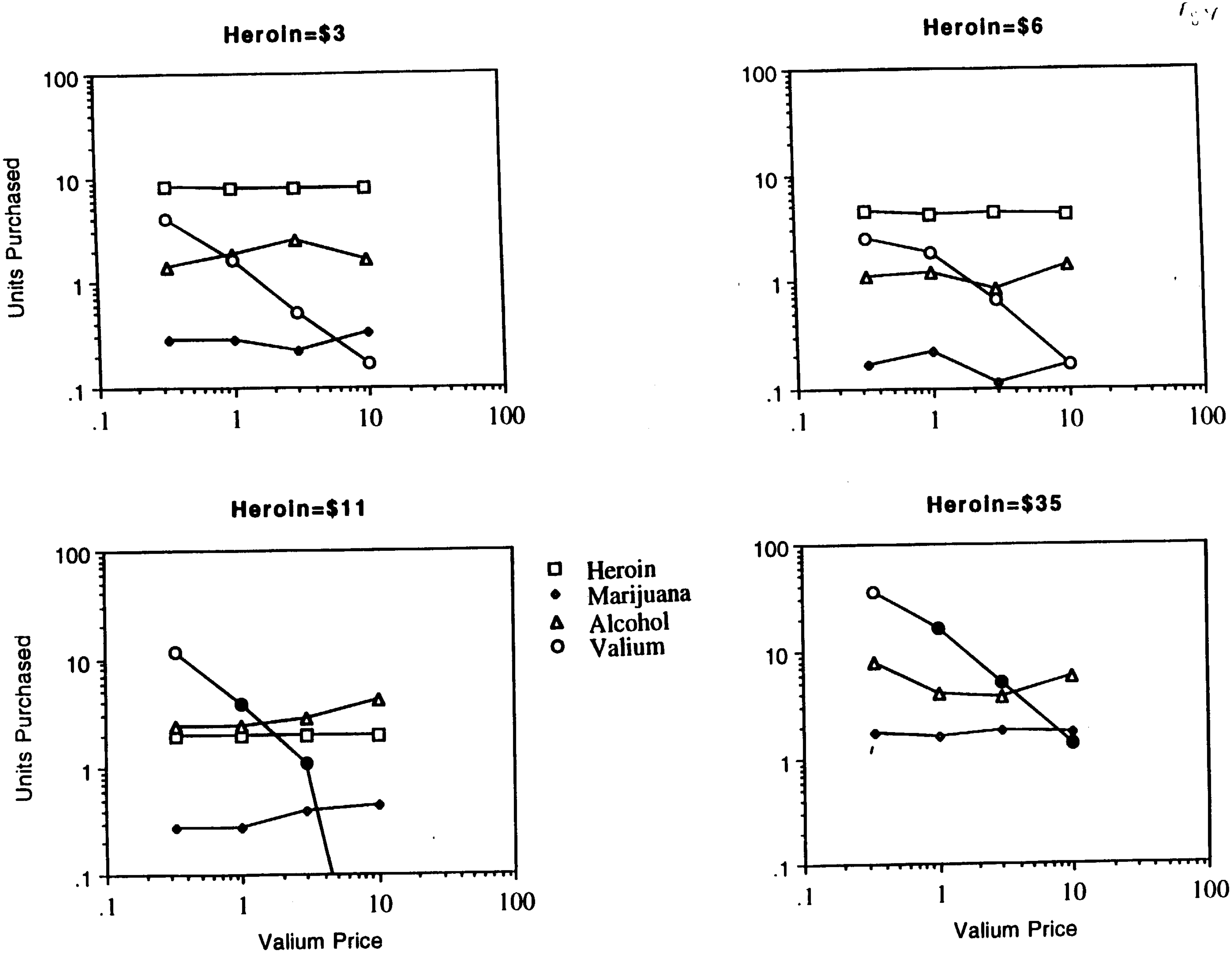


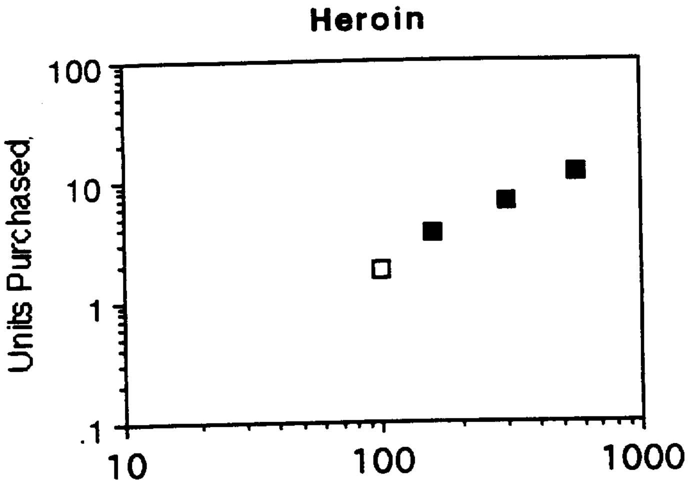
Elasticity of Heroin
Elastic
Inelastic
Percent of Subjects
100
75
50
25
0
$3-$6
$6-$11
$11-$35
Valium
Percent of Subjects
100
75
50
25
0
$3-$6
$6-$11
$11-$35
Complement
Independent
Substitute
Alcohol
100
75
50
25
0
$3-$6
$6-$11
$11-$35
Marijuana
Percent of Subjects
100
75
50
25
0
$3-$6
$6-$11
$11-$35
Change in Heroin Price
Cocaine
100
75
50
25
0
$3-$6
$6-$11
$11-$35
Change in Heroin Price

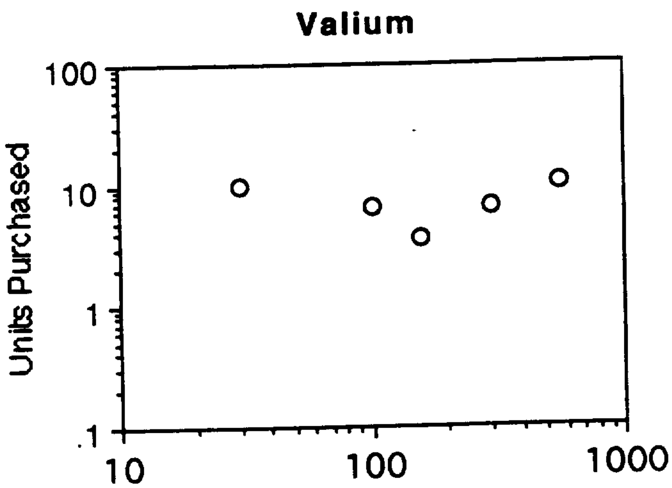
Fig 3

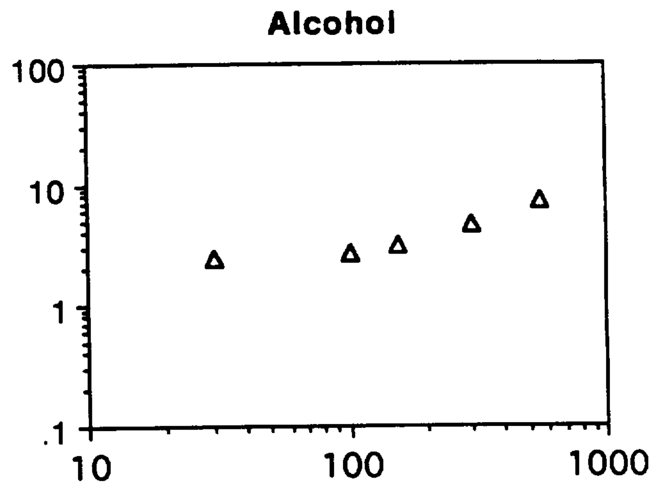


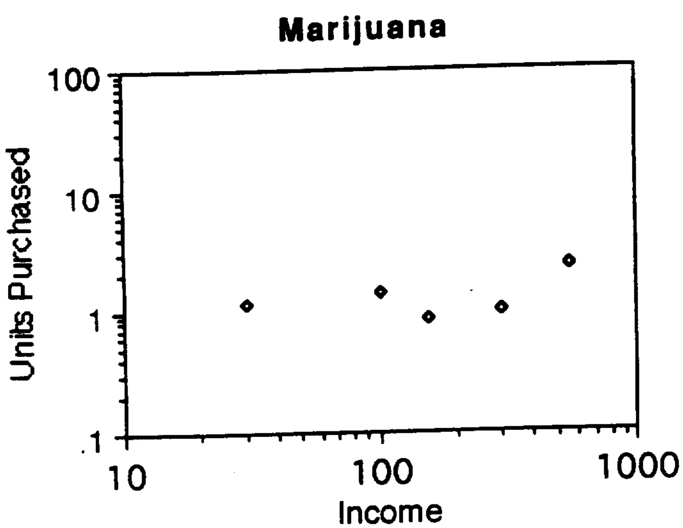
Vallum=$0.33
Vallum=$1
Vallum=$3
Vallum=$10
Units Purchased
Heroin Price
100
10
1
.1
Heroin
Marijuana
Alcohol
Valium

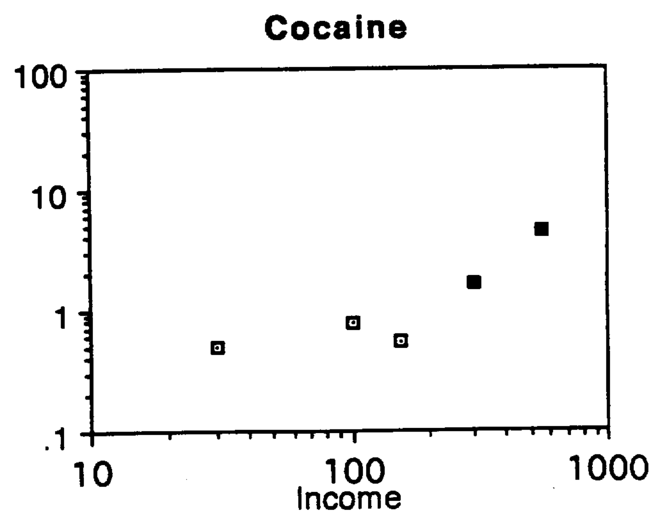

Heroin=$3
Heroin=$6
Heroin=$11
Heroin=$35
Units Purchased
100
10
1
.1
.1
1
10
100
Valium Price
Heroin
Marijuana
Alcohol
Valium


Heroin
Units Purchased
100
10
1
.1
10
100
1000


Valium
Units Purchased
100
10
1
.1
10
100
1000


Alcohol
100
10
1
.1
10
100
1000


Marijuana
Units Purchased
100
10
1
.1
10
100
1000
Income


Cocaine
100
10
1
.1
10
100
1000
Income

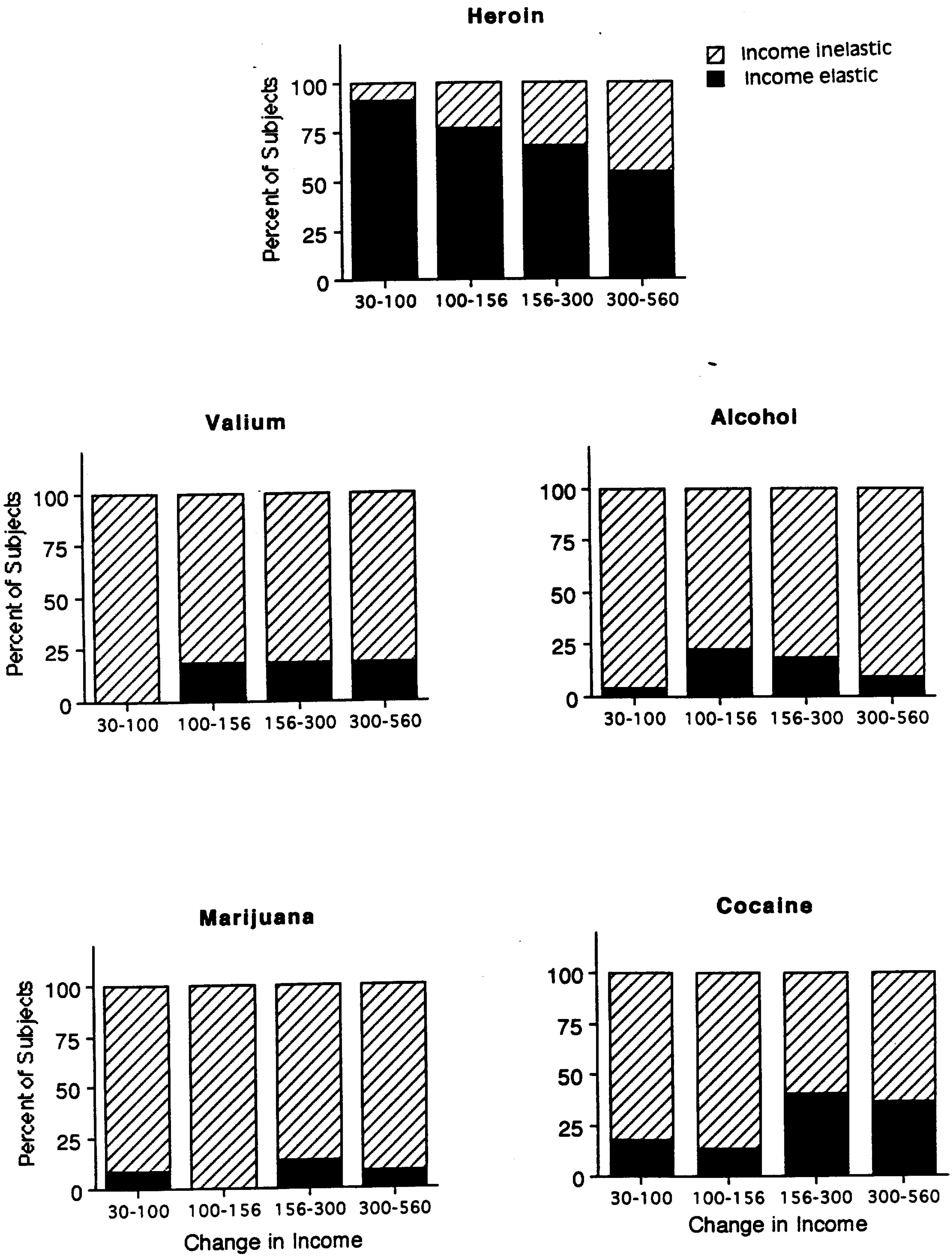

Heroin
Income inelastic
Income elastic
Percent of Subjects
100
75
50
25
0
30-100
100-156
156-300
300-560
Valium
Percent of Subjects
100
75
50
25
0
30-100
100-156
156-300
300-560
Alcohol
100
75
50
25
0
30-100
100-156
156-300
300-560
Marijuana
Percent of Subjects
100
75
50
25
0
30-100
100-156
156-300
300-560
Change in Income
Cocaine
100
75
50
25
0
30-100
100-156
156-300
300-560
Change in Income

Table 1: Own-Price Elasticity Coefficients of Heroin and Cross-Price Elasticity Coefficients of Other Drugs Determined from Mean Units Purchased

Heroin Price	Heroin	Valium	Alcohol	Marijuana	Cocaine
3					
6	-0.861	0.380	1.311	0.000	-4.170
11	-1.258	1.686	0.188	0.409	2.655
35		1.015	0.181	0.726	2.203
Slope of Best Fitting Line	-1.042	1.056	0.451	0.464	0.822

Table 2: Elasticity Coefficients for Mean Units Purchased as Heroin Price Increases

Heroin Price	Valium Price	Own Price Heroin	Cross Price Valium	Cross Price Marijuana	Cross Price Alcohol
3	0.33				
6	0.33	-0.897	-0.678	-0.735	-0.322
11	0.33	-1.317	2.502	0.841	1.263
35	0.33		0.986	1.576	1.038
Slope of best fitting line		-1.088	1.024	0.819	0.780
3	1				
6	1	-0.923	0.186	-0.325	-0.651
11	1	-1.232	1.217	0.371	1.220
35	1		1.252	1.518	0.438
Slope of best fitting line		-1.064	0.990	0.746	0.403
3	3				
6	3	-0.874	0.416	-1.000	-1.469
11	3	-1.322	0.842	2.069	1.923
35	3		1.328	1.338	0.223
Slope of best fitting line		-1.064	0.990	0.746	0.403
3	10				
6	10	-0.904	0.000	-0.996	-0.214
11	10	-1.233	2.953	1.613	1.834
35	10		0.234	1.199	0.254
Slope of best fitting line		-1.054	0.929	0.797	0.594

Table 3: Percent of Subjects Demonstrating Inelasticity or Elasticity for Heroin and Cross Price Elasticities for Other Drugs

Change in Heroin Price	Heroin Inelasitic	Elastic	Valium Substitute	Valium Independent	Valium Complement	Marijuana Substitute	Marijuana Independent	Marijuana Complement	Alcohol Substitute	Alcohol Independent	Alcohol Complement
BZ=$.33											
$3-$6	88.9	11.1	11.1	66.7	22.2	0.0	94.4	5.6	11.1	83.3	5.6
$6-$11	11.1	88.9	61.1	33.3	5.6	16.7	77.8	5.6	27.8	72.2	0.0
$11-$35	0.0	100.0	38.9	55.6	5.6	33.3	66.7	0.0	22.2	72.2	5.6
BZ=$1											
$3-$6	77.8	22.2	16.7	66.7	16.7	0.0	94.4	5.6	11.1	83.3	5.6
$6-$11	22.2	77.8	50.0	38.9	11.1	16.7	72.2	11.1	22.2	77.8	0.0
$11-$35	0.0	100.0	61.1	33.3	5.6	38.9	61.1	0.0	11.1	72.2	16.7
BZ=$3											
$3-$6	88.9	11.1	5.6	83.3	11.1	0.0	88.9	11.1	0.0	77.8	22.2
$6-$11	16.7	83.3	44.4	44.4	11.1	27.8	72.2	0.0	38.9	50.0	11.1
$11-$35	5.6	94.4	55.6	44.4	0.0	33.3	66.7	0.0	5.6	83.3	11.1
BZ=$10											
$3-$6	88.9	11.1	5.6	88.9	5.6	0.0	88.9	11.1	22.2	66.7	11.1
$6-$11	22.2	77.8	0.0	88.9	11.1	33.3	61.1	5.6	44.4	50.0	5.6
$11-$35	0.0	100.0	55.6	44.4	0.0	27.8	72.2	0.0	5.6	61.1	33.3

Table 4: Elasticity Coefficients for Mean Units Purchased as Valium Price Increases

Valium Price	Heroin Price	Own Price Valium	Cross Price Heroin	Cross Price Marijuana	Cross Price Alcohol
0.33	3				
1	3	-0.820	-0.031	0.000	0.250
3	3	-1.065	-0.006	-0.205	0.262
10	3	-0.911	-0.006	0.337	-0.346
Slope of best fitting line		-0.944	-0.013	0.300	0.061
0.33	6				
1	6	-0.280	-0.047	0.257	0.044
3	6	-0.920	0.024	-0.631	-0.307
10	6	-1.150	-0.022	0.339	0.425
Slope of best fitting line		-0.809	-0.011	-0.059	0.032
0.33	11				
1	11	-0.982	0.000	0.000	0.021
3	11	-1.128	-0.026	0.306	0.134
10	11	-7.737	0.024	0.110	0.331
Slope of best fitting line		-1.055	-0.002	0.154	0.165
0.33	35				
1	35	-0.705		-0.060	-0.606
3	35	-1.047		0.118	-0.092
10	35	-1.091		-0.025	0.362
Slope of best fitting line		-0.962		0.020	-0.094

Table 5: Percent of Subjects Demonstrating Inelasticity or Elasticity for Valium and Cross Price Elasticities for Other Drugs

Change in Valium Price	Valium Inelasitic	Valium Elastic	Heroin Substitute	Heroin Independent	Heroin Complement	Marijuana Substitute	Marijuana Independent	Marijuana Complement	Alcohol Substitute	Alcohol Independent	Alcohol Complement
Heroin=$3											
$.33-$1	94.4	5.6	0.0	100.0	0.0	0.0	100.0	0.0	5.6	94.4	0.0
$1-$3	83.3	16.7	0.0	100.0	0.0	0.0	100.0	0.0	5.6	94.4	0.0
$3-$10	94.4	5.6	0.0	100.0	0.0	0.0	100.0	0.0	0.0	88.9	11.1
Heroin=$6											
$.33-$1	94.4	5.6	0.0	100.0	0.0	0.0	100.0	0.0	0.0	100.0	0.0
$1-$3	88.9	11.1	0.0	100.0	0.0	0.0	100.0	0.0	0.0	94.4	5.6
$3-$10	88.9	11.1	0.0	100.0	0.0	0.0	100.0	0.0	11.1	88.9	0.0
Heroin=$11											
$.33-$1	72.2	27.8	0.0	100.0	0.0	0.0	100.0	0.0	5.6	83.3	11.1
$1-$3	55.6	44.4	0.0	100.0	0.0	0.0	100.0	0.0	16.7	72.2	11.1
$3-$10	72.2	27.8	0.0	100.0	0.0	0.0	100.0	0.0	33.3	66.7	0.0
Heroin=$35											
$.33-$1	100.0	0.0	0.0	100.0	0.0	0.0	100.0	0.0	0.0	77.8	22.2
$1-$3	55.6	44.4	0.0	100.0	0.0	5.6	94.4	0.0	16.7	77.8	5.6
$3-$10	61.1	38.9	0.0	100.0	0.0	5.6	88.9	5.6	5.6	88.9	5.6

Table 6: Income Elasticity Coefficients
Determined from Mean Units Purchased

Income	Heroin	Valium	Alcohol	Marijuana	Cocaine
30					
100		-0.335	0.075	0.200	0.359
156	1.583	-1.310	0.320	-1.175	-0.757
300	0.912	0.912	0.651	0.231	1.671
560	0.863	0.759	0.680	1.376	1.617
Slope of Best Fitting Line	1.038	-0.004	0.370	0.152	0.708