Substitution and Complementarity in the Consumption of Alcohol, Cannabis, and Opiates: Insights from Historical Data

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Abstract

Aim: Understanding the behavior of populations of drug consumers has been and remains a topic of keen interest. We analyze a number of questions of contemporary interest. The first is whether consumers treat alcohol, cannabis, and opiates as substitutes or complements in a legal regime. Second, we explore evidence of habit formation consistent with addiction and the responsiveness of consumption to changes in prices of these substances.

Methods: Using data on twenty-five districts from Bengal, India, from 1911 to 1925, we model the consumption of alcohol, *bhang* (cannabis leaf), *ganja* (cannabis bud), and opium as functions of past consumption, their own prices, prices of the other substances, and wages using dynamic panel data methods.

Results: We find evidence (i) of habit formation for all of these substances; (ii) that alcohol is a substitute for cannabis bud and a complement for cannabis leaf and opium; (iii) cannabis leaf is a complement for alcohol and a substitute for cannabis bud, but neither cannabis bud nor opium consumption are associated with changes in the prices of other substances; (iv) changes in the consumption of alcohol, opium, and cannabis leaf are associated with changes in their own prices; and (v) alcohol, cannabis bud, and opium consumption are associated with changes in wages.

Conclusions: Alcohol consumption is interrelated with the consumption of all three other substances. Three of the drugs display either price or wage associations. Understanding how the consumption patterns of these substances are associated with economic variables informed harm reduction strategies in the early 20th century and should continue to do so.

Keywords: Substitution; complementarity; alcohol; cannabis; opiates; prices; income; elasticity.

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1 Introduction

In the early 20th century, a variety of psychoactive substances, including alcohol, cannabis, cocaine, and opium, remained legal throughout much of the world. In colonial Asia, sales of alcohol, cannabis, and opium formed important sources of tax revenue much as alcohol and tobacco sales contribute to government budgets today. Debates about the legal status and degree of regulation of these drugs were as common then as they are today. It is unsurprising, therefore, that researchers then (as now) felt it important to understand how populations of drug consumers would respond to changes in a variety of economic variables, including the prices of these substances and their own incomes.

Two of the most comprehensive research projects on drugs were conducted in the late 19th century precisely to create this kind of understanding. In response to debates about the legal status of cannabis in India, the House of Commons in London created the Indian Hemp Drugs Commission, charging it to inquire into the "desirability of prohibiting ... the sale of ganja and allied drugs" ((Indian Hemp Drugs Commission 1894), v.1, p.1). Shortly thereafter, the Royal Commission on Opium was created to answer similar questions, this time about opium and its cultivation, manufacture, and sale throughout Asia. The questions that these two commissions addressed should sound very familiar to drug researchers today. Using data from India in the early 20th century, but analyzing them using methods that were not available to members of the two above commissions, we explore a variety of questions that were of interest to the Indian Hemp Drugs Commission and the Royal Commission of Opium as well as to the drug research community today.

The behavior of consumers of psychoactive substances including alcohol, cannabinoids and opiates has been and remains a subject of great interest to drug researchers. Understanding how the consumption of these substances interacts with economic incentives can inform harm reduction strategies. Debates past and present about the legal status of these substances are usually informed by whether (i) consumers will consume more or less of other psychoactive substances depending on the legal status of the substance under consideration; (ii) the degree to which consumption may be habit forming (Becker et al. 1994); (iii) the responsiveness of populations of users to changes in economic conditions, including prices and income; and (iv) health effects (Fleming et al. 2021; Simmons et al. 2020). In addition, substituting one psychoactive product for another with the aim of reducing adverse outcomes is a common treatment or public health strategy (Barnett 1999; Moore et al. 2009; Reiman 2009). Empirical studies have shown that the additive effects of two psychoactive substances can be detrimental for public safety (Bramness et al. 2010a, 2010b; Gossop et al. 2002; Sewell et al. 2009; Simmons et al. 2020), and policies targeting the use of one substance might inadvertently affect consumption of another (Subbaraman 2016).

Economic studies of the behavior of populations of consumers of psychoactive substances focus on responses to changes in key economic variables, including prices and incomes or wages (Becker et al. 1994; Chandra and Chandra 2015; Gallet 2014; Pacula and Lundberg 2013; Van Ours 2007; Van Ours and Williams 2007). While studies on alcohol and tobacco are numerous and easy to conduct because of their legal status (Bader et al. 2011; Baltagi and Levin 1992; F. Chaloupka 1991; F. J. Chaloupka 1999; Chaloupka et al. 2002), there are far fewer studies that focus on cannabinoids, which have only recently been legalized or decriminalized in limited regions of the world. Studies on opiates, which remain illegal throughout most of the world, are even scarcer, and have had to rely on data from the early 20th century, when opium was legal and its sale was carefully recorded for accounting purposes. The absence of reliable price and consumption data on cannabinoids and opiates presents a high hurdle for research on the properties of these drugs (Caulkins 2007; Chandra and Barkell 2013), and the only study that used population level data on the simultaneous consumption of opiates and cannabinoids drew on data from the Punjab province of India for the years 1907 to 1918 (Chandra and Chandra 2015). Patterns of consumption, including substitution and complementarity among populations that are simultaneously consuming alcohol, cannabinoids and opiates have never been studied. Yet there exists a unique dataset from Bengal in India which contains population-level data on the simultaneous consumption of all of these drugs.

The central aim of this study, therefore, is to analyze the simultaneous consumption of alcohol, cannabis, and opium with a view to determining the degree to which these different substances are treated as substitutes or complements for one another. Other aims of this paper include investigating whether, in a regime in which all three substances are legal, (i) alcohol, cannabis, and opium display habit forming characteristics consistent with addiction, (ii) changes in their consumption are associated with changes in their own prices, and (iii) changes in consumption are associated with changes in wages.

In the early 1900s in British India, the production and sale of alcohol, cannabinoids, and opiates was legal and heavily regulated by the government. Bengal was one of the largest administrative subdivisions of India in terms of area. According to the *Census of 1921*, Bengal was also the most populous province in India with a population of 47 million, 93.3% of whom lived in rural areas (Marten 1924). Supported by excise laws, the government exercised sweeping authority over the production and sale of alcohol, cannabis, and opium (Bengal, Excise Department 1909). Across the districts of Bengal, the District Collectors and Excise Commissioners, as the senior-most representatives of the government in a district, implemented the provisions of the excise laws. For a fee, farmers, manufacturers, and retailers were licensed to grow, manufacture, or sell alcohol, cannabis, or opium. Cannabis and opium were cultivated by farmers in Bengal and its neighboring provinces, and transported to their end markets under direct or indirect government supervision. Prices and rates of taxation were fixed by the government. According to the Administration Report of Bengal of 1923-24, excise revenues, 82% of which were derived from the sales of alcohol, cannabis, and opium constituted 21% of the government's overall revenue ((Bengal 1924), p. 122; (Bengal, Excise Department, various years), p. 6-14).

2 Data and Methodology

Data

This study uses retail sales and price data for country spirits, cannabis leaf (*bhang*), cannabis bud (*ganja*), and opium reported in the Excise Reports of Bengal Presidency ((Bengal, Excise Department, various years), 1911/12 to 1925/26) over a period of 15 years for 25 districts of Bengal Presidency (n = 375). These 25 districts spanned the present nation of Bangladesh and the state of West Bengal in India. We also collected data on daily wages for agricultural workers, who formed the vast majority of the population across Bengal, from two sources, (i) the *Annual Report of Prices and Wages in India* for 1911 and 1916 (the wages for Bengal were updated in five-year intervals and (ii) the *Report on the Fourth Wage Census of Bengal* for 1925, yielding wage data for three years, 1911, 1916 and 1925. We linearly interpolated these data to produce time series of the daily wage for the period 1911-1925 for each district. In order to compute per capita consumption of the four drugs being analyzed, we divided retail sales for each district by the population in that district (Chandra et al. 2012). Finally, we used annual district-level data on the price of rice, the staple food crop of Bengal from the Season and Crop Reports of Bengal ((Bengal, Department of Agriculture, various years), 1911/12 to 1925/26) to adjust the wage and price data for inflation. Table 1 contains summary statistics and units of measure for the variables used in the models estimated in this study.

Country spirits were sold at various strengths in different districts, the strength being decided by the Government. The issuance of licenses, and the setting of strength, license fees, rates of duty, and retail prices through administrative orders were the pri-

Table 1: Summary Statistics for Variables Used in the Models (n=375)

Variable *(units)*	Mean	SD	Median	IQR	Min	Max
Real* Price of Alcohol *(pies per liter)*	2.38	1.04	2.20	1.20	0.35	8.14
Real* Price of Opium *(pies per gram)*	138.43	60.10	125.55	74.74	40.63	465.26
Real* Price of Cannabis bud *(pies per gram)*	89.07	39.66	77.63	46.79	35.12	313.16
Real* Price of Cannabis leaf *(pies per gram)*	17.34	10.74	13.92	14.96	3.76	71.58
Real* Wage *(pies per day)*	0.69	0.28	0.63	0.27	0.28	2.38
Per Capita Consumption of Alcohol *(liters per capita)*	0.05	0.05	0.032	0.06	0.00	0.26
Per Capita Consumption of Opium *(grams per capita)*	0.75	0.66	0.49	0.72	0.02	2.83
Per Capita Consumption of Cannabis bud *(grams per capita)*	1.48	0.78	1.31	0.92	0.24	5.44
Per Capita Consumption of Cannabis leaf *(grams per capita)*	0.29	0.40	0.08	0.36	0.00	1.71

*These variables are adjusted for the price of rice (the key staple grain of Bengal), which was used as an indicator of the cost of living (i.e., inflation). SD is the Standard Deviation, and IQR is the Inter-Quartile Range.

mary mechanisms through which the Government exercised control over the market for country spirits ((Bengal, Excise Department, various years), 1915/16 to 1918/19). For example, the Government issued an Administrative Order with effect from April 1, 1917 setting the strength and prices at which retail vendors could sell Country Spirits in Calcutta ((Bengal, Excise Department, various years), 1916/17). We converted all quantities of country spirit to their London Proof equivalent, measured in Imperial Gallons. Similar forms of regulation were exercised for cannabis and opium. As an example, the Government raised the retail price of cannabis leaf, cannabis bud and opium for the districts of Hooghly, Howrah, 24 Parganas and Calcutta with effect from April 1918 ((Bengal, Excise Department, various years), 1917/18).

In line with the government's classification of cannabis products, we treated cannabis leaf (*bhang*) and cannabis bud (*ganja*) as different products because (a) they differed in potency, with the leaf being the less potent of the two, and (b) they were perceived as being different by consumers. Cannabis leaf, which was usually ingested, was consumed during religious festivals ((Indian Hemp Drugs Commission 1894), pp. 160-61), recreationally, and as an energizing or cooling drink. Cannabis bud, on the other hand, was often smoked ((Indian Hemp Drugs Commission 1894), p. 154). Because of its closer association with religious ritual, the consumption of cannabis leaf was also more socially acceptable than cannabis bud. Differences between the two cannabis products are discussed in more detail in Appendix A.

We adjusted the price of country spirits for strength by computing a quantity-weighted average of price. Reflecting the widespread use of rice, comprising 85% of all agricultural produce in Bengal ((Bengal, Department of Agriculture, various years), 1911/12 to 1925/26), as a staple food, we adjusted the retail prices of country spirit, cannabis leaf, cannabis bud, and alcohol for inflation using the price of rice as a deflator. Finally, in keeping with standard practice for such models, we transformed all of the original variables into their natural logarithms. Appendix B contains plots of the time series of consumption of the four drugs against their prices. In general, when the price rises, consumption falls and vice versa.

We calculated per capita measures of consumption for alcohol, cannabis, and opium in any year by dividing total consumption in each district by an estimate of the population of that district in that year, derived from Chandra et al. (2012). Because we use officially recorded data on the sales of psychoactive substances, our data are not affected by the threats to validity observed in self-reported data on the consumption of such substances (Brener et al. 2003).

2.1 Econometric Model

For each of the four substances, we modeled the logarithm of current consumption as a function of the logarithms of past consumption, the real price of the substance, the real prices of the three other substances, and real wages. Econometric models of the consumption of psychoactive substances capture the phenomenon of habit formation by including past consumption as an explanatory variable (Becker and Murphy 1988; Becker et al. 1994; Boyer 1983; Stigler and Becker 1977; Suranovic et al. 1999). A positive parameter estimate between 0 and 1 in value is interpreted as evidence of habit formation. In the logarithmic specification, the parameter estimates for all of the other variables (own price, price of other substances, and wages) can be interpreted as an elasticity or the percentage change in consumption associated with a 1% change in the variable under consideration. Thus, in the model of alcohol consumption, a parameter estimate of -0.91 on the price of alcohol would indicate that a 1% increase in the price of alcohol is associated with a 0.91% decrease in its consumption. Similarly, a parameter estimate of 1.05 on the price of cannabis bud would indicate that a 1% increase in the price of cannabis bud is associated with a 1.05% increase in alcohol consumption, suggesting substitution from cannabis bud to alcohol as cannabis bud becomes more expensive.

A common issue that arises in the estimation of price elasticities of consumption is that of identification. In an unregulated market, since quantities consumed are a function of the price, which is determined by the interaction of the forces of demand and supply, observed variations in consumption in response to changes in the price cannot be attributed solely to consumer behavior — competing producers also respond to changes in price by adjusting their output. Fortunately, the heavily regulated nature of markets for excise goods in India eliminates this identification problem — rather than a collection of competing profit-maximizing producers making production decisions, a single government entity artificially fixed the price for a mix of stated and often conflicting reasons, from raising revenue to curbing negative public health consequences from widespread consumption and dampening opposition to the practice from prohibitionist forces, including large segments of the missionary community in India. Therefore, a simplifying but reasonable assumption underlying this study is that the prices of the four products being analyzed were exogenous in the sense that they were not spontaneously determined by the interaction of the forces of demand and supply as would be the case in an unregulated market. Therefore, we assume that prices are exogenously determined and treat them as predetermined variables in the econometric model.

The general econometric model for each drug is specified as follows:

$$C_{i,t} = \beta_0 + \beta_1 C_{i,t-1} + \beta_2 P_{i,t} + \beta_3 P'_{i,t} + \beta_4 \tilde{P}_{i,t} + \beta_5 \ddot{P}_{i,t} + \beta_6 \omega_{i,t} + \epsilon_{i,t}. \tag{1}$$

Here, $C_{i,t}$ is the logarithm of per capita consumption of the drug in question in district i in year t; $C_{i,t-1}$ is the one-period lag of the logarithm of per capita consumption of that drug; $P_{i,t}$ is the logarithm of the real price of alcohol, $P'_{i,t}$ is the logarithm of the real price of opium, $\tilde{P}_{i,t}$ is the logarithm of the real price of cannabis bud, $\ddot{P}_{i,t}$ is the logarithm of the real price of cannabis leaf, $\omega_{i,t}$ is the logarithm of real wages and $\epsilon_{i,t}$ is a random error term. We estimated the above model for each of the four drugs for which we had data, i.e., alcohol, opium, cannabis bud, and cannabis leaf.

The above model is classified as a Dynamic Panel Data (DPD) Model because it utilizes the lag of the dependent variable (consumption) as an explanatory variable. The inclusion of lagged consumption introduces the problem of endogeneity because lagged consumption is correlated with the error term, leading to biased estimates (Greene 2003; Wooldridge 2010). Econometricians have developed a variety of statistical techniques to address endogeneity and generate efficient estimates in such models (Arellano and Bond 1991; Arellano and Bover 1995; Baltagi and Levin 1992; Blundell and Bond 1998), including the widely used Generalized Methods of Moments (GMM) class of estimators (Greene 2003; Wooldridge 2010). Using these panel data methods avoids issues such as autocorrelation that can arise when aggregate data on habit-forming substances are being used, thereby addressing an important critique of such models (Auld and Grootendorst 2004).

GMM estimators can be estimated using Difference GMM or System GMM Models, both of which employ instrumental variables. Difference GMM estimates parameters using first differences of the original variables in the model. First differencing eliminates time-invariant unobserved heterogeneity within the groups (in this case, districts). The endogenous first-differenced variables are instrumented with their lagged levels as they are uncorrelated with the differenced error terms (Arellano and Bond 1991; Arellano and Bover 1995). By contrast, System GMM estimates a levels equation in conjunction with the first difference equation. The level equation is instrumented using first differences of independent variables (Arellano and Bover 1995; Blundell and Bond 1998). We prefer 'Two-Step' GMM estimates over 'One-Step' GMM estimates since they are both asymptotically efficient and robust to heteroscedasticity and cross-correlation (Roodman 2006, 2009). Appendix C provides further technical details of these methods and tests. As a robustness check, we also present results from One-Step GMM models in Appendix D.

Finally, as additional robustness checks, we estimated models (i) without cross-price effects, (ii) including variables for the number of opium and cannabis shops, and (iii) the number of seizures of smuggled opium. In all cases, the models yielded substantially similar results.

3 Results

Estimates from the Two-Step System GMM models for alcohol, cannabis leaf, and cannabis bud and the Two-Step Difference GMM model for opium are reported in Table D4. The coefficient of the log of lagged consumption (β_1) for all four substances is positive, statistically significant and less than 1, indicating habit formation or addictive behavior (Becker and Murphy 1988) manifested in the positive relationship between levels of past and current consumption. This relationship implies that long-term changes in consumption in response to a one-time change in the current price are larger than the short-term (i.e., current) change in consumption associated with the change in the price (see Appendix E). Changes in the consumption of alcohol, opium, and cannabis leaf are associated with changes in their own prices (i.e., negative coefficients), but this association is limited or inelastic (i.e., the coefficient in question is less than 1 in absolute value). For cannabis bud, this coefficient is not statistically significant. The coefficient of the logarithm of wages is positive and less than 1 in value for alcohol, opium and cannabis bud, indicating wage inelasticity. For cannabis leaf, this coefficient is statistically insignificant. Taken together, these three properties for the four drugs are consistent with habit forming substances for which price and income incentives alter behavior, albeit in a limited manner.

Interestingly, the cross price elasticity estimates reveal evidence of a variety of interrelationships in the consumption of the four substances. For example, an increase in the price of cannabis bud is associated with an increase in the consumption of alcohol (β_4=1.049, p=0.001; a substitution effect), and increases in the prices of opium and cannabis leaf are associated with drops in alcohol consumption (β_3=-0.527, p=0.044 and β_5=-0.303, p=0.066; both complementarity effects). In addition, an increase in the price of cannabis bud is associated with an increase in the consumption of cannabis leaf

Table 2: Estimates from the Dynamic Panel Data Models

Substance	Alcohol (Country Spirit)	Cannabis bud	Cannabis leaf	Opium
Estimation Method	System GMM	System GMM	System GMM	Difference GMM
Lagged Log of Consumption (β_1)	0.235 [0.0170, 0.452]	0.383 [0.168, 0.598]	0.485 [0.106, 0.864]	0.567 [0.351, 0.782]
Log of Price of Alcohol (β_2)	-0.909 [-1.465, -0.352]	0.0984 [-0.049, 0.246]	-0.400 [-0.762, -0.038]	0.0453 [-0.097, 0.187]
Log of Price of Opium (β_3)	-0.527 [-1.039, -0.015]	-0.217 [-0.551, 0.116]	0.044 [-0.242, 0.330]	-0.535 [-0.747, -0.324]
Log of Price of Cannabis bud (β_4)	1.049 [0.461, 1.636]	-0.261 [-0.740, 0.219]	0.883 [-0.011, 1.778]	0.073 [-0.270, 0.415]
Log of Price of Cannabis leaf (β_5)	-0.303 [-0.627, 0.022]	-0.098 [-0.311, 0.114]	-0.626 [-1.123, -0.128]	-0.052 [-0.128, 0.024]
Log of Wage (β_6)	0.690 [-0.060, 1.440]	0.447 [0.024, 0.870]	0.003 [-0.475, 0.481]	0.432 [0.251, 0.614]
Constant (β_0)	-2.681 [-4.428, -0.935]	-1.707 [-2.970, -0.443]	-6.144 [-11.187, -1.102]	—
Arellano-Bond test for AR(2)	0.73	0.82	0.64	1.14
$(Pr > z)$	0.46	0.41	0.52	0.25
Hansen Test for Overidentification (χ^2)	2.50	0.11	2.10	0.00
$(Pr > z)$	0.29	0.74	0.35	—
Observations	306	312	309	287
Number of Groups	25	25	25	25
Number of Instruments	9	8	9	6

Notes: Results shown for Two-Step System GMM for Alcohol, Cannabis bud, and Cannabis leaf; and Two-Step Difference GMM for Opium. Difference GMM results for Opium are preferred since System GMM showed evidence of overidentification. 95 percent confidence intervals constructed using Windmeijer-Corrected cluster robust standard errors reported in brackets; the 'collapse' option was used to reduce the number of instruments (see Roodman (2009) for details).

(β_4=0.883, p=0.053; a substitution effect), and an increase in the price of alcohol is associated with a drop in cannabis leaf consumption (β_2=-0.400, p=0.032; a complementarity effect).

4 Discussion

Key findings of this study are, first, evidence consistent with limited price and income responsiveness in the consumption of the four substances. These effects, where present, have the expected signs, i.e., price increases are associated with decreases in consumption, and wage increases are associated with increases in consumption. Second, we observe substitution effects from cannabis bud to cannabis leaf and alcohol, a one-way complementarity effect between opium and alcohol triggered by changes in the price of opium, and a two-way complementarity effect (i.e., triggered by the price of either good) between cannabis leaf and alcohol. Unlike the first set of findings on own-price and wage associations, which are consistent with findings from earlier studies (Becker et al. 1994; Chandra and Chandra 2015; Gallet 2014; Pacula and Lundberg 2013; Van Ours and Williams 2007), the second set of findings on substitution and complementarity is new to the literature on the consumption of psychoactive substances. These findings are summarized in the table in Appendix E.

Moreover, a number of these findings broadly align with anecdotal evidence from documents relating to the consumption of these substances in India, including various editions of the *Administration Report of the Excise Department* and the *Indian Hemp Drugs Commission Report*. Table 3 below lists the frequency with which phenomena that can be interpreted as own-price, wage, or cross-price elasticity appeared in annual issues of the *Excise Administration Report for Bengal* from which the statistical data were drawn (i.e., 1911-1925). The maximum value that any cell can take is 14, i.e. the phenomenon was mentioned in each of the 14 annual issues of the report for which this information was available. Specific excerpts from these reports and the *Indian Hemp Drugs Commission Report* are presented in Appendix F.

Table 3: Frequency* of Mentions of Own-Price, Wage, and Cross-Price Responsiveness of Consumption of Alcohol, Cannabis Bud, Cannabis Leaf, and Opium, 1911-1925

Phenomenon	Substance			
	Alcohol (Country Spirit)	Cannabis bud	Cannabis leaf	Opium
Own-price responsiveness	13	13	11	10
Cross-price responsiveness	1	6**	2	1
Wage responsiveness	14	12	3	8

*Mentions were sourced from the 14 annual reports for which qualitative data were available. Hence the maximum possible value for the frequency is 14, indicating that the phenomenon in question was mentioned at least once in each of the 14 annual reports.
**The majority of mentions supporting cross-price responsiveness refer to increases in consumption of cannabis bud in response to higher prices of alcohol (country spirit), i.e., a substitution effect.

The reports provide evidence supporting the habit forming properties of cannabis and convey a sense that, in the event of prohibition or other restrictions on the consumption of cannabis, consumers would switch to alcohol and other drugs (see Appendix F). This aligns with the observation of a substitution effect from cannabis bud, the most widely consumed form of cannabis in Bengal, to alcohol.

The results on habit formation or addictive behavior and own-price and wage elasticity also align closely with the findings of earlier studies which have employed a similar methodology (Chandra and Chandra 2015; Liu et al. 1999; Van Ours 1995). Furthermore, depending on the cannabis product in question, we find a substitution effect between alcohol and cannabis bud, which is broadly in line with findings from earlier studies (Karoly et al. 2021; Lucas et al. 2013; Reiman 2009; Subbaraman 2016) as well as a two-way complementarity effect between alcohol and cannabis leaf, which aligns with findings from other studies (Ellickson and Hays 1991; Gripe et al. 2018; Kandel and Maloff 1983; Pacula 1998; Pape et al. 2009). While the cited studies differ in their methodologies and some do not measure cross price elasticities in a simultaneous and legal consumption regime, our findings suggest that different types of cannabis products may be treated differently by consumers in relation to other products. This may be for reasons of relative strength (cannabis leaf is less potent than the resin-rich cannabis bud), culture (different forms of cannabis in India were and continue to be used for different reasons, including religious ritual and recreation in a manner analogous to the use of alcohol in some western societies), or mode of consumption (i.e., ingested (cannabis leaf) vs. smoked (cannabis bud)).

A limitation of this study is its contextual specificity — the data cover a specific regulatory regime (i.e., alcohol, cannabis, and opium were simultaneously legal) in a specific location (Bengal, India) at a specific time in history (the early 20th century) in a primarily rural population. To the extent that the findings align with those of studies looking at other combinations of drugs, however, they suggest phenomena that are robust across such contexts and likely of a predominantly biological or psychological nature. A second limitation of this study concerns the individual-oriented interpretation of findings based on aggregate data. While this is valid only under strict assumptions (Stoker 1993), the findings have the advantage of reflecting market phenomena that cannot be characterized using data from a group of individuals unless that group is very carefully constructed.

The above limitations notwithstanding, this study makes a number of contributions to the literature on the behavior of populations of drug consumers. The analysis of the simultaneous consumption of alcohol, cannabis, and opiates in a regime in which all three classes of drugs are legally available, made possible by the unique nature of the dataset, allows us to test hypotheses not only about own-price and wage associations with the consumption of these drugs in such a regulatory milieu, but also on how and the degree to which the consumption of these drugs is interrelated. Because there exists no regime in the world today in which all three drug classes are simultaneously legally available for recreational use and for which systematic data on prices, consumption, and wages are being collected, this analysis allows us to present unique insights into the behavior of populations of consumers.

Additionally, the results of this study contribute to a variety of ongoing debates on the properties of and policies relating to psychoactive substances. In the context of the debate on the legalization of cannabis, the study provides clues about how populations of cannabis consumers may respond to price and income changes in a legal but regulated regime. First, changes in income are associated with changes in consumption for cannabis leaf, suggesting that income-focused policies, such as taxation or subsidization, can affect consumption. Second, the evidence of habit formation suggests that a change in prices or income, possibly effected through different types of taxation or subsidization, will have not only short-term effects on cannabis leaf consumption, but also long-term effects because of the intertemporal relationship between present and future consumption levels inherent in habit-formation models. Third, the differentiated consumer responses between cannabis leaf and cannabis bud suggest that product differentiation matters because different products may have differing potency, be consumed by different types of consumers in different contexts and ways, and be viewed differently in the social and cultural context of the time and place in which they are being consumed. The variety of ways in which cannabis is consumed today (i.e., ingested or smoked, and variations therein) and behaviors specific to those different modes of consumption should, therefore, be taken into account in the design of policies in much the same way in which policies relating to alcohol (by type of beverage) and tobacco (by mode of consumption — smoked vs. ingested) are often differentiated. A synthesis of aspects of the findings of this study that transcend context with an understanding of the context in which cannabis and other drugs are consumed today has the potential to contribute to better policy and practice with the ultimate benefit of greater harm reduction.

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Appendices

A Appendix A

A.1 Definitions of and Distinctions between Cannabis Leaf (*Bhang*) and Cannabis Bud (*Ganja*)

Cannabis was consumed in various forms in British India. In Bengal, the vast majority of cannabis was consumed in the form of *bhang* (cannabis leaf) and *ganja* (cannabis bud). *Bhang* was defined as:

> "the dry leaves of the hemp plant, whether male or female and whether cultivated or uncultivated."

Indian Hemp Drugs Commission (1894), v. 4, p. i

Ganja, by contrast, consisted

> "of the dried flowering tops of cultivated female hemp plants which have become coated with resin in consequence of having been unable to set seeds freely."

Indian Hemp Drugs Commission (1894), v. 4, p. i

The resin present in cannabis bud, which is rich in THC and cannabidiol, contributed to significantly greater potency of the bud compared to the leaf,

> "The bhangs contain from 8.31 to 12.63 per cent. of resins, or an average of about 10 per cent. which is one-half the amount yielded by average samples of ganja."

Indian Hemp Drugs Commission (1894), v. 3, p. 204

B Appendix B

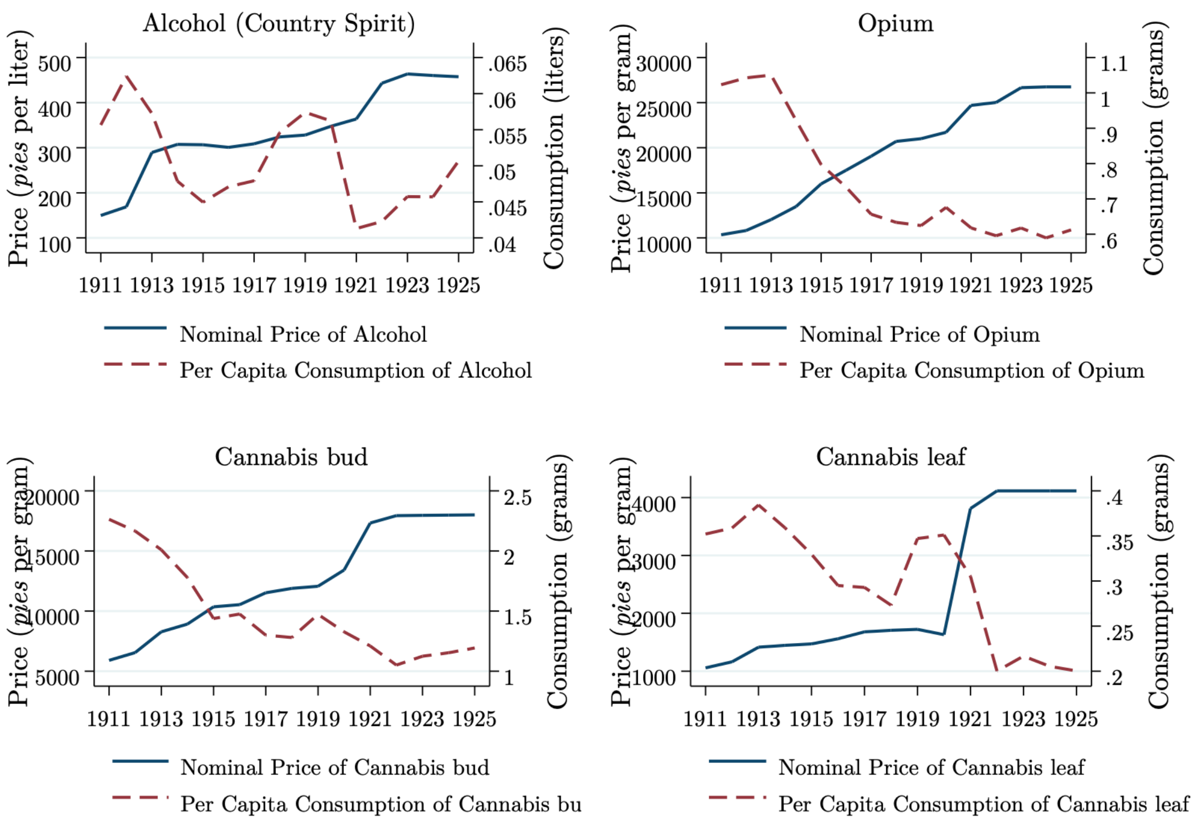

Figure B1: Nominal Price and Per Capita Consumption of Alcohol, Opium, Cannabis Bud, and Cannabis Leaf

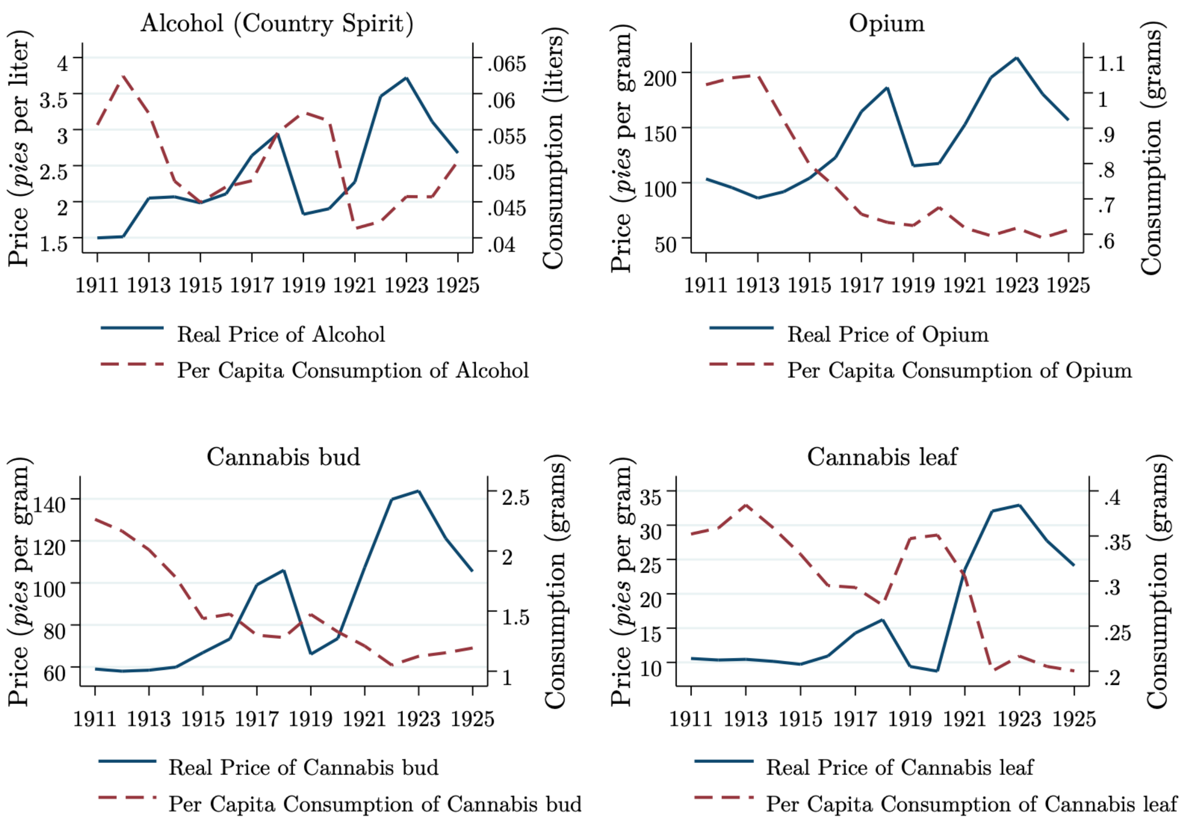

Figure B2: Real Price and Per Capita Consumption of Alcohol, Opium, Cannabis Bud, and Cannabis Leaf

C Appendix C

We used a combination of the Sargan/Hansen test for overidentifying restrictions and the Arellano-Bond Test for second order autocorrelation, AR(2) ((Hansen 1982)) to determine the number of lags of the dependent variable to be included as instruments in the equations for the System and Difference GMM models. These tests indicated a choice of up to two periods for the first equation and a single lag for the second equation. A final choice was between the 'One-Step' and 'Two-Step' model computation procedures. These procedures differ in the specification of the weighting matrix and moment conditions used to generate estimates. Though estimates from both procedures are consistent, two step estimators are both asymptotically efficient and robust to heteroscedasticity and cross-correlation ((Roodman 2006, 2009)). Hence, Two-Step GMM estimates are usually favored over One-Step estimates.

Based on the above considerations, we selected Two-Step System GMM estimates for the models of alcohol, cannabis bud, and cannabis leaf consumption. Because the Two-Step System GMM model for opium consumption showed evidence of overidentification, we selected Two-Step Difference GMM estimates for the opium model. As a robustness check, we also estimated One-Step System GMM models for alcohol, cannabis leaf, and cannabis bud (see Appendix D). Because the Difference GMM model for opium was exactly identified, (i.e. the number of instruments is equal to the number of regressors), the One- and Two-Step GMM estimates yielded identical estimates (Greene 2003; Wooldridge 2010). We used the *xtabond2* function in Stata developed by Roodman (2006) and Roodman (2009) to estimate all the GMM models.

D Appendix D

D.1 One-Step GMM Estimates

Table D1: Estimates from the Dynamic Panel Data Models (One-Step GMM)

Substance	Alcohol (Country Spirit)	Cannabis bud	Cannabis leaf	Opium
Estimation Method	System GMM	System GMM	System GMM	Difference GMM
Lagged Log of Consumption (β_1)	0.298 [0.071, 0.525]	0.380 [0.157, 0.604]	0.626 [0.125, 1.127]	0.567 [0.351, 0.782]
Log of Price of Alcohol (β_2)	-0.674 [-1.261, -0.087]	0.0981 [-0.049, 0.245]	-0.271 [-0.749, 0.206]	0.0453 [-0.097, 0.187]
Log of Price of Opium (β_3)	-0.232 [-0.866, 0.403]	-0.226 [-0.558, 0.106]	0.141 [-0.241, 0.523]	-0.535 [-0.747, -0.324]
Log of Price of Cannabis bud (β_4)	0.756 [0.018, 1.494]	-0.237 [-0.728, 0.255]	0.571 [-0.427, 1.570]	0.073 [-0.270, 0.415]
Log of Price of Cannabis leaf (β_5)	-0.185 [-0.521, 0.151]	-0.109 [-0.323, 0.104]	-0.462 [-0.981, 0.057]	-0.052 [-0.128, 0.024]
Log of Wage (β_6)	0.269 [-0.573, 1.112]	0.452 [0.044, 0.861]	-0.176 [-0.861, 0.509]	0.432 [0.251, 0.614]
Constant (β_0)	-3.542 [-5.498, -1.587]	-1.752 [-3.036, -0.467]	-4.788 [-11.356, 1.779]	—
Arellano-Bond test for AR(2)	1.42	0.85	0.62	1.14
$(Pr > z)$	0.16	0.40	0.54	0.25
Hansen Test for Overidentification (χ^2)	2.50	0.11	2.10	0.00
$(Pr > z)$	0.29	0.74	0.35	—
Observations	306	312	309	287
Number of Groups	25	25	25	25
Number of Instruments	9	8	9	6

Notes: Results shown for One-Step System GMM for Alcohol, Cannabis bud, and Cannabis leaf; and Two-Step Difference GMM for Opium. Difference GMM results for Opium are preferred since System GMM showed evidence of overidentification. 95 percent confidence intervals constructed using Windmeijer-Corrected cluster robust standard errors reported in brackets; the 'collapse' option was used to reduce the number of instruments (see Roodman (2009) for details).

D.2 Two-Step GMM Estimates without cross-price effects

Table D2: Estimates from the Dynamic Panel Data Models without Cross-price Effects

Substance	Alcohol (Country Spirit)	Cannabis bud	Cannabis leaf	Opium
Estimation Method	System GMM	System GMM	System GMM	Difference GMM
Lagged Log of Consumption (β_1)	0.203 [0.0627, 0.344]	0.475 [0.223, 0.728]	0.641 [0.449, 0.833]	0.624 [0.456, 0.791]
Log of Price of Alcohol (β_2)	-0.796 [-1.101, -0.490]			
Log of Price of Opium (β_3)				-0.477 [-0.626, -0.328]
Log of Price of Cannabis bud (β_4)		-0.419 [-0.718, -0.121]		
Log of Price of Cannabis leaf (β_5)			-0.255 [-0.435, -0.075]	
Log of Wage (β_6)	0.623 [0.237, 1.010]	0.352 [0.054, 0.649]	0.078 [-0.410, 0.567]	0.426 [0.322, 0.529]
Constant (β_0)	-1.852 [-2.680, -1.024]	-1.496 [-2.505, -0.486]	-2.531 [-4.371, -0.691]	—
Arellano-Bond test for AR(2)	0.51	0.21	1.02	1.09
$(Pr > z)$	0.61	0.83	0.31	0.27
Hansen Test for Overidentification (χ^2)	0.21	1.27	3.44	0.00
$(Pr > z)$	0.89	0.26	0.18	—
Observations	339	343	311	320
Number of Groups	25	25	25	25
Number of Instruments	6	5	6	3

Notes: Results shown for Two-Step System GMM for Alcohol, Cannabis bud, and Cannabis leaf; and Two-Step Difference GMM for Opium. Difference GMM results for Opium are preferred since System GMM showed evidence of overidentification. 95 percent confidence intervals constructed using Windmeijer-Corrected cluster robust standard errors reported in brackets; the 'collapse' option was used to reduce the number of instruments (see Roodman (2009) for details).

D.3 Two-Step GMM Estimates including Number of Licensed Opium and Cannabis shops

Table D3: Estimates from the Dynamic Panel Data Models

Substance	Cannabis bud	Cannabis leaf	Opium
Estimation Method	System GMM	System GMM	Difference GMM
Lagged Log of Consumption (β_1)	0.030 [-1.174, 1.234]	0.695 [0.461, 0.928]	0.632 [0.426, 0.838]
Log of Price of Alcohol (β_2)	0.173 [-0.328, 0.675]	-0.148 [-0.340, 0.044]	0.038 [-0.093, 0.170]
Log of Price of Opium (β_3)	-0.429 [-1.447, 0.619]	0.152 [-0.157, 0.461]	-0.432 [-0.631, -0.232]
Log of Price of Cannabis bud (β_4)	-0.422 [-1.332, 0.488]	0.367 [-0.014, 0.748]	0.092 [-0.283, 0.467]
Log of Price of Cannabis leaf (β_5)	-0.171 [-0.554, 0.211]	-0.417 [-0.639, -0.196]	-0.061 [-0.157, 0.036]
Log of Wage (β_6)	0.862 [-0.814, 2.538]	-0.146 [-0.615, 0.322]	0.339 [0.153, 0.525]
Number of Shops (β_7)	0.009 [-0.004, 0.023]	0.023 [0.002, 0.044]	0.010 [0.003, 0.017]
Constant (β_0)	-2.518 [-4.670, -0.367]	-3.966 [-7.535, -0.397]	—
Arellano-Bond test for AR(2)	0.16	1.03	1.18
$(Pr > z)$	0.87	0.30	0.24
Hansen Test for Overidentification (χ^2)	0.01	3.02	0.00
$(Pr > z)$	0.93	0.22	—
Observations	297	294	271
Number of Groups	26	26	24
Number of Instruments	9	10	7

Notes: Results shown for Two-Step System GMM for Cannabis bud and Cannabis leaf; and Two-Step Difference GMM for Opium. Difference GMM results for Opium are preferred since System GMM showed evidence of overidentification. 95 percent confidence intervals constructed using Windmeijer-Corrected cluster robust standard errors reported in brackets; the 'collapse' option was used to reduce the number of instruments (see Roodman (2009) for details).

D.4 Two-Step GMM Estimates for Opium model with smuggling

Table D4: Estimates from the Dynamic Panel Data Models

Substance	Opium
Estimation Method	Difference GMM
Lagged Log of Consumption (β_1)	0.468 [0.251, 0.684]
Log of Price of Alcohol (β_2)	0.061 [-0.085, 0.207]
Log of Price of Opium (β_3)	-0.426 [-0.609, -0.242]
Log of Price of Cannabis bud (β_4)	0.148 [-0.243, 0.539]
Log of Price of Cannabis leaf (β_5)	-0.071 [-0.164, 0.022]
Log of Wage (β_6)	0.292 [0.046, 0.539]
Log of Smuggling amount (β_7)	-0.069 [-0.140, 0.001]
Arellano-Bond test for AR(2)	1.33
$(Pr > z)$	0.18
Hansen Test for Overidentification (χ^2)	0.00
$(Pr > z)$	—
Observations	271
Number of Groups	26
Number of Instruments	7

Notes: Results shown for Two-Step Difference GMM for Opium. Difference GMM for Opium are preferred since System GMM showed evidence of overidentification. 95 percent confidence intervals constructed using Windmeijer-Corrected cluster robust standard errors reported in brackets; the 'collapse' option was used to reduce the number of instruments (see Roodman (2009) for details).

E Appendix E

E.1 Summary of the Results from the Two-Step GMM Models

Interpretation of Two-Step GMM Model results from Table D4

			Alcohol (Country Spirit)	Cannabis bud	Cannabis leaf	Opium
			System GMM	System GMM	System GMM	Difference GMM
Phenomenon	Addiction		✓	✓	✓	✓
	Own-price Association	Elastic/inelastic	Inelastic	None	Inelastic	Inelastic
		Short-term elasticity	-0.91	-0.26	-0.63	-0.54
		Long-term elasticity*	-1.19	-0.42	-1.22	-1.25
	Income Association	Elastic/inelastic	Inelastic	Inelastic	None	Inelastic
		Short-term elasticity	0.69	0.45	0.00	0.43
		Long-term elasticity*	0.90	0.72	0.01	1.00
	Relationship to Alcohol (Country Spirit)		—	None	Complement with Alcohol	None
	Relationship to Cannabis bud		Substitute for Cannabis bud	—	Substitute for Cannabis bud	None
	Relationship to Cannabis leaf		Complement with Cannabis leaf	None	—	None
	Relationship to Opium		Complement with Opium	None	None	—
Technical Issues	Autocorrelation		None	None	None	None
	Overidentification		None	None	None	None

*The long-term elasticity in each case is calculated as $\frac{\beta_j}{1-\beta_1}$, where β_1 is the parameter estimate for lagged consumption for the drug being modeled and β_j is the parameter estimate for the short-term elasticity of the drug with respect to the specific variable (price or income) being analyzed.

F Appendix F

This appendix contains selected excerpts from two sets of reports that provide evidence for the own-price, wage, and cross-price responsiveness of the consumption of alcohol, cannabis bud, cannabis leaf, and opium in India. These include Volume 1 of the *Indian Hemp Drugs Commission Report* of 1893-94 (henceforth *IHDCR*) and annual issues of the *Report on the Administration of the Excise Department in the Presidency of Bengal* from 1911 to 1925 (henceforth *ER*).

F.1 Anecdotal Evidence of Own-Price Responsiveness of Consumption of Alcohol, Cannabis Leaf, Cannabis Bud, and Opium

"In districts where the consumption has decreased, there are witnesses who say that the enhanced cost of ganja has reduced, and is reducing, the habit. . . ." *IHDCR*, v.1, p.134

"The higher prices operated in more ways than one to reduce the consumption of country spirit." *ER*, 1913-14, p.9

"Coming as it did in a year of economic depression, the general increase in the retail price of opium naturally resulted in a decrease in local consumption." *ER*, 1915-16, p.18

"The general decrease [in consumption of alcohol] was, however, mainly due to the . . . high prices caused by the war ...." *ER* 1915-16, p.8

F.2 Anecdotal Evidence of Wage Responsiveness of Consumption of Alcohol, Cannabis Leaf, Cannabis Bud, and Opium

"The general decrease [in consumption of alcohol] was, however, mainly due to the continuance of the economic depression .... caused by the war..." *ER* 1915-16, p.8

"The better wages earned by the labouring classes, who are the principal consumers of [cannabis bud], is sometimes held to account for the increase." *IHDCR*, v.1, p.134

"He is also of the opinion that the use has spread among the labouring classes, whose wages have greatly risen in recent years." *IHDCR*, v.1, p.150

"In Bankura and Midnapur the greater part of the increase [in consumption of alcohol] took place in the old outstill area and was largely due to an improvement in the condition of the labouring classes, who are the principal consumers, owing to a rise in wages." *ER*, 1913-14, p.8

"The increase of 1 maund 37 seers [of opium] in Mymensingh is less than the decrease in the preceding year and may be attributed to the conditions of prosperity which caused an increase in the consumption of excisable articles of every description." *ER*, 1913-14, pp.20-21

F.3 Anecdotal Evidence of the Presence or Absence of Substitution or Complementarity Effects between Alcohol, Cannabis Leaf, Cannabis Bud, and Opium:

Alcohol as a substitute for Cannabis Bud:

"other causes also may have been at work to produce the result. The growing taste for liquor is one of the principal causes mentioned." *IHDCR*, v.1, p.134

> "The principal cause of decrease is the change . . . . in the direction of liquor." *IHDCR*, v.1, p.138

> "...rise in the price of spirits, many people who formerly drank spirits have taken to drugs as a substitute." *IHDCR*, p.366.

> "The principal cause of decrease is the change ... in the direction of liquor." *IHDCR*, v.1, p.138

> "...rise in the price of spirits, many people who formerly drank spirits have taken to drugs as a substitute." *IHDCR*, v.1, p.366.

Cannabis bud as a substitute for alcohol:

> "...the great cost of the liquor habit and its deleterious effects are making the same classes go back to ganja." *IHDCR*, v.1, p.134

> "He shows pretty conclusively that the hemp drug revenue has risen when the price of liquor has been raised, and that it has fallen when . . . liquor has been made more plentiful and more cheap." *IHDCR*, v.1, p. 137.

> "The preponderance of testimony is in favor of increasing consumption and the high price of liquor is more frequently alleged as the cause than anything else." *IHDCR*, v.1, p.137.

> "The Collector of Pabna reports that the ganja habit is spreading among the upper classes, and that ganja is sometimes used by prostitutes as a cheap substitute for liquor." *ER*, 1912-13, p.14

> "From the 24-Parganas it has been reported that the increase in consumption was due to a certain extent to the fact that many of the consumers of liquor indulged in the smoking of ganja owing to the high price of country spirit." *ER*, 1919-20, p. 15

> "From Howrah it has been reported that the increase in consumption [of ganja] was due to a certain extent to the fact that many of the liquor consumers indulge in the smoking of ganja owing to the high price of country spirit." *ER*, 1921-22, p. 14

Finally, in a few instances, there is evidence of effects not observed in our models, for example, cannabis leaf as a substitute for cannabis bud and alcohol:

> "...if ... bhang ... is left untouched by the prohibitory measure of the Government, consumers of ganja or charas will get in it a substitute. . . " *IHDCR*, v.1, p.375

> "The increase [in consumption of Cannabis leaf] in Calcutta was partly due to the influx of up-country men in the town and party to higher price of ganja. . . . The increase in the other districts was also due to higher price of ganja." *ER*, 1920-21, p. 15