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On the Effects of Drug Policy *

by

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Abstract

This paper presents a simple analytical model of the market for hard drugs. The key assumptions are (i) a distinction between new users and existing addicts, (ii) imperfect competition, (iii) selective marketing efforts towards potential users, and (iv) the existence of policy effects on consumer loyalty as well as on the static price elasticity of demand facing individual suppliers at any given moment. It is shown that the long-run effects of stricter enforcement may be an increase in both the number of addicts and total consumption.

JEL classification: D43, D92, I18, K14, K32

Key words: Drugs, enforcement strategy, addiction, consumer loyalty, marketing of illicit drugs, transaction costs.

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Section 1: Introduction

Drug policy sometimes appears to have unexpected effects. In the US, for instance, the War on Drugs in the 1980s coincided with the increased availability of both heroin and cocaine (Johnston et al, 1992). This finding in itself does not prove that the policy was ineffectual (or perhaps even counterproductive) but other studies also cast doubt on the effectiveness of traditional policies. Another famous example is alcohol prohibition in the 1920s and early 1930s which appears to have had only modest effects on alcohol consumption (Miron and Zwiebel (1991)). Furthermore, it is well-documented that drug policies can have serious social and economic side-effects; increased violence and crime, a negative impact on health, increased corruption and political instability are among the consequences (e.g. United Nations (1995), Rasmussen and Benson (1994), Benson et al (1992), Niskanen (1992), Miron and Zwiebel (1995)).

It is the purpose of this paper to present a simple, analytical model of the drug market and the potential dangers of current drug policy. The model focuses on risks and transaction costs. These features characterize all illicit markets but in the drug market they interact with dynamic elements of both demand and supply.

On the demand side, some proportion of new users of hard drugs become addicts. This addictive nature of drugs implies an important intertemporal linkage between current consumption by new users and future levels of demand. Turning to the supply side, a large body of empirical evidence indicates that the market is imperfectly competitive. Goldstein el. at. (1984), for instance, describe the marketing of heroin in New York. They emphasize the presence of serious problems of quality uncertainty arising from the illegality and unregulated nature of the market and document the reactions by consumers and dealers to these problems: the use by consumers of regular and trusted dealers (consumer loyalty) and the development by dealers of `brand names'.[1]

The absence of perfect competition might not matter much if the degree of market power were independent of drug policy. But this independence assumption is implausible. As pointed out by, among others, Rottenberg (1969), Eatherly (1974) and Miron and Zwiebel (1995), enforcement policy influences the conditions of new entry and the possibility of cartelization as well as the responsiveness of users to price differences.

Both static and dynamic aspects are important. Enforcement policy affects both the individual supplier's perceived elasticity of demand at each moment and the degree of consumer loyalty. At one extreme, perfect competition, there is neither static monopoly power nor consumer loyalty; consumers always buy from a supplier offering the lowest price. At the other extreme, full monopoly, consumers have to stay with the monopoly supplier (or give up their consumption of the good). In the relevant, intermediate cases, however, tough sanctions and strict enforcement will tend to increase both static monopoly power and consumer loyalty. The market for hard drugs is characterized by quality uncertainty and high costs of search and transaction, and stricter policy will raise these costs by increasing the risk of detection and / or the sanction in case of detection. Consumers thereby get an increased incentive to stay with a known and trusted source of supply.

Taken together, the effects on static market power and consumer loyalty imply that restrictive and heavily enforced drug policies may <u>encourage</u> the marketing of drugs to new users by raising both the profitability of sales to addicts and the probability that new users will remain

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[1] United Nations (1995, p. 11) summarize the market conditions in the drug trade in the following paragraph: "Individuals do not appear to be major players, and early analogies to a cottage industry now make little sense for the illicit drug trade. The trade has become increasingly organized, particularly at the production, wholesale, and middleman levels, pronouncedly so for cocaine and heroin, less so for marijuana. It tends to be controlled by organized groups, and in some cases cartels, often organized along ethnic lines to create stronger cohesiveness."

loyal to an initial supplier who engages in costly marketing. Depending on the magnitude of the different effects, the results of the policy therefore can be paradoxical: the War on Drugs may have contributed to the observed increase in the availability of hard drugs.

Elements of the argument can be found separately in other models of the drug market. Lee (1993), for example, analyses the role of transactions costs, arguing that the paradoxical outcome of the War on Drugs can be explained by endogenous changes in the trading pattern following the tightening of drug policy. Unfortunately, Lee's model is conceptually flawed. He assumes that the market structure can be modelled as perfect competition with price taking suppliers and that transaction risk gives rise to a constant (expected) cost per transaction. He then goes on to argue that, due to the competitive nature of the market, sellers face an exogenously given transactions size as well as an exogenously given unit-price. Any rational seller, however, would immediately offer a slight discount on large transactions and charge a premium on small transactions. Thus, the market should be analyzed by a price function rather than in terms of a scalar price: the unit price will depend on the size of the quantity transacted. A respecification along these lines undermines Lee's explanation of the empirical observations.

Our distinction between new users and addicts also exists in the literature. It is central to the argument in both Moore (1973) and Claque (1973) and is also, together with monopolistic competition, an essential part of the analysis in White and Luksetich (1983). These papers do not, however, seriously consider the intertemporal aspects and ignore the incentives for suppliers to expand future demand through current marketing to new users. The intertemporal links between current sales to new users and the number of future addicts are noted in Prinz (1994). In his formalization, however, Prinz attempts to model the intertemporal links using a completely static setup: it is assumed that firms engage in price discrimination, and the intertemporal linkages are then captured by letting the demand from addicts depend on the prices to both addicts and new users.

Intertemporal issues are analyzed explicitly and carefully by Caputo and Ostrom (1996) but their focus is quite different from ours: they analyze the dynamic effects of introducing legal supplies into the drug market but make no distinction between addicts and new users. Furthermore, after the introduction of the government-supplied legal good illegal suppliers are treated as a competitive fringe. Richardson (1992) and Caulkins (1993) also present formal models of the effects of changes in drug policy but again the focus is very different, and neither of these papers considers intertemporal aspects.

We may note, finally, that at a general level, our argument turns Buchanan's (1973) "defense of organized crime" on its head. In a market with important external effects, increased monopolization may not lead to lower production: monopolization enables producers to internalize the external benefits. Our argument differs from Buchanan's also in another respect. Buchanan assumed that in the absence of deliberate competition policy, the competitive structure of criminal activity is independent of the level of law enforcement. Our analysis, by contrast, is based on the assumption that stricter enforcement tends to raise the degree of market power as well as consumer loyalty.

Section 2: Demand structure

Theoretical models of `rational addiction' (Becker and Murphy (1988)) typically impose restrictive assumptions and have had mixed empirical success with respect to hard drugs.[2] Furthermore, the plausibility of models of rational behavior for the analysis of drugs is debatable (Akerlof (1991)). Drug addicts are implausible candidates for far-sighted rational planning, and since non-addicts

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[2] Becker et al (1994) find support for the Becker-Murphy model in data for US cigarette consumption. Ours (1995), however, argues that "when it comes to opium there is no strong evidence for rational addiction" (p. 277, n. 5).

rarely expect to become addicts themselves, they too will tend to discount the intertemporal addiction effect and in this respect act myopically (Orphanides and Zervos (1995)). On the empirical side, we have only limited information about the structure of demand for hard drugs like heroin. These drugs, however, are highly addictive and it is widely accepted that consumption by addicts dominate the demand side.

Our specification of the demand side is designed to capture these aspects of demand in a simple and stylized way. Ignoring the demand from casual users (or assuming that this component of demand is proportional to the demand from addicts) we write aggregate demand as the product of the number of addicts and the demand per addict.[3] At each moment, the demand per addict is a function of price (probably quite inelastic), while the number of addicts is assumed predetermined. Over time, however, the number of addicts changes depending on the price of drugs and the marketing activity by the suppliers. Specifically, we assume that reductions in price and increases in marketing effort cause an increase in the rate of growth of the number of addicts. The reasoning behind this assumption is straightforward. Both price and marketing influence the number of new users that try the drug, and empirically it is reasonable to assume that some fraction of these new users become addicted. In addition, the price of drugs may affect the flow out of addiction: high prices may reduce consumption per addict (and thus the degree of addiction) and, more generally, may make detoxification and long-term treatment programmes seem more attractive.[4]

Assuming a symmetric equilibrium in which all suppliers set the same price, our specification of aggregate demand is given by:

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[3] This approach seems plausible for heroin and other hard drugs but clearly not with respect to marijuana.

[4] The number of addicts also changes due to mortality. Substance-abuse mortality has been increasing world-wide (United Nations (1995)).

$$Q(t) = A(t)\, q(t) \tag{1}$$

$$q(t) = B\, p(t)^{-\gamma} \tag{2}$$

$$\hat{A}(t) = F(p(t),m(t))\ ;\ \ F_p \leq 0,\ F_m > 0 \tag{3}$$

where Q and q denote aggregate demand and demand per addict, A is the number of addicts, p is the price and m the marketing cost per addict; B and γ are parameters; subscripts are used to denote partial derivatives of a function (e.g. $F_p = \partial F/\partial p$) and carets denote growth rates ($\hat{A}$ = dA/dt 1/A).

As argued in section 1, the market for hard drugs is best characterized by some form of imperfect competition, and the individual supplier's conjectured demand curve should also allow for the presence of consumer loyalty. We model this dynamic aspect by assuming that the position of the conjectured demand curve depends on the supplier's existing customer base of `regulars' (A_i), and that the number of regulars, in turn, changes endogenously as a function of the supplier's price and marketing decisions: the lower the price (p_i) and the higher the marketing effort per addict (m_i), the higher the growth rate of A_i. If the supplier chooses a price and a marketing effort equal to those of its rivals, its customer base may be expected to grow at the same rate as the total number of addicts. A price above and marketing below that of the rivals tend to reduce the growth rate of the supplier's customer base. As a simple specification with these properties we assume that the i'th supplier faces the following conjectured demand structure:

$$Q_i(t) = A_i(t)\, q_i(t) \tag{4}$$

$$q_i(t) = B\, p_i(t)^{-\alpha}\, \tilde{p}(t)^{\alpha-\gamma}\ \ ;\ \ \alpha>1,\ \alpha>\gamma>0 \tag{5}$$

$$\hat{A}_i(t) = F(\tilde{p}(t),\tilde{m}(t)) - a_p \log(p_i(t)/\tilde{p}(t)) + a_m \log(m_i(t)/\tilde{m}(t))\ ;\ \ a_p>0,\ a_m>0 \tag{6}$$

where $\tilde{p}(t)$ and $\tilde{m}(t)$ denote the average price and marketing decisions of the rival suppliers. Equation (4) gives the supplier's total demand as the product of the current customer base and the demand per addict. For simplicity, the specification in equation (5) of demand per addict assumes constant elasticities with respect to both the supplier's own price and the price charged by rivals; the specification is otherwise quite standard. Equation (6), finally, describes the change in the customer base. The average price p(t) and marketing effort m(t) for the market as a whole are weighted averages of $(\tilde{p}(t),\tilde{m}(t))$ and $(p_i(t),m_i(t))$, and in a symmetric equilibrium $(\tilde{p}(t),\tilde{m}(t))=(p_i(t),m_i(t))$. Equations (5)-(6) are therefore consistent with equations (2)-(3) above.

Section 3: Price and marketing decisions

In a Nash equilibrium each supplier maximizes the net present value of its future profits, taking as given the price and marketing decisions $(\tilde{p}(t),\tilde{m}(t))$ of its rivals. If β is the discount rate, this amounts to the maximization of

$$V_i = \int_0^\infty e^{-\beta t} [Q_i(t)(p_i(t)-c_i(t)) - A_i(t)m_i(t)]\, dt \qquad (7)$$

subject to the constraints (4)-(6), the given initial value of $A_i(0)$ and non-negativity constraints on the control variables $p_i(t)$ and $m_i(t)$. For simplicity we assume that all suppliers have the same unit cost, that unit cost is independent of the level of supply and that it is expected to remain constant over time; that is, $c_i(t)=c$.[5]

The optimization problem can be solved using the Pontryagin maximum principle and, as shown in Appendix A, we get the following result.

Proposition 1:
If
(i) $\tilde{p}(t)=\tilde{p}$ and $\tilde{m}(t)=\tilde{m}$ are constant and
(ii) there are no values of $p_i(t)>0$ and $m_i(t)\geq 0$ such that $Bp_i(t)^{-\alpha}\tilde{p}^{\alpha-\gamma}(p_i(t)-c)-m_i(t)\geq 0$ and $\hat{A}_i(t)\geq\beta$

then the constrained maximization of (7) -- subject to the constraints (4)-(6), a given initial value $A_i(0)>0$ and non-negativity constraints on $p_i(t)$ and $m_i(t)$ -- has a unique solution $(p_i^*(t), m_i^*(t), A_i^*(t))$. Furthermore, the optimal price and marketing effort per addict are constant, that is,

[5] Direct production costs constitute a very small fraction of unit cost. By far the most important element is the (pecuniary and non-pecuniary) cost associated with the illicit nature of the market and the risk of detection.

$p_i^*(t)=p_i^*$ and $m_i^*(t)=m_i^*$ (and hence $\hat{A}_i^*(t)=\hat{A}^*$).

Notice that condition (ii) in the proposition must be satisfied for the problem to be interesting and meaningful: if (ii) fails to hold, infinite discounted net profits become possible.

Proposition 1 implies that it will be optimal for each supplier to maintain constant values of p_i and m_i as long as other suppliers do the same. In a symmetric equilibrium, however, we must also have $p_i=\tilde{p}$ and $m_i=\tilde{m}$. As shown in Appendix B, a symmetric Nash equilibrium of this kind exists. We have:

<u>Proposition 2</u>

Given the assumptions in proposition 1, there is at least one equilibrium with $p_i=\tilde{p}=p$, $m_i=\tilde{m}=m$ and $\hat{A}_i=\hat{A}$. The equilibrium values of p and m $\hat{A}$ satisfy the following equations:

$$\psi(p,m,\theta) = Bp^{-\gamma}(p-c)-m + \theta(F(p,m)-\beta) = 0 \qquad (8)$$

$$Bp^{1-\gamma}(1-\alpha+\alpha c/p) = a_p\theta \qquad (9)$$

$$m = a_m\theta \qquad (10)$$

for some $\theta>0$.

If the external effects of $\tilde{p}$ and $\tilde{m}$ on the supplier's optimization programme are sufficiently strong then, in principle, equations (8)-(10) could have multiple solutions; that is, the function $(p_i^*,m_i^*)=h(\tilde{p},\tilde{m})$ defined implicitly by the maximization problem (Proposition 1) may have more than one fix-point. To simplify the analysis, however, we rule out this possibility and assume a unique market equilibrium.[6]

Propositions 1 and 2 show that the differential game has an equilibrium solution without transitional dynamics. The control and costate variables are constant over time and the state variable A, the number of addicts, grows exponentially at a constant rate. The specifications of the change in number of addicts A and A_i in equations (3) and (6), respectively, are crucial for the absence of transitional dynamics. Equations (3) and (6) assume that the growth rates of A and A_i

[6] In case of uniqueness, the market equilibrium is stable on plausible assumptions. In the case of multiple equilibria, the comparative results below will be valid (locally) for all (locally) stable equilibria.

are determined entirely by the current values of the control variables p and m. Just as in the simple "AK-model" of economic growth, the growth rate of the state variable is independent of its own level and -- just as in the "AK-model" -- the control and costate variables become constant in the optimal plan, as does the rate of growth of the state variable.[7]

Section 4: Effects of changes in drug policy

Drug policy affects price and marketing through several channels. One likely effect of stricter policy is an increase in effective unit costs c, the larger part of which derives from the risk and costs of detection. Additionally, one would expect a decrease in the perceived price elasticity of demand, that is a fall in α. This elasticity effect may come about partly as a result of increased cartelization among suppliers and partly as a result of increased search and transaction costs for consumers.[8] A third effect is an increase in `consumer loyalty'. The increase in search and transaction costs following a tightening of policy means that addicts will get a stronger incentive to stay with their known sources of supply. A change in consumer loyalty is captured by a_m and a_p. The parameter a_m, which reflects the probability that new consumers will become addicts and remain loyal to the initial supplier, will increase. The parameter a_p, on the other hand, will fall: a higher degree of consumer loyalty (reduced consumer mobility between suppliers) implies a fall in the future gains in the share of customers associated with a lower current price.

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7 The constant growth rate of A (that is, the absence of feedback effects from the level of A to the growth rate of A) is implausible in the ultra-long run. If, say, total population grows at a given rate, a high growth rate of A implies that eventually the number of addicts will exceed total population. This conclusion clearly is absurd, but in this respect the model is no different than most other models of steady growth. Constant population growth, for instance, implies that asymptotically an infinite population will be living in a finite space. Positive steady growth rates, whether of total population or the number of addicts, may be a good approximation for a long time, however, even though the maintenance of these growth rates becomes nonsensical in the very long run.

8 Stricter policy may also affect the composition of the customer base. Less addicted consumers with a relatively high price elasticity may leave the market, causing the average price elasticity to decline.

Using equation (8)-(10) the effects of these parameter changes on price and marketing can be calculated (see Appendix C). The results are summarized in Table 1. Surprisingly perhaps, none of the parameter changes associated with stricter policy causes an unambiguous decline in the rate of increase in the number of addicts. Looking at the separate effects of the four parameter changes on price and marketing, it turns out that four of these effects unambiguously tend to raise $\hat{A}$ while the remaining four cannot be signed.

Table 1 about here.

A standard economic argument (e.g. White and Luksetich (1983)) focuses on the increase in costs (c): higher costs will raise prices, and higher prices reduce the consumption of current addicts and also stem the increase in the number of addicts as fewer people will now experiment with the drug. This argument ignores the influence of policy on price elasticity and consumer loyalty (i.e. the parameters α, a_m and a_p), but even disregarding these effects a rise in unit cost does not unambiguously reduce $\hat{A}$ in the present model. The intuition is straightforward: if the market demand curve is inelastic (γ<1) then a proportionate increase in costs and prices will raise profits per addict; this rise in profits gives suppliers an incentive to increase marketing, and the overall result may be an increase in $\hat{A}$.

The changes in the other three parameters all lead to increased marketing. In the case of α, increased marketing is caused by the tendency to higher prices and increased profits per addict when the elasticity of demand is reduced.[9] A decline in a_p has similar effects (but for dynamic reasons): as a_p falls, a price rise is less costly in terms of lower future demand, and the resulting

[9] The guarded formulation is deliberate: a reduction in α gives a tendency to higher prices, but higher marketing and higher growth in the number of addicts tend to reduce prices. The equilibrium outcome for prices, therefore, is ambiguous.

tendency for profits per addict to increase makes it profitable to increase marketing. Higher consumer loyalty in the form of an increase in a_m, finally, raises the marginal benefit of marketing, and as marketing expands and $\hat{A}$ increases, this produces an unambiguous decline in prices (which reinforces the increase in $\hat{A}$). Thus, of the four parameter changes only the rise in a_m has a clearcut effect on $\hat{A}$: the rate of growth of the number of addicts will increase as a result of the rise in a_m.

As indicated by Table 1, the long-term combined effect of increased enforcement on the number of drug addicts is uncertain in the absence of detailed knowledge about the magnitudes of the different effects. For the case with γ=1 and F_p=0, however, this uncertainty disappears. The results for this benchmark case are given in Table 2.

Table 2 about here.

Given the benchmark assumptions, stricter policy unambiguously causes an increase in the growth rate of the number of addicts, that is, it aggravates one of the key problems it was supposed to solve. But are the benchmark assumptions plausible? Empirical studies show that the demand for hard drugs like heroin is highly inelastic, suggesting that the value of γ may be well below unity.[10] A low value of γ tends to reduce the beneficial effects of strict policy, and by choosing a benchmark value of γ=1 we therefore bias the results in favor of strict policy. The assumption that F_p=0 (i.e. that higher prices have no effect on the growth rate of the total number of addicts) is the dynamic equivalent to low price elasticity. Individual suppliers clearly may lose customers if they raise their prices, but a rise in the average price of the drug is likely to have

[10] Silverman and Spruill (1977), for instance, find a price elasticity for heroin of about -.27.

small effects on the change in the number of addicts.[11] The incentive to give up drugs may be marginally increased but as pointed out by Marks (1991) "the addictive mental state is relatively impermeable to external intervention" (p.321). Moreover, an increase in the price of drugs creates pressures for the current addicts to intensify their retail-dealing in order to finance their own consumption (Marks (1991, p.324)). This is an aspect so far not considered in this paper. The price-induced marketing effect at the street level is distinct from the marketing decisions derived from the maximization of (7). The maximization of (7) determines the optimal level of costly marketing activities by a profit maximizing high-level supplier. By contrast, the costs associated with the intensified `marketing' activities by the supplier's existing customers are borne entirely by these customers, and from the point of view of the high-level suppliers, the extra marketing by existing customers is an external benefit from higher prices.

As a more serious objection to the benchmark case, it could be argued that stricter policy will raise the cost of all marketing activities and that any given marketing cost, m, will therefore have a smaller effect on the growth rate of the number of addicts. In terms of the model, this effect can be captured by a downward shift in the F(.,.) function. Furthermore, criminalization and harsh enforcement may act as independent deterrents on the demand side. Criminalization imposes non-price costs on consumers, and an increase in these costs may reduce both the demand from existing addicts and the increase in the number of addicts. Thus, one may also want to include effects on the level of demand (the parameter B) as well as demand effects on the growth rate of the number of addicts (a shift in the function F).[12]

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[11] Note that it is the price paid by addicts. Price discrimination with low prices for potential new users can be an important element of marketing effort (Prinz (1994)).

[12] The magnitude of these effects is debatable (Normand et al (1994)).

Table 3 about here

The implications of these shifts in B and the F(.,.) function are presented in Table 3. In the benchmark case both of these shifts cause a decline in the growth rate of the number of addicts. Whether the positive effects in table 2 or the negative effects in table 3 will dominate cannot be decided a priori.

Section 5: Concluding remarks

It is difficult to analyze price and marketing decisions empirically in an illicit market like the market for drugs, but the key assumptions underlying the model in this paper seem plausible. There is empirical evidence that suppliers engage in selective marketing aimed at potential new consumers and there are theoretical reasons to expect this kind of behavior. The addictive nature of drugs, secondly, is well-established, and the distinction between new users and addicts is standard in the literature. A priori, finally, one would expect drug policy to influence market power, and empirical studies seem consistent with this expectation.

We have analyzed the implications of these aspects of the drug market using a simple, stylized model. The analysis implies that stricter policy reduces drug consumption in the short to medium term. The number of current addicts is predetermined, and stricter policy will raise costs and (most likely also) price, causing a decline in the consumption per addict. The long-term effects on total use, however, depend on the change in the number of addicts, and real marketing effort may increase. The outcome depends on whether this marketing effect dominates the sum of the price effect and the direct policy effect on demand. This question cannot be settled a priori, and the availability and quality of existing data are insufficient to allow estimation of the various parameters of the model. The empirical evidence, however, does show that criminalization and strict policy have often been associated with the increasing availability of drugs and an increase in the number of addicts. This finding could be the result of reverse causation (policy may be tightened in situations where the drug problems appear to be increasing), but it is hard to rule out the possibility that in many cases the policy itself may have aggravated the situation.[13]

The analysis raises important policy issues. One alternative to current policy is complete liberalization. The desirability of liberalization depends on both the externalities involved and the information and foresight of potential users. The present paper does not address these questions, but it does suggest that careful attention should be given to the question of whether, and to what extent, drug policy affects the incentives and abilities of organized suppliers to recruit new users. Current policies may well be self-defeating precisely because they strengthen these incentives, and alternatives - other than full liberalization - do exist. A `British system' in which addicts may obtain drugs for their own use from doctors or special clinics may undermine illegal suppliers: why devote resources to the recruitment of new addicts if, once addicted, most of these addicts will simply get the drugs free from public clinics?[14] In Britain this system has been widely criticized, and since the 1960s it has been somewhat undermined by an increasingly restrictive administration of the system. But as argued by Niskanen (1992) and Miron and Zwiebel (1995) and as shown by the success of the introduction of a full-fledged version of the system in the town of Widnes (Lofts (1992)), it is difficult to construct an empirical case against the `British system'.

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[13] In addition to increasing drug addiction itself, there are other - arguably more disturbing - implications of current policies; e.g. high crime rates in consumer countries and the fostering of powerful drug syndicates in producer countries.

[14] Note that in the model the direct demand effects of tighter drug policy - the only ones that spoke in favor of criminalization - worked precisely because they tend to undermine the market.

It should be noted that similar policy conclusions have been reached by, among others, Claque (1973).

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Appendix A: Proof of Proposition 1.

Substituting equations (4)-(6) into (7) we get the following expression for the current-value Hamiltonian

$$H = A_i(t)[Bp_i(t)^{-\alpha}\tilde{p}(t)^{\alpha-\gamma}(p_i(t)-c) - m_i(t)]$$

$$+ \theta_i(t)\, A_i(t)(F(\tilde{p}(t),\tilde{m}(t)) - a_p \log(p_i(t)/\tilde{p}(t)) + a_m \log(m_i(t)/\tilde{m}(t))) \qquad (a1)$$

The first order conditions for a maximum require that

$$\partial H/\partial p_i(t) = A_i(t)\, [B\tilde{p}(t)^{\alpha-\gamma}((1-\alpha)p_i(t)^{-\alpha}+\alpha c p_i(t)^{-\alpha-1}) - \theta_i(t)a_p/p_i(t)] = 0 \qquad (a2)$$

$$\partial H/\partial m_i(t) = A_i(t)\, [-1 + \theta_i(t)a_m/m_i(t)] = 0 \qquad (a3)$$

$$d\theta_i(t)/dt = -\partial H/\partial A_i(t) + \beta\theta_i(t) = \theta_i(t)\beta - [Bp_i(t)^{-\alpha}\tilde{p}(t)^{\alpha-\gamma}(p_i(t)-c)-m_i(t)$$

$$+ \theta_i(t)(F(\tilde{p}(t),\tilde{m}(t))-a_p\log(p_i(t)/\tilde{p}(t))+a_m\log(m_i(t)/\tilde{m}(t)))] = \phi(p_i(t),m_i(t),\theta_i(t)) \qquad (a4)$$

The function H is strictly concave in $(p_i(t),m_i(t))$ and the first order conditions (a2)-(a3) ensure that $(p_i(t),m_i(t))$ maximizes H.

By assumption $\tilde{p}(t)=\tilde{p}$ and $\tilde{m}(t)=\tilde{m}$ are constant, and given these values of $\tilde{p}$ and $\tilde{m}$ (and the other parameters of the problem) equations (a2)-(a3) imply that $p_i(t)=p_i(\theta_i(t))$ and $m_i(t)=m_i(\theta_i(t))$ with $dp_i/d\theta_i<0$ and $dm_i/d\theta_i>0$. Substituting these relations into the Euler equation (a4) gives

$$d\theta_i(t)/dt = \theta_i(t)\beta - \{Bp_i(t)^{-\alpha}\tilde{p}^{\alpha-\gamma}(p_i(t)-c)-m_i(t)$$

$$+ \theta_i(t)[F(\tilde{p},\tilde{m})-a_p\log(p_i(t)/\tilde{p})+a_m\log(m_i(t)/\tilde{m})]\} = \phi(p_i(\theta_i(t)),\, m_i(\theta_i(t)),\, \theta_i(t)) \qquad (a5)$$

The differential equation (a5), which gives the rate of change of θ as a function of the level of θ, has at most one stationary equilibrium in the region of θ where $\beta-\hat{A}>0$, and if it exists, this equilibrium will be unstable. To see this, differentiate (a5) with respect to $\theta_i(t)$

$$d(d\theta_i(t)/dt)/d\theta_i(t) = \phi_p dp_i(t)/d\theta_i(t) + \phi_m dm_i(t)/d\theta_i(t) + \phi_\theta = \phi_\theta =$$

$$\beta - [F(\tilde{p},\tilde{m})-a_p\log(p_i(t)/\tilde{p})+a_m\log(m_i(t)/\tilde{m})] = \beta - \hat{A}_i(t) \qquad (a6)$$

where the second equality in (a6) follows from (a2)-(a3). Equation (a6) shows that the change in θ depends positively on the level of θ for $\beta-\hat{A}_i>0$. Assuming existence, uniqueness and instability of the stationary equilibrium therefore follow.

Existence of a stationary equilibrium in the interval with $\beta-\hat{A}_i$ is ensured when condition (ii) of the proposition is satisfied. If condition (ii) holds it is readily seen that $d\theta/dt>0$ for $\theta=\underline{\theta}$ where $\underline{\theta}$ is defined by the condition that $[Bp_i(t)^{-\alpha}\tilde{p}^{\alpha-\gamma}(p_i(t)-c) - m_i(t)]=0$ for $\theta=\underline{\theta}$. Existence therefore follows if $d\theta_i/dt<0$ for $\theta_i=0$. To establish this inequality, note that $d\theta_i/dt=-[Bp_i(t)^{-\alpha}\tilde{p}^{\alpha-\gamma}(p_i(t)-c)-m_i(t)]=-1/A_i\ H(p_i,m_i,\theta_i)$ for $\theta_i=0$. Since p_i and m_i maximize H, we get $d\theta_i/dt<0$ for $\theta_i=0$.

Let θ^* denote the stationary solution to equation (a5). It can be shown that no unstable path with $\theta(t)\neq\theta^*$ can be optimal. If $\theta(0)<\theta^*$ then (a5)-(a6) imply that $\theta(t)$ must become negative from some point onwards but this would violate the non-negativity constraints on m (see equation (a3)). Paths with $\theta(0)>\theta^*$ on the other hand must satisfy $\theta(t)>\theta^*$ for all t, and since profits at time t is a decreasing function of $\theta(t)$ the feasible solution associated with θ^* clearly dominates all paths with $\theta(0)>\theta^*$.

The conditions of Mangasarian's sufficiency theorem (Seierstad and Sydsæter (1987, p.234), finally, are satisfied for the path associated with $\theta_i(t)=\theta^*$. It follows that $p_i(t)=p_i(\theta^*)$ and $m_i(t)=m_i(\theta^*)$ describe the unique solution to the optimization problem.

Appendix B: Proof of proposition 2

In a symmetric equilibrium, all firms choose the same price and marketing effort, i.e. $p_i=\tilde{p}=p$, $m_i=\tilde{m}=m$ and $\theta_i=\theta$. Substituting these symmetry conditions into the first order conditions (a2)-(a4) (and using the result that θ, p and m are constant over time) we get equations (8)-(10). It is readily seen that if (p_0,m_0,θ_0) satisfies (8)-(10) then it defines a symmetric equilibrium: simply set $\tilde{p}=p_0$ and $\tilde{m}=m_0$ and observe that $m_i^*=m_0$, $p_i^*=p_0$ and $\theta_i^*=\theta_0$ will then solve the supplier's first-order conditions (a2)-(a4).

To prove the existence of a solution to (8)-(10), note first that equations (9)-(10) define p and m as functions of θ, $p=p(\theta)$ and $m=m(\theta)$ with $p'<0$ and $m'>0$. Using these expressions for p and m, $\psi(p(\theta),m(\theta),\theta)$ becomes a function of θ, and condition (ii) of Proposition 1 implies that $\psi(p(\underline{\theta}),m(\underline{\theta}),\underline{\theta})<0$ where $\underline{\theta}>0$ is determined by the condition that $Bp(\theta)^{-\gamma}(p(\theta)-c)-m(\theta)=0$ for $\theta=\underline{\theta}$. Since $\psi(p(0),m(0),0)>0$, continuity of ψ implies that $\psi(p(\theta),m(\theta),\theta)=0$ has a solution θ^* with $0<\theta^*<\underline{\theta}$.

Note that since, by assumption, multiple equilibria are ruled out, the system (8)-(10) has a unique solution (θ^*,p^*,m^*) in the relevant interval $0<\theta<\underline{\theta}$. Since $\psi(p(\theta),m(\theta),\theta)>0$ for $\theta=0$ and $\psi(p(\theta),m(\theta),\theta)<0$ for $\theta=\underline{\theta}$ we then have

$$\psi_p p_\theta + \psi_m m_\theta + \psi_\theta < 0 \qquad \text{(b1)}$$

at the equilibrium solution.

Appendix C: Comparative statics

By assumption tighter drug policies implies an increase in c, a decrease in α, an increase in a_m, a decrease an a_p as well as direct demand effects and marketing cost effects that cause a decrease in B and a downwards shift of the function F. The effects of these parameter changes can be derived from the system (8)-(10) which is reprinted here for convenience.

$$\psi(p,m,\theta) = Bp^{-\gamma}(p-c)-m + \theta(F(p,m)-\beta) = 0 \qquad \text{(c1)}$$

$$Bp^{1-\gamma}(1-\alpha+\alpha c/p) = a_p\theta \qquad \text{(c2)}$$

$$m = a_m\theta \qquad \text{(c3)}$$

The partial derivatives of ψ with respect to (p,m,θ) and the relevant parameters are given by

$$\psi_p = Bp^{-\gamma}(\alpha-\gamma)(1-c/p) + \theta(F_p+a_p/p) > 0 \qquad \text{(c4)}$$

$$\psi_m = F_m m/a_m - 1 > 0 \qquad \text{(c5)}$$

$$\psi_\theta = F - \beta < 0 \qquad \text{(c6)}$$

$$\psi_c = - B\, p^{-\gamma} < 0 \qquad (c7)$$

$$\psi_B = p^{-\gamma}(p-c) > 0 \qquad (c8)$$

The first order condition (a2) has been used to derive the expression in (c4), and the inequality in (c4) follows from the fact that $\alpha>\gamma$ and $a_p/p>-F_p$ (the price elasticities of the static demand and of the growth in the number of regulars are higher for an individual firm than for the market as a whole). The inequality in (c5) follows from the fact that $a_m/m<F_m$ (some of the new addicts recruited by a supplier subsequently become regulars of rival suppliers), and the inequality in (c6) is necessary to exclude cases where the present value of future profits becomes infinite (cf. Proposition 1).

Equation (c2) defines p as a function of θ (and the parameters B,α,c and a_p), and (c3) gives m as a function of θ (and the parameter a_m):

$$p=p(\theta;\, B,\alpha,c,a_p) \quad m=m(\theta;\, a_m) \qquad (c9)$$

and

$$p_\theta = - a_p\, D < 0 \qquad (c10)$$

$$p_{ap} = - \theta\, D < 0 \qquad (c11)$$

$$p_\alpha = -Bp^{1-\gamma}(1-c/p)\, D < 0 \qquad (c12)$$

$$p_c = \alpha B p^{-\gamma}\, D > 0 \qquad (c13)$$

$$p_B = (a_p\theta/B)\, D > 0 \qquad (c14)$$

$$m_\theta = a_m > 0 \qquad (c15)$$

$$m_{am} = \theta > 0 \qquad (c16)$$

where

$$D = [Bp^{-\gamma}(\alpha\gamma c/p - (1-\alpha)(1-\gamma))]^{-1} > 0 \qquad (c17)$$

Uniqueness of equilibrium, finally, implies that (see inequality (b1))

$$E = \psi_p p_\theta + \psi_m m_\theta + \psi_\theta < 0 \qquad (c18)$$

The effects of changes in the parameters can now be calculated using the implicit function theorem and the expressions in (c4)-(c18).

Effects of an increase in c

We get

$$d\theta/dc = -\ (\psi_p p_c+\psi_c)/E \qquad \text{(c19)}$$

and - since E<0 - it follows that sign($d\theta/dc$)=sign($\psi_p p_c+\psi_c$). As $\psi_c<0$ and $\psi_p p_c>0$, the result is ambiguous. It may seem most plausible that ψ_c dominates, but a positive effect of c on θ cannot be ruled out: this happens, for instance, if $a_p=F_p=0$ (or, more generally, are close to zero) and market demand is inelastic with $\gamma<1$.

The effect on p is given by

$$dp/dc = (p_\theta d\theta/dc + p_c) \qquad \text{(c20)}$$

and again the outcome is ambiguous, but $d\theta/dc\leq 0$ is sufficient to ensure dp/dc>0 (it can be shown, also, that $\gamma\geq 1$ is sufficient the ensure dp/dc>0). The effect of c on m, finally, is fully determined by the effect on θ:

$$dm/dc = a_m d\theta/dc \qquad \text{(c21)}$$

Effects of a decrease in α

We get

$$d\theta/d\alpha = -\ \psi_p p_\alpha/E < 0 \qquad \text{(c22)}$$

$$dp/d\alpha = p_\theta d\theta/d\alpha + p_\alpha \qquad \text{(c23)}$$

$$dm/d\alpha = a_m d\theta/d\alpha < 0 \qquad \text{(c24)}$$

Thus a fall in α raises θ and m. The effect on p is ambiguous, but using (c23), (c4), (c10) and (c12) it follows that a fall in α causes an increase in p iff $\psi_m m_\theta+\psi_\theta<0$; this would seem the most plausible case.

<u>Effects of an increase in a_m</u>

Here the results are unambiguous. We get

$$d\theta/da_m = -\psi_m m_{am}/E > 0 \qquad (c25)$$

$$dp/da_m = p_\theta d\theta/da_m < 0 \qquad (c26)$$

$$dm/da_m = \theta + a_m\, d\theta/da_m > 0 \qquad (c27)$$

An increase in a_m raises θ and m and reduces p.

<u>Effects of a decrease in a_p</u>

We get

$$d\theta/da_p = -\psi_p p_{ap}/E < 0 \qquad (c28)$$

$$dp/da_p = p_\theta d\theta/da_p + p_{ap} \qquad (c29)$$

$$dm/da_p = a_m\, d\theta/da_p < 0 \qquad (c30)$$

From the expressions for p_θ and p_{ap} it follows that dp/da_p is positive iff $d\theta/da_p>-\theta/a_p$, or, equivalently, iff $\psi_m m_\theta+\psi_\theta<0$. Although highly plausible, this condition need not be satisfied, and the effects on p of a decrease in a_p is ambiguous. Both θ and m unambiguously increase.

<u>Effects of a decrease in B</u>

We get

$$d\theta/dB = -(\psi_p p_B+\psi_B)/E > 0 \qquad (c31)$$

$$dp/dB = p_\theta d\theta/dB + p_B = p_\theta \theta/B\, [(c/\theta)d\theta/dB - 1]$$

$$= p_\theta \theta/B\, [1 - \theta F_m/E - 1] = p_\theta \theta/B\, (-\theta F_m/E) > 0 \qquad (c32)$$

$$dm/dB = a_m\, d\theta/dB > 0 \qquad (c33)$$

Thus, a decrease in B causes a decline in θ, p and m.

<u>Effects of a downwards shift in the F-function</u>

Assume, for simplicity, that the shift is additive, i.e. that F can be written

$$F(p,m) = b + G(p,m) \qquad (c34)$$

and that tighter policy leads to a drop in b. We then get

$$d\theta/db = -\theta/E > 0 \tag{c35}$$

$$dp/db = p_\theta d\theta/db < 0 \tag{c36}$$

$$dm/db = a_m\, d\theta/db > 0 \tag{c37}$$

and a fall in b causes a decrease in θ and m and an increase in p.

A benchmark case

If $\gamma=1$ and $F_p=0$ then the ambiguity concerning the effects of an increase in c disappears. In this case equation (c2) reduces to

$$p = [B\alpha/(a_p\theta+B(\alpha-1))]\, c \tag{c38}$$

and (c1) can be rewritten

$$(a_p\theta+B(\alpha-1))/\alpha - m + \theta(F(m)-\beta) = 0 \tag{c39}$$

Equations (c39) and (c3) determine m and θ independently of c, i.e. changes in c cause proportional changes in p but do not influence the equilibrium values of m and θ.

Table 1: Effects of stricter enforcement

Parameter change \ Effect on	p	m	Â
c↑	?	?	?
α↓	?	+	?
a_m↑	–	+	+
a_p↓	?	+	?

Table 2: A benchmark case with $\gamma = 1$ and $F_p = 0$

Parameter change \ Effect on	p	m	Â
c↑	+	0	0
α↓	?	+	+
a_m↑	–	+	+
a_p↓	?	+	+

Table 3: Direct demand effects and increased cost of marketing.

Parameter change \ Effect on	p	m	Â
B↓	–	–	?
F(.,.)↓	+	–	–

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