Empirical modelling of narcotics trafficking from farm gate to street*

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ABSTRACT

The mass distribution of illicit drugs requires large organizations and industrial-scale activity. In the present article, the worldwide cocaine distribution system is analysed and modelled with a view to identifying "business" patterns common to all levels of trafficking and comparing them with those for other drugs of mass distribution. Three models are developed and discussed: the user function (the pattern of cocaine consumption among users in the United States of America), the price-quantity scaling relationship for cocaine (the near-perfect correlation of observed prices per pure gram to transaction quantities in pure grams at each level of the cocaine trade) and a generic model for mainstream cocaine trafficker organizations that applies to all levels, from the source zone to United States streets. The user function illustrates both methodological and consumption pattern issues. The form of the price-quantity scaling relationship is explained by the influence of three constraints common to all levels of drug trafficking: lack of trust, competition and law enforcement pressure. The trafficker organization model incorporates the three constraints, the parameters of the scaling relationship and the results from the analysis of seizure rates across trafficker levels. Together, the scaling relationship and the trafficker organization models explain the observed price dynamics associating source-zone counter-cocaine operations with price swings and user responses in the United States. The three models provide insight into drug use and the complex narcotics trafficking business, point to the vulnerabilities of

*The views expressed in the present article are those of the authors and do not represent an official position of the Institute for Defense Analyses or of its sponsors.

**The present article synthesizes more than a decade's worth of empirical analysis and model-building by researchers at the Institute of Defense Analyses. The invaluable contributions of Arthur (Rex) Rivolo, Stephen Hanson, Samir Soneji, Larry Lyons and Barry Crane are especially acknowledged. Rex Rivolo laid the theoretical foundations underpinning the analyses of the System To Retrieve Information from Drug Evidence (STRIDE) database, the cocaine user function and the indicators of cocaine abuse. While working as a summer intern, Stephen Hanson collected extensive and essential data from a wide variety of sources in the United States and Peru that enabled the detailed analysis of the air bridge interception efforts. Also working as a summer intern, Samir Soneji conducted comprehensive time series analyses of the Peru air interceptions and other source-zone events relative to features in the United States price index. Larry Lyons provided law enforcement data and insights that supported and illuminated the analyses. Finally, during his tenure at the Institute, the remarkable leadership, drive and expertise of Barry Crane spearheaded the individual and collective research efforts.

the cocaine production and distribution system, map the limits of trafficker adaptability, offer a basis for measuring supply-control performance at each market level and create a common framework within which experts can exchange knowledge.

Keywords: Drug trafficking; cocaine; price; purity; interception; seizures; international; drug transactions; time series.

Introduction

The present article synthesizes over a decade's worth of empirical analysis and model-building by analysts of the Institute of Defense Analyses. Several methodological innovations were necessary to extract coherent patterns and create verifiable models from over a dozen major data sets on cocaine trafficking, counter-cocaine operations and indicators of damage to the illicit cocaine distribution system. The results measure the effectiveness of supply-control efforts as a complement to other counter-cocaine efforts such as education, demand reduction and treatment.

There are many reasons to construct and to validate models of narcotics usage and trafficking: *(a)* to provide a shorthand for thinking about narcotics production, trafficking and usage so that any overall patterns and the conditions that shape them may be recognized; *(b)* to find the vulnerabilities of the narcotics production and distribution system, as the basis for focusing supply-control efforts; *(c)* to understand the options and mechanisms by which narcotics businesses can adapt to threats from counter-drug activities, as well as the changing business environment, so that traffickers' reactions can be anticipated and countered; *(d)* to measure and report on the effectiveness of supply control at every level so that the benefits of counter-drug operations can be judged realistically and resources allocated effectively; and *(e)* to create a common framework within which diverse experiences and expert views can contribute coherently.

In the present article, the use of the term "modelling" entails more than an abstract exercise to test preconceptions of how the drug business works. It is guided by and relies critically on real data and the actual experiences of those working to reduce the supply of illicit drugs. While the illegal drug business is complex and barriers are intentionally created to stop people obtaining information about it, several practical constraints apply to those in the business, regardless of the level at which they operate. These restrictions are sufficient to produce observable regularities that can be used as a basis for creating three insightful and useful models: the first is the user function describing relative intensities of consumption; the second is a representation of cocaine distribution from farm gate to street users worldwide and its associated market dynamics in response to major source-zone counter-drug operations; and the third is a generic "business model" common to all levels of trafficking. Although the models used necessarily collapse a great deal of variation into caricature representations, they are nonetheless sufficient to address our objectives.

After commenting on the complexity of the narcotics trafficking business sector, the user function of cocaine abuse is described, followed by three simplifying constraints that facilitate the development of the common trafficker business model. Next, data from the System To Retrieve Information from Drug Evidence (STRIDE) of the United States Drug Enforcement Administration are employed to reveal remarkably consistent scaling relationships across five major narcotics. For cocaine, a variety of additional data are employed to extend the scaling back towards the top of the trafficker hierarchy in the source zone, that is, to the major drug trafficker organizations, and from there back down another collection hierarchy to the farm gate. Combining early Peruvian data with the sweeping market changes of the 1980s, the reason for the drop in the price of cocaine in the United States before demand abated is explained. Finally, the dynamics of the cocaine business up to the 1990s is analysed in detail, establishing that successful major counter-cocaine operations in the source zone can substantially affect the purity and price of domestic cocaine and cause significant shifts in leading indicators of cocaine abuse.

Complexities and constraints

Considering the diversity of conditions and factors influencing drug trafficking, one might wonder whether analysis and modelling can offer insights. Traffickers operate in several countries and geographical environments. Most United States counter-drug efforts have focused on cocaine, but cocaine is only one of several narcotics of mass distribution. Even for cocaine moving from farm gate to the United States streets, traffickers must perform several tasks in addition to buying and selling drugs. For example, they must reprocess or repackage the drugs, maintain security, launder money, communicate, smuggle through hostile environments and avoid both competitors and law enforcement. Many of these tasks are performed by quasi-independent contractors to the trafficker organizations who own the drugs. Furthermore, narcotics traffickers are secretive about their operations and decision processes. Thus, only limited types of information are available to guide, verify or calibrate any modelling effort. Lack of access to information also means that analysts and modellers have far fewer case studies of illicit businesses than licit businesses. This creates a risk that theories and models of licit businesses might be adopted inappropriately to analyse and model illicit drug businesses.

These complexities of business practices give rise to a number of methodological problems. One of the most challenging is the recurrence of extremely broad and fat-tailed statistical distributions of prices and other transactional characteristics. To illustrate this problem with an important related example, a comparable fat-tailed statistical distribution representing the amounts of cocaine consumed by users is explained.* Then, once again, the trafficking business is

*It will be seen that this fat-tailed distribution has a divergent integral for its theoretical variance; thus, the Central Limit Theorem, which is the theoretical basis for interpreting mean values and using regression analysis methods, fails. Instead, the distribution of the number of users by the amounts they consume appears to follow an inverse power distribution.

discussed and three important simplifying constraints imposed upon narcotics traffickers at all levels of the distribution hierarchy (lack of trust, competition and law enforcement) are considered.

The user function for cocaine abusers in the United States

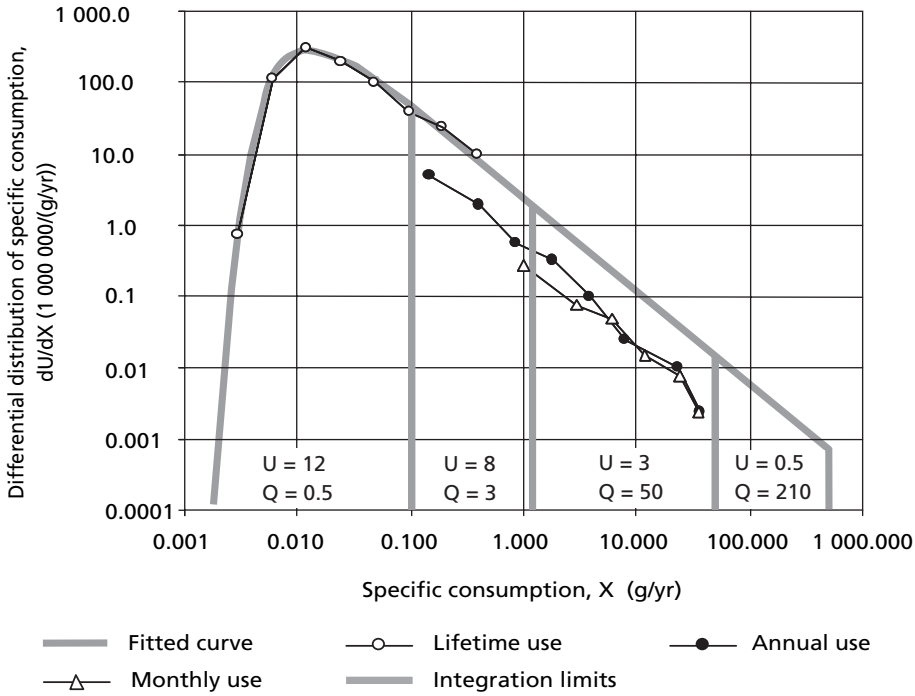
Data from the United States National Household Survey on Drug Abuse were examined to study the statistical distribution of the numbers of users consuming specific amounts of cocaine [1]. Figure I shows the differential distributions of specific consumption for users aged 12 to 35, expressed as annualized consumption in grams (g) per year, for the three categories of usage defined by the survey: lifetime, last-year and last-month use. This plot combines and renormalizes data from the 1990-1994 household surveys, at which time consumption was at roughly half the level of the 1985-1987 peak of the "cocaine epidemic" in the United States. Since the survey asks respondents the "number of times" they used a drug rather than the quantity they used, for the purpose of this research 100 milligrams was taken as a typical dose to obtain grams per year. Thus, the figures for specific consumption of less than 0.1 g per year, given in figure I, represent a lifetime frequency of less than one dose per year. The change of slope and drop in the curve below 0.01 g per year indicates the large number of people who experimented with cocaine, for example, using it once over a 10-year period.

The three empirical distributions of consumption in figure I do not match in overlap regions and this calls for explanation. For example, the lifetime specific consumption ends at a level nearly five times greater than that of the beginning of the annual reported consumption. While the twofold drop from the peak of the cocaine epidemic might explain double the number of lifetime users at a given rate of consumption, it seems implausible that the number of users consuming between 1 and 30 g a year was five times greater during the cocaine epidemic of the 1980s than in the 1990-1994 samples. A plausible explanation might be that users who quit were more willing to report their consumption than those who continued to abuse cocaine. A similar consideration might apply to the greater reported consumption during the last year compared to the last month.

Additional biases may apply to current heavy users. Those reporting the highest levels of consumption during the last year or month would have to remember over 300 doses for the annual question and 30 doses for the monthly question. At a level of abuse averaging about once a day, one might expect such users to have difficulty accurately remembering true counts or to be unavailable as a result of their addiction. Thus, in figure I, the downward slope of −1.3, which corresponds to the exponent of an inverse power-law, might exaggerate the true decline in numbers of users.

However, the discrepancy most difficult to explain is the gross inconsistency between the cumulative consumption estimated from the reported yearly or monthly distribution compared with known levels of trafficking. Total

Figure I. Cocaine distributions of specific consumption



U = Number of users in millions; Q = Total consumption in metric tons

Source: United States National Household Survey on Drug Abuse, 1990-1994.

consumption, obtained by integrating the fitted distribution weighted by amounts consumed, sums to barely 25 metric tons, less than 10 per cent of the total consumption estimated from agricultural surveys and trafficking volumes.*

To reconcile total consumption with these reported rates of consumption, the data were fitted to a power-law distribution truncated at the low end by a Fermi step function and at the high end by a sharp cut-off.** To arrive at a smooth, continuous function, the segments derived from "annual" and "monthly" consumption were scaled up or down as necessary as part of the fitting procedure. The exponent value was also allowed to float and the data were fitted by a chi-squared minimization. This fitted distribution was called the "user function". Total consumption for this fitted curve, as indicated in figure I, still would not exceed 50 metric tons if the high side cut-off to the integral were placed where the data ends. This is less than one quarter of what is believed

*All contemporaneous estimates of United States consumption during this time frame were approximately 250 metric tons and, even in 2000, a good estimate would be 210 metric tons, as found in table C.1 of annex C.

**A Fermi step function is a logistic curve with a very narrow transition from near zero to near maximum values.

to have been consumed during this period. Extending the high side cut-off to 500 g per year, a reasonable physiological limit, increases the total consumption to approximately 263 metric tons, which is a value consistent with estimated consumption from other sources. This calculation implies that the great bulk of consumption occurred in a population not sampled by the National Household Survey on Drug Abuse.

The key methodological implication of this analysis is that the total number of lifetime users (U) is almost entirely driven by the lower specific consumption cut-off of 0.01 g per year, while the total annual consumption (Q) is almost entirely driven by the upper limit cut-off of 500 g per year. Fully 80 per cent of consumption results from abusers who consume 50-500 g per year and constitute a population apparently unseen by the household survey. This population, if it exists, might be found by surveying treatment centres. Since it is difficult to conceive of individuals consuming 10 g per week for 52 consecutive weeks, more effort needs to be focused on measuring this user function with increased accuracy. Ultimately, new evidence might relax one or more of the constraints imposed upon the user function such as a reduced estimate of total annual cocaine consumption, an increased estimate for heavy user responses or a better understanding of abuse patterns by very heavy users.

The estimated user function shown in figure I shows that the "average" consumption for this period was 263/23 = 11 g per year, while the median or "typical" user consumed only about 0.1 g, a single dose, per year. Here the average is a poor indicator of usage, between 5 and 50 times below the heavy use level and 10 times the typical use level. Worse, the average is driven entirely by the upper cut-off at 500 g per year, which is the least understood portion of the overall distribution. In general, the mean value of a power-law distribution or similar long-tailed distribution is essentially determined by the upper limit and poorly characterizes the distribution or changes to the distribution. Better measures are the median and other percentiles or some set of the parameters of the distribution itself, such as the exponent and cut-off points.*

Since this user function for cocaine has the same shape (that is, it is dominated by a power-law fat tail) as the user function for the legal drugs alcohol and nicotine, it must reflect a fundamental property of human susceptibility to substance abuse across a large population. If so, deriving and comparing the user functions for several legal and illicit drugs should provide important a priori knowledge about prevalence estimates and abuse patterns. This might also compensate for survey biases when abusers are inaccessible or only partially sampled. Furthermore, by deriving and comparing the user function for several narcotics, it would be possible to place the abuse of illicit drugs into the continuum of legal prescribed uses of psychotropic substances.

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*If one attempts to compute a variance for this user function, one obtains a divergent integral because $U^2.U^{-1.3} = U^{0.7}$, which diverges when integrated to infinity. Thus, the Central Limit Theorem does not apply to the mean of this power-law distribution.

Three common constraints on all traffickers

Lack of trust, competition and risks from law enforcement interception commonly constrain all traffickers. Lack of trust applies to relationships within business organizations and to transactions with outsiders, including trade in narcotics and contracting for essential services. In fact, interviews with smugglers reveal that their primary concern is with informants [2, 3]. As a reaction to low levels of trust, personal familiarity and constant monitoring are essential to survival. This need for personal familiarity limits organizational size to about 50 to 80 people, with embedded cells of about 5 to 10 people for specialized high-risk tasks such as arranging transactions, providing security or managing untraceable communications. A central individual, or at most a few people, controls the organization and those in charge keep subordinates from knowing enough to become a threat. Withholding key information and forbidding collateral relationships among subordinate cells are necessary practices to suppress threats of displacement by ambitious insiders. Often, outside contractors provide cocaine-processing, smuggling, money-laundering and other services.* These considerations fragment organizations into loosely connected webs of small, specialized cells and constrain horizontal and vertical integration.**

Competition among traffickers is intense because criminals operate outside the mitigating effects of strong social sanctions and a system of justice. Individuals and organizations are under the constant threat of being supplanted by competitors. Encroachment is possible from a supplier, customer or collateral organization. The diversity of sources, buyers, specialized contractors and trafficking options seldom offers any business the leverage necessary to exercise monopoly control.***

Law enforcement acts as a direct threat by seizing narcotics, assets or investments and sometimes by arresting traffickers. It also acts indirectly by employing informants motivated by rewards, exposing a competitor, seeking revenge or bargaining for a lighter sentence. Each business activity must hide from detection or pay for protection from corrupt officials. All of these threats raise the cost of every aspect of the narcotics trafficking business.

For a multitude of trafficking enterprises, each subject to these three constraints, to form a network capable of distributing narcotics to millions of customers each month from sources in remote areas of distant countries, they must be organized into a multi-level hierarchy. Nonetheless, the lack of trust

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*The law enforcement experience of Larry Lyons, Drug Enforcement Administration station chief in Colombia for several years, provided this and other important information about trafficker operations.

**During the cocaine epidemic phase of the late 1970s to late 1980s, profits were truly excessive and expanding trafficker operations could support hirelings to organize distribution. But afterwards, competitive pressures reduced profit margins and law enforcement focused on the largest trafficking operations. Together, these forces suppressed vertical and horizontal integration.

***Although the cocaine cartels exercised near-monopoly control of the laboratory-processing of cocaine base into hydrochloride, they were not capable of sustaining monopoly prices as the cocaine supply caught up with the demand during the 1980s. Without the extreme profits of the epidemic, belonging to a vertically and horizontally integrated organization became more of a liability than an advantage.

prevents these trafficking enterprises from merging into a vertically integrated organization. Since all three restrictions apply to all trafficking enterprises and to all levels of the hierarchy, it should be possible to model each of them as a "typical" trafficking enterprise operating with a common set of strategies. For a hierarchy of such enterprises, these common strategies should lead mathematically to a scaling relationship across the distribution levels.

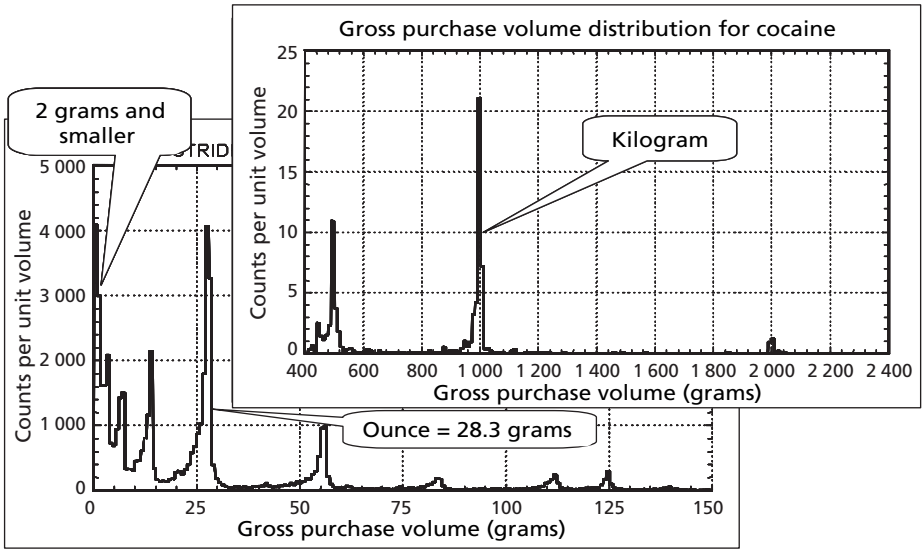
Price-quantity scaling relationship in United States transactions

Most people would expect that traffickers buying in large quantities would get big discounts; however, it is not so obvious that this discounting would lead to a price-quantity scaling relationship. Before explaining this, the data and the analytical methods used in the present research must be introduced.

The STRIDE database of the Drug Enforcement Administration provided the first and best evidence of scaling among trafficker transactions [4]. For two decades, the Drug Enforcement Administration employed undercover agents to make purchases of cocaine (as well as other illicit drugs such as heroin, methamphetamine, marijuana and Ecstasy) and forward the samples to their laboratory for analysis. As shown in figure II, most STRIDE purchases cluster tightly into a spectrum of discrete quantities (weights): kilograms (kg), ounces or grams (g) and fractions thereof. This corresponds to an approximate stratification of traffickers into wholesalers buying kilograms and selling ounces and dealers buying ounces and selling in grams. Although many transactions take place in fractions or multiples of kilograms, ounces or grams, for the purposes of the present research, the model of the distribution system used is simplified by focusing only these principal quantities: kilogram, ounce and gram. However, the model is not so precise that it excludes a wide range of quantities and prices at each step. This restores realism and demonstrates that the results of the research remain valid if generalized to actual ranges of variability. It should be noted that, because one ounce is 28.3 g, the hierarchy of trafficking branches with a ratio of about 32, since $1{,}000/28.3 \approx 35$, $28.3/1.0 \approx 28$ and, also, the square root of 1,000 is $31.6... \approx 32$.

Licit businesses offer opportunities for one level to purchase companies at other levels to create a vertically, as well as horizontally, controlled distribution process, but illicit businesses encounter many impediments to integration. While some criminal organizations might buy kilogram quantities and, for example, pay for services in gram quantities, such cases of absorbing middle-level dealing are probably rare exceptions. A wholesaler attempting to sell directly to 1,000 one-gram street customers without being revealed and arrested would, of course, be overwhelmed by the task. Alternatively, if a cocaine wholesaler attempted to force his dealers to work for him, he would be at great risk because controlling dealer cheating would also involve many more contacts than 32 sale transactions.

Figure II. Spectrum of cocaine raw purchase volumes, 1980 to mid-1996



Source: System To Retrieve Information from Drug Evidence (STRIDE) database.

Since the STRIDE data collection process reflects law enforcement priorities rather than an effort to orchestrate a rigorously balanced statistical survey of all United States markets, it presents a number of methodological problems to overcome. For example, there are variations in the number of transactions across different drugs, transaction volumes, geographical areas and seizure rates. Also, regions are not sampled in proportion to their population or level of drug trafficking activity; therefore, aggregate STRIDE prices do not represent a true national average [4]. Despite these sampling distortions, annex A establishes that such effects have only a minimal impact on the utility of STRIDE for analysing features and trends of relative prices. There are usually large price variations for a given quantity of narcotic at the same time within a neighbourhood and purchase purity at the ounce and gram levels of the distribution system varies even more than price, ranging down to zero for a complete swindle. The statistical distribution of sale prices per pure gram is so skewed that, for the smallest volumes, an average is a very misleading measure and, in principle, might not even be mathematically defined for the true distribution function [4]. Within this context, annex B illustrates that medians are much more informative than averages when characterizing very broad and long-tailed distributions.

Cocaine price-quantity relation

The most direct way to analyse any scaling relationship across trafficker distribution levels for cocaine is to plot the logarithm of the price of cocaine against the logarithm of the quantity of cocaine being transacted. Since multiplicative

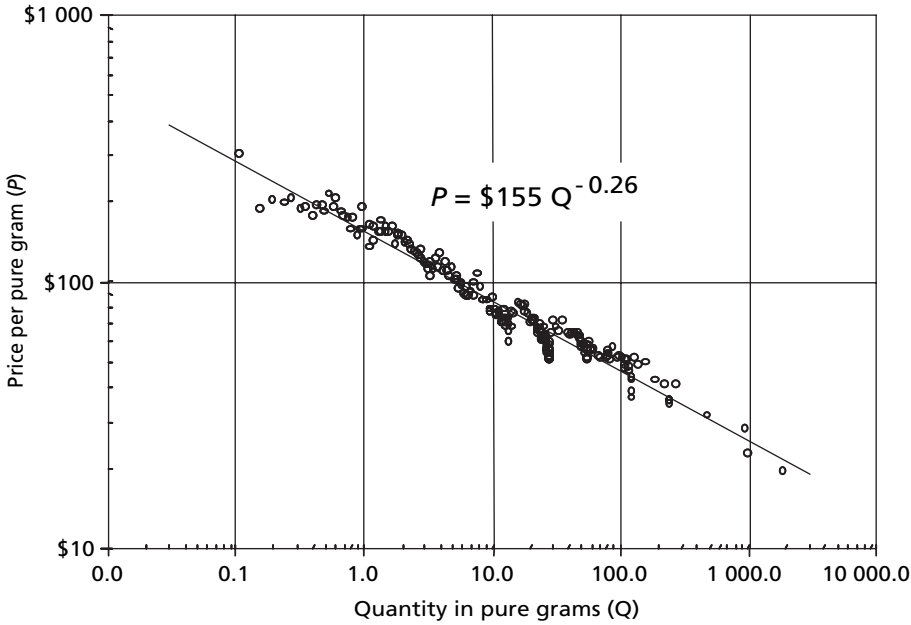
factors become constant intervals on logarithmic scales, a common price mark-up would appear as the same-sized interval on such a plot, no matter whether it applied to gram quantities or kilogram quantities. Similarly, the trade-off between risk and profit leading to typical number of customers generates a common ratio for the quantity bought divided by the quantity sold for each trafficking level. This common ratio is also represented by a fixed interval on the logarithmic scale of transaction quantities. Thus, ideally, a scaling relationship between price and quantity should appear as a simple linear trend on such a price-quantity plot. Because cocaine purity varies widely across and within transaction levels, the analytical procedure must be somewhat more complicated.

To determine the price-quantity scaling relationship, the following procedure overcomes the previously identified data shortcomings: for each transaction recorded in STRIDE, the purchase price per pure gram (referred to as the "normalized purchase price") is calculated, thereby properly including variations in purity among transactions. For the same reason, the transaction quantity is normalized to pure grams. Next, the data are ordered by increasing purchase quantity and the median of their normalized purchase prices is computed for each successive 200 or so quantities throughout the entire data set [4]. Finally, the logarithms of the respective medians of purchase quantity and normalized price for each sample point are taken. It should be noted that this procedure is also insensitive to the lower sampling rate of STRIDE for the gram- and kilogram-transaction quantities relative to ounces. Although the median prices are biased by the non-uniform sampling of regions of the United States, the sampling bias should apply to all quantities alike, therefore preserving the accuracy of the slope of the data trend, that is, the scaling relationship itself. Examination of regional differences among median prices indicates that a true median would fall within 10 per cent of the STRIDE median.

Figure III shows median normalized purchase prices for a spectrum of purchased amounts represented by their pure cocaine content. It should be noted that, in the range between 14 and 28 g, the declining diagonal trend of sample points represents the variation in price and purity for one-ounce transactions. Overall, the remarkably uniform downward linear trend of these medians when plotted as the logarithm of unit price versus logarithm of normalized quantity reveals a scaling relationship with slope −0.26.* Thus, for two different scales of transaction, Q_L for large volume and Q_S for small volume, the corresponding price ratio is $P_S/P_L = (Q_S/Q_L)^{-0.26}$. Supposing $Q_S/Q_L = 32$ (for the levels of the simplified distribution model), then $P_S/P_L = 2.5$, that is, the price mark-up is a factor of 2.5. To gain larger mark-ups while constrained by this scaling

*By 1989, cocaine prices had reached a floor that was sustained until late 1999, with the exception of several rises typically less than a doubling. Medians of 200 successive purchases ranked by pure quantity were taken. The regression line slope is −0.262 ± 0.003 and the adjusted R-squared is 0.95. A hypothesized quadratic curvature of this trend yielded a regression coefficient less than its standard error. The quality of this fit to a simple regression argues strongly that it represents an important regularity of the cocaine trade; a similar mathematical relationship was reported previously in the literature (J. Caulkins and P. Rema, "Quantity discounts and quality premia for illicit drugs", *Journal of the American Statistical Association*, vol. 88, No. 423 (1993), pp. 748-757).

Figure III. Cocaine purchase price-quantity relation, 1989-2003



Source: System To Retrieve Information from Drug Evidence (STRIDE) database.

relationship, traffickers would have to make more sales for every purchase, but more sales mean more risks in arranging those additional transactions.

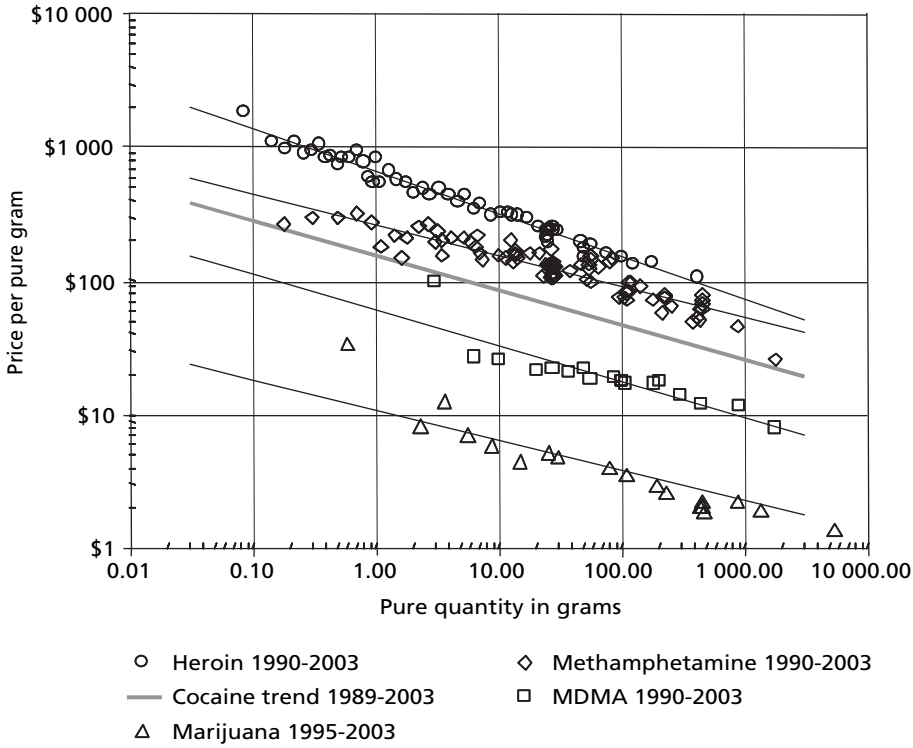
The following idealized example based on pure quantities illustrates how competition maintains this linear trend. Let us suppose that a wholesaler buying kilograms and selling ounces was able to find dealers who would buy at a unit price of $100 per pure gram rather than the scaling relationship value of $64. While the wholesaler would achieve a mark-up of 3.9, the dealers selling grams to users would find it difficult to sell at much above $155 per gram and therefore difficult to survive with a mark-up of only 1.6. Encroachment could come from any direction: from collateral wholesalers selling at the $64 unit price, from dealers setting up business as a wholesaler to compete or from a spin-off member of the distributor network moving into a lucrative niche as a wholesaler. Alternatively, if a wholesaler were forced to sell to dealers for a much lower mark-up of 1.6, that wholesaler would have little incentive to stay in business, would have trouble covering costs and would be a threat to competing wholesalers.

Thus, the three constraints lead to a simplification. Lack of trust restricts the number of transactions much beyond dealing with familiar individuals; for cocaine this is about 32 customers. Large business risks also require large price mark-ups compared with licit businesses; for cocaine this is a mark-up of 2.5 times purchase price. Finally, competition enforces this "business model" across all major traffickers at all levels. Hence, the scaling relationship expresses the equality of risk-taking per mark-up gain for each trafficking level.

Quantity discounts for other narcotics

If risks, lack of trust and competition among traffickers cause a uniform price-quantity scaling relationship for cocaine, they should also cause scaling for other illicit narcotics. This is illustrated in figure IV, which depicts the price-quantity relationships for four other major drugs: heroin, methamphetamine, marijuana's active ingredient tetrahydrocannabinol at an assumed 1 per cent concentration of purchased weight and 3,4-methylenedioxy-N-methylamphetamine, also known as Ecstasy (MDMA). The data for cocaine, which were shown in figure III, have been omitted from the trend line for cocaine to reduce clutter. Both MDMA and marijuana show an abrupt doubling or greater price mark-up for the smallest quantities sold, possibly resulting from sales in entertainment clubs. Since the Drug Enforcement Administration collects more data on heroin and cocaine and their respective markets appear more stable over time, they fit the regression trends better than the remaining three narcotics (as indicated by the adjusted R-square values in table 1). Consequently, their respective slopes are known more precisely than the others.

Figure IV. Price-quantity discount for all major United States narcotics



Source: System To Retrieve Information from Drug Evidence (STRIDE) database.

Table 1. Price-quantity relationship parameters for major United States narcotics

Narcotic	*Purchase per median*	*Exponent*	*Adjusted R-square*	*Price per pure gram*	*Customers per 2.5 mark-up*	*Revenue*
Heroin	200	–0.32	0.97	$661	17	$11 200
Methamphetamine	100	–0.23	0.84	$266	52	$13 800
Cocaine	200	–0.26	0.95	$155	33	$5 100
MDMA (Ecstasy)	50	–0.27	0.77	$61	30	$1 830
Marijuana	50	–0.23	0.74	$11	57	$627

Source: System To Retrieve Information from Drug Evidence (STRIDE) database.

Since all these drugs compete with the other drugs at one or more levels of the narcotics distribution hierarchy and also compete for heavy users in the poly-drug abuse environment, the profitability of each drug relative to its risks must be comparable. This competition among alternative criminal "investments" also implies that there should be a generic narcotics distribution network ready to distribute any new promising drug to a mass market. If competition led all traffickers to base their business models on a mark-up of 2.5 times the purchase price, then the price-quantity exponent for each drug would imply different numbers of sales transactions, as indicated in the column headed "Customers per 2.5 mark-up" in table 1. Heroin dealers would need to conduct only half as many transactions as cocaine or Ecstasy dealers, who in turn would make roughly half as many sales as methamphetamine* and marijuana dealers. With the exception of methamphetamine, this sequence corresponds to higher returns for those drugs with greater trafficking risk and to risk moderation for selling to fewer customers.

Scaling extended to the source zone

If a lack of trust, high risk and competition enforce a common scaling for all major United States narcotics businesses, these constraints might apply with equal force to the trafficking levels leading back to the source zone.

Farm gate to United States streets in the mid-1990s

Table 2 shows the transaction quantities and prices for cocaine distribution during the 1990s from farm gate to the United States streets. The source-zone data for the consolidation steps represent depressed cocaine base prices and the

*The methamphetamine market in the United States is very volatile and would require detailed analysis to explain this anomaly.

large mark-ups for those few remaining pilots willing to smuggle from Peru to Colombia following the implementation of the "force-down or shoot-down" policy in 1995 [5]. Pilots' fees rose at the expense of coca growers' profits because Peruvian cocaine base arriving in Colombia had to sell for competitive prices [5, 6]. Transaction volumes and prices for the major drug trafficker organizations are severely constrained by the juncture between the concentration and distribution steps. Transactions between Colombian major drug trafficker organizations and Mexican or Caribbean transit-zone traffickers may take place at sea or at other intermediate locations; thus, the Colombian "wholesaler" prices might be lower as a result of diversion closer to the source. It is known that about equal quantities of narcotics are smuggled by "go-fast boats" (speedboats) and fishing vessels, with air trafficking and other modes of transport carrying a minor fraction of the total. While fishing vessels might carry 4 metric tons, often several major drug trafficker organizations pool shipments to make up large loads; hence the transaction volume is many times less than the smuggler load size.

Data sources for the source-zone and transit-zone distribution steps generally do not associate a price with a quantity and it was found that serious methodological distortions resulted from attempting to assign broadly reported typical prices to similarly reported quantities.* For example, access-zone smuggling into the United States spans a very diverse range of methods and quantities. Therefore, wide uncertainty ranges were adopted for transaction quantities; table 2 gives approximate ranges for these. As mentioned in the section above on the price-quantity scaling relationship in United States transactions, the lack of systematic sampling in the accumulation of STRIDE data implies that both raw and normalized price medians for the United States as a whole might differ from actual values by 10 per cent. Thus, a generous uncertainty range was adopted for prices: plus or minus 30 per cent. These wide ranges also span the few values available from classified sources, which also support the findings of the research.

Because transaction quantities from source zone to consumer zone range from metric tons to fractions of a gram, even large uncertainties for individual transactions do not seriously compromise the main result. Four steps, each with a 2.5 mark-up, separated by five transactions, break down a metric ton of cocaine into gram quantities sold on the street; ideally, each trafficker would sell to 32 customers. Figure V depicts this adjusted version of the STRIDE price-quantity trend extrapolated from the consumer zone into the source zone. For the 1990s, the price-quantity model becomes $P = 145 \cdot Q^{-0.265}$ rather than $P = 155 \cdot Q^{-0.262}$; lower 1990 prices lead to the $145 factor and the difference in the exponents is less than the statistical uncertainty. This trend passes through the uncertainty ranges for Mexican and Caribbean transit-zone markets, the major drug trafficker organization to transit-zone trafficker exchange and eventually connects with the size

*This problem arises even with a large quantity of data from the STRIDE database: taking medians of quantity and price individually and then combining those medians gives different results from the proper method of normalizing price and quantity for individual transactions and then taking the medians.

Table 2. Cocaine transaction quantities and prices, 1990-1999

Production/ concentration/ distribution step: activity at point of transaction	*Quantity of transaction*			*Approximate prices for each transaction (unit price per gram)*			
	Range	*Nominal raw weight*	*Pure grams*	*Transaction price (dollars)*	*Raw unit price (dollars per kg)*	*Price of pure gram (dollars)*	
						Observed	*Model*
Leaf harvesting, selling by *arroba*[a]	A few *arroba* of leaf	11.5 kg	82	12	12 per 11.5 kg	0.15	0.18
Base[b]	500 g to 2 kg	1.0 kg	800	320	320 per kg	0.40	0.29
Transport to cocaine hydro chloride laboraory[c]	250 kg to 1.0 metric-ton	500 kg	400 000	400 000	800 per kg	1.0	1.1
Major drug trafficker organization laboratory prices are artificial[d]	6-20 metric tons	10 metric tons	8 000 000	16 000 000	1 600 per kg	2.0	2.1
Transit zone smuggling[e]	0.5-4 metric tons	1.0 metric ton	800 000	2 400 000	2 400 per kg	3.0	3.9
Access zone smuggler or distributor[f]	10-100 kg	30 kg	24 000	210 000	7 000 per kg	8.8	10
Wholesaler[g]	500 g-2 kg	1.0 kg	800	20 000	20 000 per kg	25	25
Dealer[h]	05.-2 oz	29 g	20	1 360	47 per g	67	65
Consumers or consumer/dealers[i]	0.07-5 g	1.0 g	0.65	110	110 per g	169	163
One hit of crack cocaine[j]	100 mg	0.1 g	0.07	18	180 per g	260	290

Note: 1 *arroba* = 12.5 kilograms.

[a]Although there is a very limited market for leaf even in Peru, a few *arrobas* from small producers may complete a batch or add profit when base prices are up (leaf is about 0.7 per cent cocaine).

[b]Farmers process leaf and produce from 1 to a few kilograms of base of about 80 per cent purity. Prices are for the period after the force-down or shoot-down policy and before the 1999 rise.

[c]Without interception, $20 000 per load; for non-lethal risk, $90 000; and with lethal interception pilot fees rise to $200 000 [5].

[d]Major growing regions produce enough leaf for about 20 metric tons per quarterly harvest, but some small producers do not transact that amount. At the time, laboratories produced about 80 per cent pure cocaine hydrochloride.

[e]Planes and go-fast boats (speedboats) carry about 500 kg to 1 metric ton, fishing vessels about 4 metric tons and container freight that much or more.

[f]These volumes are about the typical size of cross-border smuggling, which ranges widely. They also characterize mid-level distributors' loads in the United States.

[g]Local wholesalers typically buy 1 kg quantities, grind up the bricks, dilute the powder about 10 per cent and resell in ounce quantities.

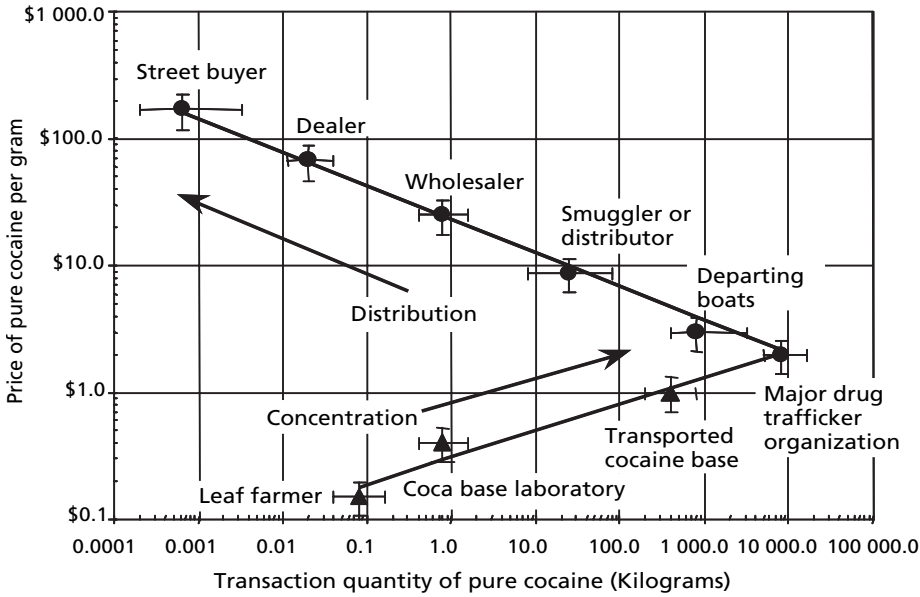
[h]Dealers purchase about an ounce, dilute it about 10 per cent and resell it in gram or partial gram quantities. Crack dealers cook the cocaine into hard, nearly pure crystals and resell in rocks or vials.

[i]Users and buyers range widely in consumption and transaction amounts. The median user may consume a gram per year, but most consumption is by heavy users absorbing over a gram per week. Some of these are user-dealers, who pay for their heavy use by selling to others.

[j]Crack cocaine is sometimes sold as a single "hit" to those with little money.

of the largest cocaine hydrochloride laboratory complex ever found. The Colombian National Police raided this laboratory complex in December of 1996 and January 1997. Judging by the equipment and chemicals found on site, it had an estimated capacity to process 100 metric tons of cocaine per month, although it did not operate continuously. A total of 7 metric tons of cocaine hydrochloride were seized, along with 1.5 metric tons of cocaine base. The laboratory complex had access to several growing regions that together produced about one third of the cocaine destined for the United States. The processing batches, or "transaction sizes", were probably comparable to the production of an entire growing region, that is, equivalent to 5-16 metric tons of pure cocaine.

Figure V. Late-1990s price-quantity trends for consolidation and distribution segments



Since the 1996-1997 raids, cocaine hydrochloride laboratories have become smaller and more dispersed and most laboratory owners contract their services to major drug trafficker organizations, which own the cocaine [7]. This spreads the risk both for the major drug trafficker organization and the laboratory owner, who most often also has several laboratories. Let us estimate a major drug trafficker organization's risk based on their number of transactions. Let us suppose that the organization buys 20 cocaine base loads of 500 kg each, processes it in five laboratories and sells metric ton loads to 10 transit-zone buyers. This represents 20 + 10 + 5 = 35 transactions, comparable to the standard business model "risk" of 32 transactions.

Ascertaining the number of major drug trafficker organizations and their potential impact on the highest levels of the cocaine business is important to

law enforcement planning. Since the price-quantity trends constrain the typical major drug trafficker organization to arrange for the processing of 5-16 metric tons of pure cocaine at each harvest, four or five times a year, it is possible to estimate their number. In 1999, Colombian cocaine hydrochloride laboratories could have produced as much as 560 metric tons of pure cocaine, 520 from Colombia itself and another 40 smuggled in from Peru. At one extreme, each major drug trafficker organization transacts 80 metric tons a year; thus, there would be 560/80 = 7 such organizations. At the opposite extreme, each transacts only 20 metric tons a year; hence there would be 28 such organizations. In reality, there must be a distribution of major drug trafficker organization sizes, with the largest possibly controlling about a third of the market.

Figure V also shows the price-quantity relationship, beginning with Peruvian coca growers on up to Colombian cocaine hydrochloride laboratories. These steps involve physical processing costs in addition to price mark-ups of about 2.5. However, traffickers collecting cocaine base from farmers in 1 or 2 kg quantities, consolidating it into 500 kg loads, smuggling it to Colombia and selling it to major drug trafficker organizations represents a concentration ratio of 250 to 500:1. These traffickers can deal with hundreds of farmers in contrast to the typical 32 customers of distributors because there is very little risk of interception or theft in the remote growing areas. Nonetheless, their mark-up remains 2.5.

Rigid adherence to the price-quantity scaling relationship

The price-quantity relationship represents the quantity discount rate for the typical trafficker's business models. Two unusual situations illustrate how rigidly the three constraints enforce this business model. First is the 1995 interception of the vessel *Natalie I* coming into Los Angeles carrying 20 metric tons of cocaine, fully 100 times more than a typical "large" 200-kg load. Even had it arrived safely, it would not have been a wise business strategy for the traffickers: either they would have had to store the bulk while parcelling it out to a limited number of wholesalers, or they would have had to sell to many more than 32 customers. Both options entail extremely high risks relative to the option of operating within the bounds of the price-quantity relationship.

Second is the 2001-2002 spate of smuggling 10 or more metric ton loads from Colombia to Mexico through Eastern Pacific routes. When the United States Coast Guard resumed interception operations following the stand-down from the terrorist attacks of 11 September 2001, they intercepted several such loads on large fishing vessels.* These load sizes were almost 10 times larger than those on the price-quantity trend. Upon closer investigation, however, police learned that these large loads were actually owned by several major drug trafficker organizations in Colombia and were being delivered to several traffickers in Mexico. This finding moves the actual transaction sizes onto the trend line. Yet it is still

*A private communication emanating from the United States Joint Interagency Task Force in 2002 recounted these events.

of concern that traffickers in both Colombia and Mexico were willing to deal with a common smuggler, apparently discounting the increased risk of betrayal from this single contact. Certainly, the smuggler would have to have detailed knowledge of all those contributing to or receiving from the load. Increased international cooperation and more effective law enforcement soon brought an end to these bulk shipments.

Cocaine price mark-ups worldwide

The United Nations listed cocaine price and purity at the wholesale (kilogram) and retail (gram) levels for countries reporting a cocaine trafficking or abuse problem in 2000 [6]. These data enabled an analysis to be carried out of the mark-up in price as cocaine moves from the Andean source-zone nations through the several transit-zone countries and finally to the four major consumer zones. These mark-ups reveal consistent patterns worldwide confirming the belief that three constraints apply across geographical barriers, ethnic differences and various law enforcement systems and systematically increase prices along each route. Since the distribution chain to the United States has a trafficker level for each 2.5 price mark-up, it is hypothesized that this is true for distribution chains worldwide. If so, the number of middlemen in these distribution chains can be estimated. In principle, this could be corroborated by law enforcement observation; however, only limited information is available for such validation.

Table 3 lists the cocaine prices and purities at both wholesale and user levels for the countries reporting to the United Nations and these are grouped into source-zone, transit-zone and consumer-zone regions for various distribution avenues. Since many countries do not report all of the data elements and some regions consist of several countries, notes below the table explain the regional aggregations and the assumptions necessary to restore missing data. To estimate the price mark-ups consistently, the prices per pure quantity are calculated in two additional columns.*

Although the United Nations reported $1,900 per kg for wholesale cocaine hydrochloride in Colombia, this price probably applies to cocaine in a major city or on its way to a coast for smuggling abroad.** For the purposes of the research, it was desired that the source-zone step would begin as cocaine base was sold for processing to cocaine hydrochloride, yet would include the processing costs. To estimate this price, $200 for laboratory processing was added to the $938 price of cocaine base to obtain $1,100 for the baseline source price. At 80 per cent purity, this implies $1,375 per pure kg. For smuggling to other South

*While several countries reported 80 per cent or greater purity in 2000, the United States Drug Enforcement Administration found kilogram bricks to have a much lower, 70 per cent median purity. Nonetheless, the United Nations reported values have been used in this analysis.

**While in table 2, $2,400 per kilogram for cocaine transactions with transit-zone traffickers was reported, this was 80 per cent pure in the 1990s, versus the 70 per cent purity in 2000. Furthermore, it is believed that the $1,900 represents a discounted wholesale price for diversion well before the transaction point with transit-zone traffickers.

American consumer-zone countries, Bolivian prices are appropriate. Even Peruvian cocaine must transit Bolivia on the way to most of these markets, although some Peruvian high-grade cocaine base goes to Colombia and a very small fraction is converted to cocaine hydrochloride for smuggling off the Pacific Coast directly to consumer-zone markets.

Table 3. Cocaine prices and purities at the wholesale and user levels

	Wholesale level			*User level*		
Country or region	*Dollars per kilogram*	*Purity*	*Dollars per pure kilogram*	*Dollars per gram*	*Purity (percentage)*	*Dollars per pure gram*
Colombia source	1 100	80	1 375	. .	. .	. .
Colombian cities	1 900	80	2 375	2.50	60	4.17
Peru[a]	. .	. .	. .	1.10	73	1.51
Bolivia	1 000	100	1 000	0.60	60	1.00
Central America	7 000	80	8 750	10	80	12.50
Mexico[b]	7 000	80	8 750	. .	. .	. .
Venezuela	4 100	80	5 125	5.00	60	8.33
Ecuador	2 000	96	2 083	1.00	70	1.43
Caribbean[c]	8 500	80	10 625	10	60	16.67
Brazil	2 500	90	2 778	4.90	60	8.17
Chile	6 000	95	6 316	2.40	60	4.00
Argentina	2 100	90	2 333	2.60	60	4.33
Africa[d]	40 000	80	50 000	12	10	120.00
W. Europe[e]	40 000	75	53 333	100	56	180.00
Canada	32 000	80	40 000	89	75	118.67
United States[f]	22 300	80	27 875	67	63	106.35

Sources: *Global Illicit Drug Trends 2001*, United Nations Office for Drug Control and Crime Prevention, 2001. Shaded numbers are from sources other than the United Nations, while missing purities were assigned consistent values.

Notes: Two dots (. .) indicate that data are not available or are not separately reported.

[a]Peru did not report a supply price; however, most Peruvian trafficking passes through Bolivia and since Peruvian quality is as good as Colombian quality, prices comparable to those in Colombia are expected.

[b]Because Mexico is not included in the United Nations tables, the wholesale price was obtained through private communications with the United States Embassy.

[c]The Caribbean is represented by the islands listed by the United Nations as having the most trafficking: the Bahamas, the Dominican Republic and Saint Lucia.

[d]Africa is represented by Nigeria because it has by far the largest user population. Ten per cent purity was assumed to achieve some mark-up, since Nigeria's users pay a very low user price relative to other African countries.

[e]European countries that are points of entry for cocaine, such as the Netherlands, have prices per kilogram in the range of $23,000 to $30,000. But these prices might be for multiple kilogram quantities and not typical of Europe as a whole. The destination countries were therefore taken as typical of European prices.

[f]The United Nations reports a United States wholesale purity of 55 per cent, which must be a typographical error.

The number of distribution steps from source to in-country wholesale level were estimated by computing the fractional number of 2.5 mark-ups, N_S, for a total mark-up, M, using the relationship $M = 2.5^{Ns}$ also written $N_s = \log(M) / \log(2.5)$. Finally, the computed steps, N_s, are rounded off in the "Transit" column of table 4.*

Table 4. Cocaine price mark-up and number of steps for transit and internal flows

Country or region	Transit market		Internal market		Steps rounded off		
	Mark-up	Steps	Mark-up	Steps	Transit	Internal	Total
Colombia	1.73	0.6	1.75	0.6	1	1	2
Peru	. .	. .	. .	. .	0	. .	. .
Bolivia	. .	. .	1.00	0.0	0	1	1
Central America	6.36	2.0	1.43	0.4	2	1	3
Mexico	6.36	2.0	. .	. .	2	1	3
Venezuela	3.73	1.4	1.63	0.5	1	1	2
Ecuador	1.82	0.7	0.69	–0.4	1	1	2
Caribbean	7.73	2.2	1.57	0.5	2	1	3
Brazil	2.50	1.0	2.94	1.2	1	2	3
Chile	6.00	2.0	0.63	–0.5	2	1	3
Argentina	2.10	0.8	1.86	0.7	1	1	2
Africa	36.36	3.9	2.40	1.0	4	1	5
Western Europe	36.36	3.9	3.38	1.3	4	2	6
Canada	29.09	3.7	2.97	1.2	4	2	6
United States	20.27	3.3	3.82	1.5	3	2	5

The mark-up ratios for the internal markets given in table 4 reveal several inconsistencies. Since the United Nations data are complete for Bolivia and Ecuador, simple arithmetic leads to the apparent conclusions that wholesale to retail trafficking in Bolivia is at cost (that is, for no profit) and similarly that trafficking in Ecuador operates at a loss (that is, less than a 1.0 mark-up). For the United States, the reported United Nations user price per pure gram is only $106, but the lowest found for that quantity from STRIDE was $134. The mark-up to $106 is only 3.82, which is just 1.5 steps, rather than the 5.8 for 2.0 steps obtained from the previous, more precise, scaling relationship analysis. In general, the "internal market" steps are all smaller than expected. One possible reason for these discrepancies is that reporting countries have not learned to

*The estimated numbers of steps, excluding the artificial estimate for Colombia, tend to cluster about integral values. A standard chi-square test of the null hypothesis of uniformly spread first decimal digits yields a p-value of 0.08. A more specialized likelihood ratio test comparing this null hypothesis against an alternative of a geometrical decline away from integer values gives a p-value of 0.06.

deal with the large price and purity spreads typical of user transactions. Therefore, a minimum of one step is assumed from supply to street for source-zone and transit-zone countries and two steps for Brazil, Europe, Canada and the United States. All of this is equivalent to adding about 0.5 to all the internal market "step" estimates. Overall, with these adjustments, the total number of steps from the simplified model agree remarkably well with the presumed relative law enforcement pressures on cocaine trafficking in each of these countries and regions.

Using the United States as a template, the analysis yields a total number of trafficking steps from source to users for each country or region. It suggests that there is an extra middleman leading to European and Canadian users. For other countries and regions, the numbers of steps are plausible, given what is known about law enforcement and drug abuse. Therefore, the analysis provides a plausible profile of worldwide cocaine trafficking to compare with observations made by law enforcement officers.

Seizures and trafficker risks

For traffickers, seizures represent both a business risk, that of losing revenues, and some personal risk of arrest. Analyses at the United Nations discovered that seizures of cocaine and heroin increase in proportion to the total volume of trafficking in these narcotics [8]. There is little if any evidence that seizures alone inhibit trafficking, as might be expected. Therefore, the detailed United Nations tabulation of seizures for 2000 were analysed to determine whether they simply provide an indicator of risk; that is, whether seizure rates, like price mark-ups, are comparable for each step in the distribution system. Because experienced smugglers believe they face about a 1:10 to 1:20 chance of being intercepted, it seems plausible that experienced traffickers also anticipate seizure losses and build these into their business models' expenses to be covered by the high profits [3, 5].

Before the seizure rate can be derived, total production must be balanced against seizures and consumption, then the total traffic in the source, transit and consumer zones can be estimated. A small adjustment for the reduced purity of seized cocaine at the consumption level improves model realism. With United Nations prevalence data by country, local consumption could be derived from population statistics if the amount consumed by the "average" abuser was known [6]. Since it has already been explained that total consumption is driven by the number of heavy users, that heavy use is limited by human physiology and that heavy use is proportional to total usage according to the user function, it follows that total consumption should be proportional to the number of users. Annex C employs this condition to derive the consumption, seizures and flows for each trafficking zone. Although this analysis depends upon a very simplified flow analysis and there are many well-recognized problems with estimating total flows, it will also be verified that the results are quite insensitive to total flow.

Seizures as a fraction of flows

Table 5 presents a simplified summary of flows from source zone to consumer zone, in which each group of rows gives information on seizures, the seizure rate, consumption and exported quantities. The table includes a group of rows for the redistribution, balancing source-zone contributions with flows leading to major consumer zones.* Along with consumption, the consumer-zone group of rows includes "adjusted seizures" expressing the reduced purity at ounce and gram levels. Finally, seizure rates are calculated from seizures divided by incoming flow before consumption.

Table 5. Balance of cocaine flows to major consumer zones showing seizure rates

Flow or rate	*Unit*	*Colombia*	*Peru*		*Bolivia*	*Total*
Source zone						
Production	Metric tons	520	175	. .	70	765
Seizures	Metric tons	64	11	. .	8	83
Seizure rate	Percentage	12	6	. .	11	. .
Consumption	Metric tons	13	7	. .	1	21
Exported	Metric tons	443	157	. .	61	661

Redistribution of flows	*Unit*	*United States and Canada*	*Europe*	*Africa*	*Other South America*	*Total*
Colombia	Metric tons	–22	22	. .	. .	0
Peru	Metric tons	. .	–59	43	16	0
Bolivia	Metric tons	. .	. .	. .	. .	0
Net exports to consumer zone	Metric tons	421	120	43	77	661
Transit zone						
Seizures	Metric tons	64	17	6	. .	86
Seizure rate	Percentage	14	14	14	. .	. .
Consumption	Metric tons	29	8	3	. .	40
Exported	Metric tons	328	95	34	77	534
Consumer zone						
Seizures	Metric tons	134	44	1	12	191
Adjusted seizures	Metric tons	112	39	1	12	163
Seizure rate	Percentage	34	40	1	16	. .
Idealized rate	Percentage	32	40	. .	12	. .
Consumption	Metric tons	216	57	34	65	371

Note: Two dots (. .) indicate that cells have been intentionally left blank because they have no defined content.

*For simplicity, Asia and Australia were left out as consumer zones. This drops about 7 metric tons from total consumption, which would adjust other consumption downward by about 1.5 per cent.

In the source and transit zones, seizure rates range from 11 per cent for Bolivia to 14 per cent for the transit zone. The sole exception is 6 per cent for Peru, which exports a large fraction of production as cocaine base rather than cocaine hydrochloride and therefore has less interception exposure. Since there are some seizures of the small portion of consumed cocaine, the transit-zone countries would have a 14 per cent seizure rate if the underlying baseline rate per step were 12 per cent.

In the consumer zone, seizure rates rise significantly: 34 per cent for the United States and Canada, 40 per cent in Europe and 16 per cent in countries in South America other than Bolivia, Colombia and Peru. Only Africa has a low rate of 0.5 per cent, suggesting there is little law enforcement effort to intercept cocaine once it arrives on the continent. The consumer-zone seizure rate for countries in South America other than Bolivia, Colombia and Peru in aggregate indicates a relatively low level of law enforcement comparable to transit-zone countries.

To understand the seizure rates in the United States and Europe requires some modelling. Table 4 indicates that for Europe there are two additional steps to arrive at the wholesale level and two more to reach users. The idealized seizure rate for Europe based on 12 per cent loss per step is calculated as $1 - (1 - 0.12)^4 = 0.40$. That is, four interception steps with a 12 per cent compounded loss at each result in a 40 per cent loss, rather than the simple linear approximation of 48 per cent. Because the United States as a consumer zone includes three additional steps, one to get in and two from wholesaler to user, a similar model yields a 32 per cent aggregate seizure rate.*

It has been assumed that the initial total flow of 80 per cent pure cocaine is approximately that given by the United States estimate of Colombian production of 520 metric tons. However, the joint United Nations and Colombian estimate is 680 metric tons. The simple scaling result was re-examined to determine whether it was undermined if total flows were 160 metric tons larger. It was also assumed that the United States and Canada, as well as Europe, effectively seized less cocaine of 80 per cent purity because a significant portion of seizures would be of a lower purity, street-grade product. Again, the scaling result was checked to determine whether this assumption might have undermined it. The seizure rates for all four combinations of the two assumptions were recalculated and it was determined that the simple scaling works in all cases. The estimated magnitude for the common seizure rate does vary, however, from case to case, ranging between 10 and 15 per cent, compared to 12 per cent for the baseline case.

Connection between seizure rates and price mark-ups

Although this analysis of price mark-ups and seizure rates worldwide is highly stylized, the model appears to be robust with regard to alternative sets of assumptions and it reveals several important findings about the cocaine traffick-

*Although Canada has an additional step, it has only 2.5 per cent of the United States flow. Canada cannot be analysed independently since an unknown fraction of Canadian consumption flows through the United States.

ing industry. Comparable seizure rates for comparable price mark-ups all along the international distribution chains for cocaine is strong evidence that both are built into traffickers' business models. If seizure rates represent trafficker risks, then higher seizure rates should cause either a higher price mark-up or the insertion of additional trafficker levels in the distribution hierarchy. Furthermore, increased seizure rates at all levels should have a compound effect on access to illicit drugs, first by reducing the supply itself and second by greatly increasing the price to users. If, however, counter-drug interception operations are to have a strategic impact rather than simply continuing to exact a tax, either significantly more than 15 per cent must be seized or traffickers must be arrested to obtain a deterrent effect [5, 9].

The findings for cocaine suggest that analysts should apply this model to the distribution systems for other major drugs of abuse. By so doing, different counter-drug organizations and countries might recognize their individual roles in the context of reducing the trafficking worldwide and see where mutual efforts might have strategic consequences. For example, countries with large traffic in several narcotics might be critical hubs enabling drug substitution or the introduction of new drugs that blunt the impact of periodic counter-drug successes against an individual narcotic.

Market dynamics in response to changing conditions

Up to this point, a static model of the cocaine distribution system has been presented, from farm gate to consumer-zone users, in which price mark-ups and seizure losses reveal distinct levels of trafficking. It must now be asked how this hierarchical distribution system adjusts to changing conditions: for example, how major events have affected business levels, how major source-zone counter-cocaine operations affect prices throughout the distribution hierarchy and how the quantity-discount relationship adjusts to market shocks.

For purposes of tracking substantive United States cocaine price trends over time, a simple two-step methodological procedure can overcome the inherent variability of the STRIDE data: *(a)* for each transaction, the purchase price is calculated per pure gram and *(b)* for a sequence of 100 or so of these nearly time-coincident normalized prices, their median is computed [4]. These medians are then called the "United States price index" and these data are often plotted along with their nine-point moving average.* In this way, a sample measure, the median, is obtained, which avoids the divergence of statistical averages or moments and includes information about cheated customers, who pay infinite unit price. Further, as annex B explains, the median provides a stable statistical measure, which also has finite variance amenable to traditional statistical methods such as informative data plotting, regression analyses, time

*The price given by the United States price index is artificial in that it corresponds roughly to the median of STRIDE sampled quantities. Since the distribution of purchase quantities in STRIDE remained stable over the period of analysis, the United States price index reveals relative shifts of normalized price with a high degree of accuracy.

series procedures, and so forth. Most importantly, data features exhibited by appropriately aggregated STRIDE statistics are remarkably robust: they are insensitive to data perturbations, internally consistent across natural partitions of the data, strongly correlated with external data sets portraying market conditions and logically compatible with the incidence and timing of specific counter-cocaine operations [4, 5, 10-15].

The end of the cocaine epidemic and business-level adjustments in Peru

Cocaine abuse began in the United States as an epidemic wave in the late 1970s, crested in the mid-1980s, receded rapidly in the late 1980s and ebbed gradually thereafter. Initially, supply was short, prices surged, purity was low, coca cultivation exploded in the Andean producer nations and vertically integrated cartel organizations expanded through ethnic connections between Colombia and the United States. While Bolivian cultivation expanded somewhat early on, its greater distance from Colombia put Bolivian farmers at a competitive disadvantage relative to those in Peru. By the early 1990s, most Bolivian cocaine was supplying South American, European or other non-United States markets. Figure VI portrays the entire epidemic cycle of United States user demand from pre-epidemic 1970 to 2000. It also shows the falling United States price index from 1980 onwards and the rising and shifting cultivation in the Andean countries [4, 5].

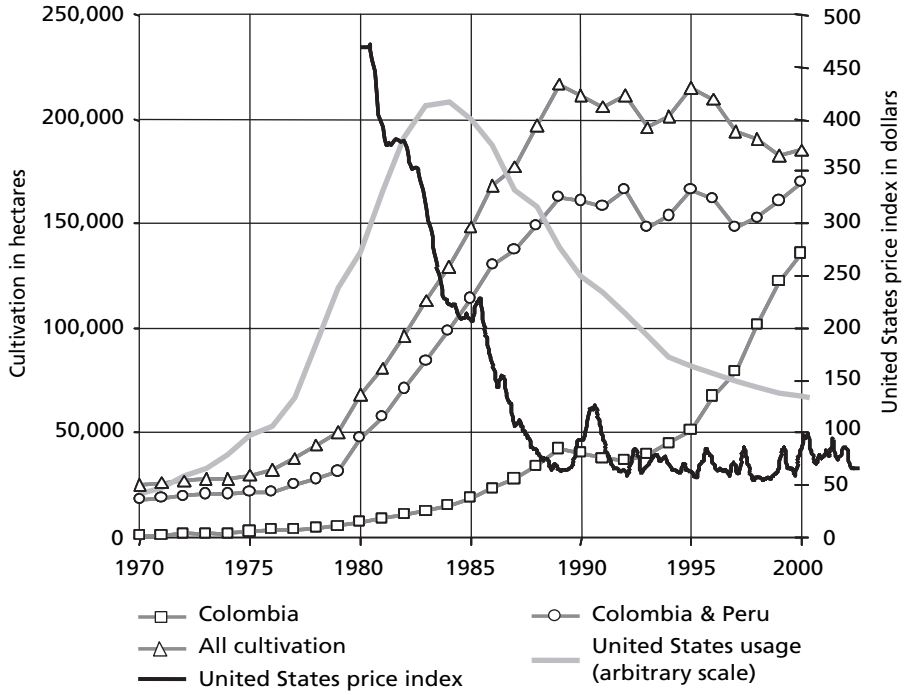
From a United States perspective alone, it is strange that cocaine prices plummeted from 1980 to 1983, while the United States household surveys indicated demand was still rising [1]. The Medellín cartel leaders surrendered in 1991, long after prices had fallen and the Cali cartel leaders surrendered three months after Peruvian cocaine base prices had collapsed in 1995 as a result of operations to sever the Peru-to-Colombia trafficking air bridge [5]. Thus, the fall of the cartels did not cause price drops.

Comparing the United States price drop with the rise in Peruvian cultivation, however, reveals a remarkable congruence. Figure VI shows the cumulative Andean cocaine production, with the stacking of contributions from Colombia, Peru and Bolivia respectively [16, 17]. The Peruvian cultivation explosion began in 1979, which was the year prices began to fall in the United States. Prices continued to fall at a rapid rate until 1989, which was the year cultivation expansion abruptly stopped in Peru and throughout the Andean region. After 1989, United States prices bottomed out at a floor that continued to hold throughout the 1990s, with only episodic surges that never approached pre-1985 levels. Demand, on the other hand, continued a smooth, uninterrupted decline through the 1989 price transition.

If the cocaine supply from Peru caught up with United States demand, leading to a price index drop of greater than a factor of six, then there should also be some evidence of this in Peru. There is indeed such evidence, as the following story explains: epidemic demand for cocaine in the United States caused

Peruvian coca leaf prices to jump from $0.60 to $3.00 per kilogram, six times higher than their traditionally established price baseline [16, 18]. This induced heavy migration into remote and lawless coca cultivation areas and a rapid expansion of the crop beyond the pre-epidemic 17,000 hectares [17]. Farmers with about 200 kg of dried leaf worked with cocaine paste processors, thereby reducing its mass by 200:1. Paste collectors either sold it for export to Colombia or brought it to cocaine base processors, who would make 1 kg of cocaine base from 2.5 kg of paste. Cocaine base collectors either sold that base for export to Colombia or, occasionally, brought it to Peruvian cocaine hydrochloride processors. Peruvian cocaine hydrochloride was sold for local consumption or transshipped to South American or European markets.

Figure VI. Cocaine epidemic and afterwards, 1970-2000



By the end of the 1980s, cocaine profits had dropped dramatically and Peruvian cultivation had stabilized at around 120,000 hectares. Most coca growers were now producing their own cocaine base to sell directly to trafficking organizations for export to Colombia. Some leaf was sold on a spot market, but this was by now a peripheral aspect of the business, since there was no longer a profit in making cocaine base from purchased leaf. Cocaine paste had virtually disappeared from the marketplace, as paste now sold for a price equal to that of the farmer's cost of growing the leaf to make it.

Figure VII shows the price series for all levels of the Peruvian cocaine business in the 1980s: dried coca leaf, cocaine paste, cocaine base and cocaine hydrochloride [4, 16, 18-21]. All prices are for a one-kilogram equivalent of cocaine. Since figure VII depicts prices on a logarithmic scale, the typical trafficking mark-up of 2.5 is a constant interval for all price ranges, as can be seen from the broad vertical bars at the left. The large crosses indicate two middlemen being forced to drop out by the late 1980s. Along the top of the figure is the United States price index developed during the research, scaled up to kilogram quantities. Immediately, the parallel decline in United States street prices with Peruvian source-zone cocaine base and hydrochloride prices becomes visible and both declines include a plateau feature between 1983 and 1985.* Since United States prices are more than 100 times those in Peru, this lock-step decline must result from a multiplicative market in which source-zone price changes are amplified as comparable percentage changes in the distant consumer zone.

Along the bottom of figure VII are two artificially constructed price series for leaf. The lowest is a flat baseline representing the cost of 500 kg of pre-cocaine-epidemic leaf. The next up from the baseline includes the investment cost necessary to expand cultivation at the rates observed during the 1980s.** All mark-ups would be measured relative to these baseline costs.

The number of researchers employing different data sources and analytical methods over different periods, coupled with the variety of trafficker practices, complicate the interpretation of the many price series depicted in figure VII [15]. Nonetheless, it can be seen that most series drop by a factor of two between 1982 and 1983 and by a factor of three between 1985 and 1989. By the end of the decade, these price drops had squeezed out the independent cocaine paste or base producers as well as the paste collectors. Instead, growers had been forced to learn how to make their own cocaine base. It should be noted that, in 1989, the United Nations began systematically collecting cocaine base prices from a wide range of growing areas, thereby causing a sharp discontinuity in reported price relative to previous series. Nonetheless, relative changes in the previously reported series should reasonably correspond to real changes in the Peruvian markets.

These results reinforce and extend the hierarchical distribution model. A reduction in price of a factor of six caused a structural change, squeezing out two trafficking levels, each with the standard mark-up of 2.5, that is, $2.5^2 = 6.25$. Leading to street users, a five-step mark-up amplified price changes in the source zone by 100, with virtually mechanical precision throughout the transition. And the source-zone traffickers, rather than others further up the distribution chain, lost their market niches, suggesting that concentration steps are the most economically vulnerable.

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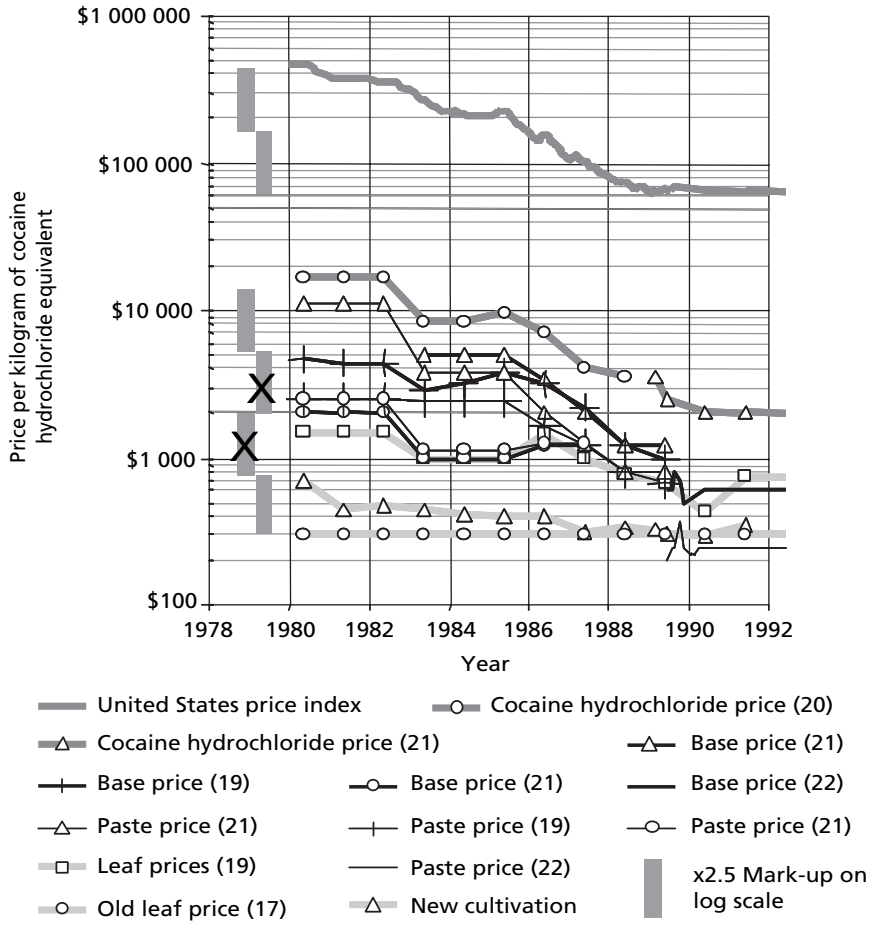
*This plateau was probably the result of Operation CHEMCON in Colombia, in which chemical drums were bugged with radios, leading to several major cocaine hydrochloride laboratory raids [4].

**During the 1980s, it cost $2,587 to plant a hectare of coca that, two years later, would produce 1,790 kg of leaf and it took 500 kg of leaf to make 1 kg of cocaine base. With these data and the relative rate of increase in production compared to the producing mature crop, the additional investment per kilogram of cocaine was computed. For example, this was $404 in 1980, dropping to $100 in 1985.

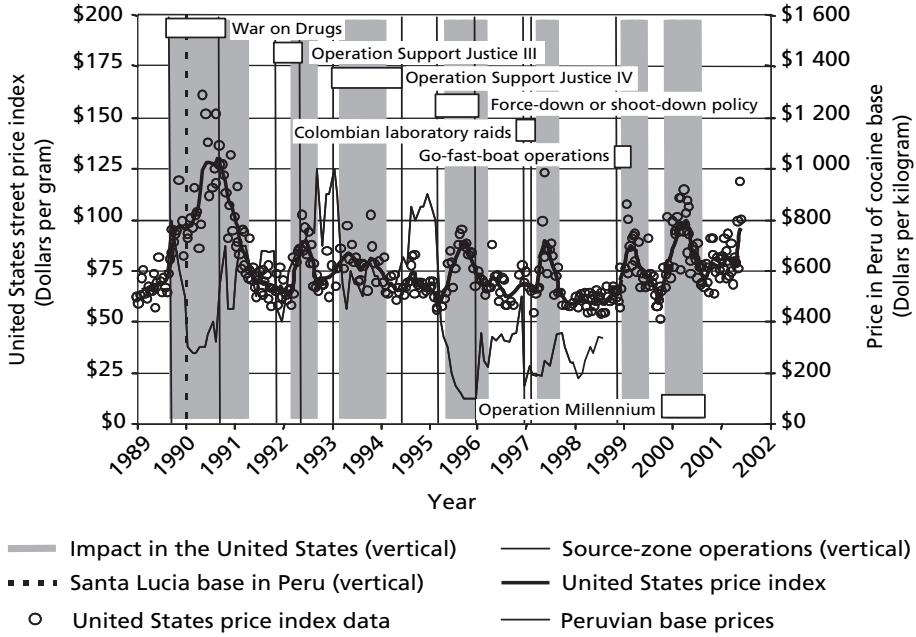
Figure VII. Decline in Peruvian cocaine prices, 1980-1992



Price reactions to source-zone and transit-zone operations in the 1990s

During the 1990s, the Peruvians, the Colombians and the Government of the United States conducted several major cocaine-interception operations targeting the strategic vulnerabilities of the cocaine-distribution system and of a scale large enough to have the potential of damaging the entire system. Figure VIII presents two time series, the United States price index and Peruvian cocaine base prices, overlaid with thin vertical lines representing the beginning and ending of each operation. Vertical grey bands represent the time-lagged intervals of significant price increase on United States streets. It should be noted that, during the 1990s, the United States price index settled to a floor of $55 to $60 whenever there were no disturbances arising from source-zone interception operations.

Figure VIII. Drops in price of cocaine base in Peru and rises in United States price index following each major source-zone or transit-zone operation of the 1990s



The following short descriptions of these operations cover only the highlights [5]:

(a) The "war on drugs" consisted of coordinated operations against the Medellín cartel in Colombia and an extensive blockade of cocaine traffic leaving Colombia to cross the Caribbean. It also included the establishment of the Saint Lucia base, supporting air interceptions against flights originating in the Upper Huallaga Valley of Peru, indicated by the dashed vertical line. Flights from Peru were reported as dropping from 50-60 per week to 5. Cocaine prices rose immediately in the United States and Peruvian cocaine base prices plunged with the drop in air traffic. The war on drugs ended with the Government of Colombia focusing on Pablo Escobar, leader of the Medellín cartel, and the United States diverting naval assets from the Caribbean for the build-up to the first Gulf War. Thereafter, United States cocaine prices returned to the price floor;

(b) Operation Support Justice III was an air interception operation in which the United States provided detection and monitoring support to the Peruvian air force.* On occasion and without sanction from the United States, the Peruvian military interceptors would fire upon trafficker aircraft. While successful for a short period of time, United States support abruptly ended when a

*Operations Support Justice I and II were short training exercises that were not expected to cause noticeable impacts.

Peruvian interceptor mistakenly fired upon a United States C-130, killing one crew member. The vertical lines in figure VIII indicate the beginning and end of Operation Support Justice III, during which time cocaine base prices dipped in Peru. The vertical grey band indicates the sharp price rise in the United States five months later;

(c) Operation Support Justice IV was also an air interception operation, but with stringent controls on the use of deadly force. Air smuggler fees rose from $20,000 to $90,000 for those flying 500 kg of cocaine base to Colombia. Traffickers took the higher smuggling fees out of farmers' pockets as cocaine base prices fell to the level of estimated production costs. Three months later, United States prices rose noticeably, earlier than five months because the Colombians began Operation Support Justice IV two months before the Peruvians. Since the interception threat was insufficient to deter traffickers, cocaine moved unabated to Colombia and United States prices approached their floor even before Operation Support Justice IV ended;

(d) Approval of the force-down or shoot-down policy by the United States Congress and President Clinton gave United States intelligence and tracking support to the Peruvian air force under a strict set of conditions and controls. The use of lethal force was justified by the insurgent and drug trafficker threats to Peru's national sovereignty. The force-down or shoot-down operations achieved a quick success in March 1995 and soon thereafter had deterred more than 80 per cent of the air trafficking. These operations continued throughout the 1990s, with only a brief interruption in December 1995, at which point cocaine base prices abruptly recovered to a less depressed level of $320 per kilogram. Severing the air bridge caused Peruvian farmers to abandon over 66 per cent of their coca crop by 1999. While some riverine and overland smuggling attempted to sustain trafficking from Peru to Colombia, delays, costs and risks prevented it from effectively substituting for the air bridge and restoring prices. Once again, operations began in Colombia two months before Peru and United States street prices began to rise three months after initiation of the force-down or shoot-down policy. Although the force-down or shoot-down policy remained in effect throughout the 1990s, Colombian growers were catching up with supply shortage and, by mid-1996, United States street prices had returned to their floor;

(e) Raids on the Colombian laboratory complex at Miraflores, Colombia, in December 1996 and January 1997. Since this laboratory complex probably processed a third of all the cocaine from Colombia and a large fraction of Peruvian production, which was smuggled into Colombia, both demand for and the price of Peruvian cocaine base abruptly dropped. Without warning, this shock rippled through the distribution chain to cause a surge in United States street prices four months later, illustrating that downstream traffickers are unable to capitalize on the knowledge of a future shortage. The nine-month moving average trend line for the price index in figure VIII truncates the spike in price, but the data points reveal that price actually rose to more than double the floor value. In late 1997, as dispersed replacement laboratories came into production, cocaine base prices returned to their former levels;

(f) Go-fast-boat operations. In 1998, coordinated operations began in the eastern Caribbean to intercept go-fast boats leaving Colombia, headed for the Yucatán peninsula. Disabling rifle fire was approved for use by the United States Coast Guard to destroy the motors of the boats; thus, smugglers could no longer ignore United States Coast Guard helicopters when they were intercepted. Simultaneously, police intercepted go-fast boats arriving at the Yucatán peninsula. This operation shut down the principal trafficking route at that time. Two months after operations began, prices rose on United States streets;

(g) Operation Millennium was a follow-up operation to those shutting down the lanes through the western Caribbean used by go-fast boats. With Drug Enforcement Administration support, the Colombian National Police penetrated the major smuggling organization operating in the go-fast lanes as it attempted to shift from the western Caribbean to the eastern Pacific and arrested its experienced leadership. Shortages ensued, resulting from a lack of trusted smuggler connections, and this caused a prolonged price increase on United States streets, indicated in figure VIII by a vertical grey band.*

During the 1990s, there was a complete correspondence between major source-zone or transit-zone events and United States price index increases above the price floor: every major operation was followed by a price increase and long periods without major source-zone or transit-zone operations had no price increases above the floor. The autoregressive integrated moving average time series analysis used in the research verified the strong statistical correlation between source-zone and transit-zone operations and movements in the United States price index [11]. Five separate classes of Peruvian air-interception events were independently fitted to the price index.** For each source-zone air-interception class, a time lag before the onset of an increase in the United States price index over a six-month window was searched for. A five-month lag fitted all five classes best, an event with odds of happening at random of only $(1/6)^4$ = 8:10,000. Also, the fitted magnitudes representing impacts on United States prices were consistent with the relative magnitudes and consequences of the interception classes. This verified the non-linear deterrence response to multiple interceptions under severe consequences. Finally, the fitted time lags to United States price increases decreased as the cocaine moved towards the United States: five-month lags for air interceptions in Peru, a four-month lag for the Colombian laboratory complex destruction and a two-month lag for the transit-zone go-fast-boat interceptions. Since the early Colombian air interceptions could not be verified in detail, they were excluded from the analysis.

*Larry Lyons of the Drug Enforcement Administration explained this event.

**In fact, seven independent classes of source-zone air-interception events were fitted to the United States price index, but only five were statistically significant. The classes were: three separate months with four or more interceptions, two lists of months with two or three interceptions and two lists of months with a single aircraft interception. The latter two classes distinguished between those before and after the implementation of the force-down or shoot-down policy. Neither of the classes with only one interception per month was statistically significant, while the coefficients representing impacts on prices for the other classes agreed with the relative magnitudes and consequences of the interceptions.

Subsequent to the go-fast-boat operations, there have been so many disruptive events in Colombia that autoregressive integrated moving average (ARIMA) analysis cannot sort them out without more precise data on their source-zone impacts. Nonetheless, the United States price rises represented by the grey bands in figure VIII are certainly a result of these source-zone operations.

Price-quantity relationship during market excursions

The price-quantity relationship derived from STRIDE data for three distinct operational periods with very different street price levels was compared, proving that the slope remains constant although the prices shift up or down for all traffickers in the distribution chain. During the initial epidemic period, from 1983 to mid-1985, prices hesitated at $294 per gram before continuing their decline. Between mid-1997 and late 1998, the gram price dropped to the floor value of $134. During the period 2000-2002, following the go-fast-boat interceptions, the price rose once again to a sustained level of $196 per pure gram. Although these three price levels were so different that the data clusters about each trend line did not overlap the other price excursions, the trend line slopes were the same within random expectations.* This implies that the price mark-ups at the wholesale and dealer levels are independent from the general price of cocaine.

Other time series indicators of damage to the cocaine business

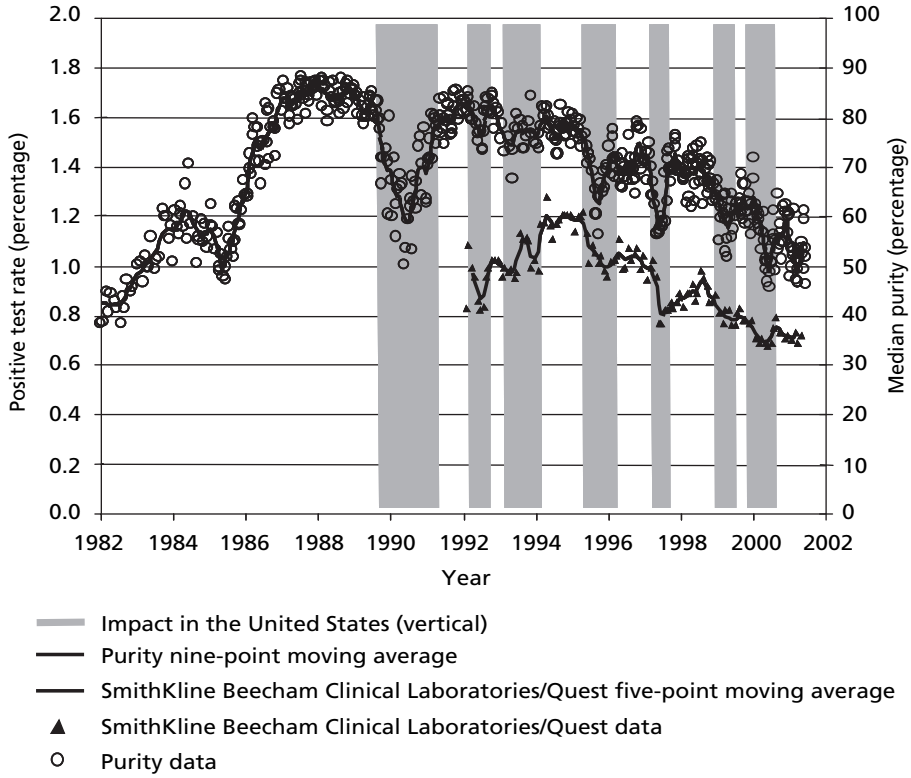
Previous work identified four separate indicators of reduced cocaine availability on United States streets: *(a)* the positive test rate for cocaine in the testing programme conducted by the SmithKline Beecham Clinical Laboratories (SBCL) (now known as Quest Diagnostics); *(b)* the positive test rate for cocaine in the Drug Usage Forecasting (DUF) (now called Arrestee Drug Abuse Monitoring (ADAM)) of the Department of Justice; *(c)* the number of cocaine treatments delivered by treatment centres participating in the Treatment Episode Data Set (TEDS) data collection programme; and *(d)* the number of hospital casualty department admissions linked to cocaine at participating hospitals in the Drug Abuse Warning Network (DAWN) data collection programme [4, 14, 22-25]. These other indicators expand the understanding of the impact of cocaine shortages in the United States and provide further empirical corroboration that the STRIDE-derived price index represents real price movements.

The SBCL/Quest programme typically conducts from 250,000 to more than 800,000 drug tests per month, covering a broad spectrum of the United States workplace. This accounts for the relatively small scatter about a five-month moving average, although the series exhibits pronounced drops during each of the operational periods (see figure IX). It should be noted that the systematic rise

*The null hypothesis that all three slopes are the same cannot be rejected at the 17 per cent level, while the differences in price are significant at the 4:100,000 level.

in positive test rate before 1994 was largely a result of SBCL establishing their customer base rather than an overall increase in cocaine abuse. Conversely, the decline by steps following the force-down or shoot-down operations and again following the go-fast-boat operations were real reductions in usage that did not recover as they slowly did following the Colombian laboratory raids.

Figure IX. Median cocaine purity and positive test rate

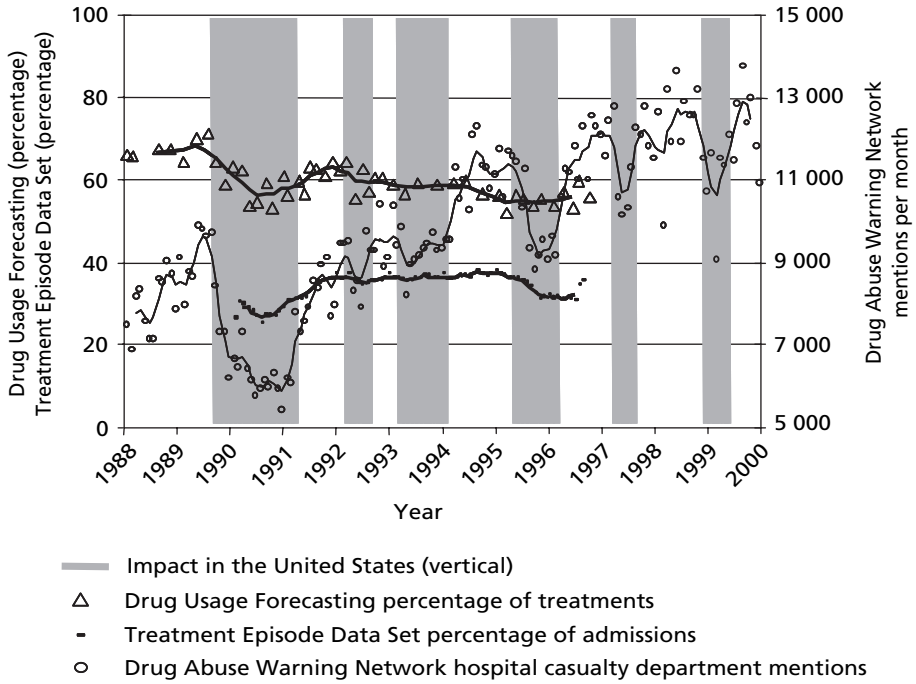


Sources: System To Retrieve Information from Drug Evidence (STRIDE) database and SmithKline Beecham Clinical Laboratories/Quest positive test rate time series.

The other time series in figure IX is median purity, also derived from STRIDE data. Each significant dip during operations makes a large contribution to price index rise because purity is in its denominator. During a shortage, traffickers clearly maintain sales volumes and revenues by cutting the cocaine quality. Early in the cocaine epidemic, when there was high demand and short supply, purity was around 40 per cent, which might be the lowest marketable purity for United States customers. More recently, the downward trend in purity shown in figure IX reversed around 11 September 2001, when most Coast Guard units were transferred to counter-terrorism roles. However, there are other plausible explanations for this reversal; thus, the root cause cannot be determined at this time.

The DUF/ADAM programme conducts semi-random drug testing on several hundred arrestees in 23 major cities every calendar quarter. For the purposes of the research, the percentage of arrestees testing positive is taken as an indicator of cocaine use. Figure X depicts the clear dip during the war on drugs and a small dip during Operation Support Justice III. Methodological problems with this indicator were corrected at the end of this series and may be responsible for the ambivalent behaviour from mid-1994 to mid-1996. Since arrestees abuse cocaine at a high rate and the chemical detected in the tests persists in the blood, even significant drops in availability and frequency of consumption do not appear strongly in this indicator.

Figure X. Data from the Drug Usage Forecasting, Treatment Episode Data Set and Drug Abuse Warning Network, 1988-2000



The TEDS time series represents the percentage of treatments linked to cocaine as a primary or secondary drug of abuse. During the periods of the war on drugs and the force-down or shoot-down policy, TEDS dropped several percentage points and the tight clustering of data about the moving average suggests that the discernable dips at the beginning of operations Support Justice III and IV are significant.

Although DUF and TEDS move little in response to United States price index increases, DAWN exhibits large, statistically significant downward excursions for each operational period. Since these data include only those users

between the ages of 12 and 35, an ageing user population is probably not the cause of the systematic rise. Rather, the shift towards crack cocaine or the occasional purity dip followed a month or so later by recovery, which catches cocaine abusers by surprise, probably combine to explain the overdoses and variation in emergency events.

Implications of the models for control of the supply of illicit narcotics

Given the broad regularities revealed by the analysis and modelling efforts, the question arises of how this information can be used to enhance supply-control operations to stem the traffic of illicit narcotics. Closely related topics are usage and trafficking models as a basis for insights, employing the models to recognize the strategic vulnerabilities of narcotics distribution systems, the limits to drug-business adaptability, measures of effectiveness for counter-drug efforts and the evolution of a common analytical framework for synthesizing disparate counter-drug efforts.

Empirically validated models of drug abuse and trafficking as a basis for insight

Three models are summarized below: the user function of drug abuse, the generic trafficker's business model and the price-quantity scaling of discounts up from farm gate to major drug trafficker organizations and from there down the distribution hierarchy to street users.

Cocaine users vary widely in their dose frequency: the great majority take only a few doses a year, while very heavy users average over 10 doses daily. This pattern follows a mathematical regularity, with the number of users diminishing as an inverse power of the amount they consume. Consequently, only 5 per cent of users are responsible for 80 per cent of all cocaine consumption. And at the opposite extreme, two thirds of all users consume only 2 per cent of the cocaine. This pattern illustrates why it is important to know whether heavy users get quantity discounts from dealers or are dealers themselves, whether heavy users must also pay elevated prices in times of shortage and experience the same purity changes and whether heavy user consumption tracks the more visible rise and fall of cocaine abuse among casual users.

Trafficker business models at every level of distribution share several common traits as a result of a lack of trust, interception risks from law enforcement and intense competition. These common traits permit a useful conceptual simplification that should enhance strategic thinking.

Lack of trust limits organizational size to the span of familiarity of at most a few central individuals, which is about 50-80 people, relegates high-risk tasks such as smuggling to small cohesive teams of 5-10 members and limits the number of customers to about 32 for cocaine and an estimated 17 for heroin and 50 for marijuana. Business associations and recruitment tend to rely on

trust mechanisms such as common ethnicity and long-term familiarity and on coercive controls, such as holding family members hostage. Aside from an epidemic expansion during which there is little competitive pressure, lack of trust prevents vertical or horizontal integration and promotes the outsourcing of specialized tasks such as laboratory processing, smuggling and money-laundering.

Interception risk from law enforcement is perceived by smugglers as a 5-10 per cent chance of arrest and, for cocaine, the seizure rate is about 12 per cent for all levels of the distribution chain.

Competition forces price mark-ups towards a common value clustering around 2.5 because encroachment reduces excessive profits, while the need to make criminal profits prevents accepting lower mark-ups. Other narcotics competing with cocaine are probably also pushed towards the same mark-up. While a 2.5 mark-up might seem large, especially when one can turn over capital four or five times a year, interception losses reduce it to 2.2 and there are major expenses such as payments to corrupt officials, risk premiums on employee wages and inflated prices for all illicit materials and services. Evidence from the source zone suggests that traffickers require a 2.5 mark-up, while other aspects of the business model can be adjusted. For example, as supply caught up with demand, two intermediate trafficking levels between farmers and major smugglers were squeezed out of business. Also, collection and smuggling organizations today accept a 2.5 mark-up, although they consolidate hundreds of farmer lots into half-ton loads, which is in sharp contrast with distribution traffickers who limit themselves to approximately 32 customers.

Other drugs deviate in some respects from the cocaine distribution model. Most opium is produced in short growing seasons, so opium, morphine and heroin must be stockpiled somewhere along the distribution chain. Also, unprocessed marijuana and synthetic drugs can be produced close to users. However, heroin distribution does resemble cocaine in that it has a long distribution chain and local law enforcement interception of marijuana or synthetic production can, to a degree, force an increase in the length of these drugs' distribution chains, thereby also increasing their street price.

Because trafficker organizations operate autonomously at each step along the distribution chain, prices compound at successive steps from farm gate to user. This multiplicative increase generates the price-quantity scaling relationship seen for all major illicit drugs of mass distribution in the United States. If price shocks occur at early steps in the cocaine distribution chain, subsequent traffickers have little choice but to pass on the price increase, raised by their standard mark-up. The net result is that shocks are passed along from source zone to consumer zone as a uniform percentage increase, amplifying, for example, a 30 per cent rise in cocaine base price per pure gram ($1.00 to $1.30) at source zone laboratories to a comparable percentage price rise ($150 to $195) for street users. Generally, street users do not see a real price increase directly, but rather experience it as a drop in purity. With loss of satisfaction, many users abandon cocaine, as is revealed by independent indicators such as workplace drug-testing and hospital casualty department visits resulting from cocaine abuse.

Strategic vulnerabilities of the drug business

Each nation's counter-cocaine efforts contribute to the 2.5 mark-up per step all along the distribution chain exhibited in the price-quantity relationship. These efforts reduce supply, increase cocaine prices to users and reduce usage; hence they have tactical utility. But there are also strategic vulnerabilities of the entire distribution chain.

The price-quantity relationship implies large transaction quantities for major drug trafficker organizations and very low unit prices throughout the source zone. Concentration at the top also implies that there are relatively few trafficker organizations conducting the bulk of the business, estimated by the research at between 7 and 28. At the source, coca growers have the least resources of all participants in the cocaine business and their crops are clearly visible from above and cannot be easily relocated. All of these features represent inherent vulnerabilities for the cocaine distribution system as a whole.

Traffickers recognize these vulnerabilities and either locate activities outside areas of police control or pay high premiums to corrupt officials. Cocaine profits also enable insurgent and paramilitary organizations to challenge Andean governments for control of remote areas, thereby creating a nexus of terrorism, lawlessness, weapons-smuggling, human rights violations and environmental damage. Reducing this mayhem would benefit many other areas in addition to those of drug control, including civil order, humanitarian relief, environmental preservation, economic development and political stability.

If traffickers' net revenues are a measure of their ability to avoid law enforcement, then low source-zone prices argue in favour of the international community investing in strategic counter-drug operations there. To understand this, let us consider the fraction of total trafficker revenues accessible to those in the source zone. Farmers, in aggregate, receive only 1 per cent of total cocaine revenues from all levels of trafficking and major drug trafficker organizations receive only 2.4 per cent of total revenues.* Even if major drug trafficker organizations received one half of the transit-zone trafficker's profits, they would get only 5 per cent of total revenues. By comparison, the aggregate of all transit-zone traffickers receive more than 5 per cent of total revenues and are much more diversified than the major drug trafficker organizations. Therefore, additional counter-cocaine dollars spent to deter source-zone farmers or major drug trafficker organizations should cause more damage to the entire distribution system than comparable investments at other steps. Even without causing strategic collapse, increasing the source-zone trafficker costs relative to their low prices should drive up street prices by a comparable percentage, thereby pricing many users out of the market.

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*Since 12 per cent of the flow is lost at each step, the actual rate of return on sales is 2.5 x 0.88 = 2.20 for each trafficking step. Ignoring source-zone and transit-zone consumption of 8.6 per cent of total flow, the total revenues from all trafficking is the street price minus at-farm-gate costs: $2.2^5 - 0.5 = 51$, where the 0.5 is the farmers' costs. Farmer revenues are 0.5 and major drug trafficker organization revenues are 2.2 - 1.0 = 1.2. Similarly, transit-zone traffickers' revenues are $2.2^2 - 2.2 = 2.6$.

The early history of the cocaine business in Peru illustrates the economic vulnerability of growers and those collecting and selling to major drug trafficker organizations. From 1980-1990, production caught up with demand, purity rose from 40-80 per cent on United States streets and real prices fell by a factor of six in both Peru and the United States. This price crunch was not shared equally by all traffickers along the distribution chain; rather, two Peruvian middlemen between the farmer and a major smuggler were squeezed out. This means that *(a)* those at the bottom of the distribution chain are the most vulnerable and *(b)* the mark-up of 2.5 in price is sustained by all surviving traffickers even as others are squeezed out of business. The vulnerability of those at the bottom is underscored by the market reaction during Operation Support Justice IV in Peru: full production continued unabated, but the extra cost of increased smuggler pilot fees came out of growers' profits. With these findings, the reactions to an effective crop eradication programme causing large persistent supply shortages can be predicted. According to the price-quantity relationship, shortages cause a serious drop in the street purity of cocaine, a significant rise in prices and, eventually, users defect to other drugs or quit altogether. With fewer users, there is less need for trafficking, yet the business model implies major drug trafficker organization transaction quantities remain unchanged at the top of the price-quantity relationship. Hence some major drug trafficker organizations would be squeezed out and law enforcement would have fewer major drug trafficker organizations to pursue.

Strategic supply-control efforts focused on the source zone could inflict much more than incremental damage on the cocaine business. Severing the air bridge between Peru and Colombia caused a collapse across the entire Peruvian cocaine business by reducing cultivation to only 18 per cent above pre-epidemic levels. Similarly, the forced eradication in the Chapare region of Bolivia reduced cultivation there to 12 per cent of its peak production. These effective supply-control efforts illustrate that a focus on source-zone vulnerabilities can cause a collapse and sustain much diminished trafficking through a combination of eradication and deterrence of major traffickers.

Supply-control strategies

Some of the options for directing supply-control efforts to exploit these source-zone vulnerabilities are given below:

(a) The coca eradication campaign should be continued and strengthened because, among other things, it costs law enforcement only half as much to spray a hectare as it costs growers to replace the crop, and coca growers have the least resources of anyone in the cocaine business. Since the coca crop is visible and impractical to disperse,* intense eradication could rapidly undermine

*Although coca grows throughout large portions of the Amazon basin, only 10 per cent or less of the land that could support coca is cultivated and 50 per cent of all production comes from only 9 per cent of this 10 per cent. Infrastructure constraints force crop concentration and, in unpublished work, the present researchers estimated that production costs would increase as the inverse of the square root of the density; for example, reducing the density to one quarter of its present level would double costs.

the major revenue source supporting lawlessness and ongoing environmental damage in Colombia [5]. If successful, there should be preparations for humanitarian assistance to some indigenous growers, as well as relocation assistance to the excess population in growing areas, who were attracted there by the boomtown profits of the past;

(b) Coca cultivation should be forced towards the interior of Colombia to increase the costs of transporting essential supplies and chemicals and of maintaining the illicit economy in a remote area and to create opportunities to intercept the transport of illegal fuel and chemicals for coca processing. As a result of previous successful blockades of transportation, such as the Peruvian air-bridge-denial operations and effective manual eradication in Bolivia, 88 per cent of the coca cultivation in excess of 1970 levels is now grown in Colombia;

(c) The leverage offered by the psychology of deterrence should be exercised against a limited number of major drug trafficker organizations [5, 7, 9]. Arresting the leaders and principal members of only 9 per cent of the major drug trafficker organizations (one to three organizations) each year and extraditing them to the United States should have a deterrent effect equivalent to the threat of lethal force and cause 80 per cent to quit;

(d) Raiding cocaine hydrochloride laboratories, intercepting cocaine or essential chemical movements within Colombia or intercepting boats leaving Colombia would require a very much greater effort to deter others and have a strategic effect and might not be practical [7]. However, technological breakthroughs in the ability to detect laboratories, material movements, or go-fast boats could facilitate a strategic breakthrough. Nonetheless, these actions are valuable tactical efforts in supply-control;

(e) Three additional actions would enhance deterrence effects: (i) increasing the level of distrust within and among trafficker organizations by employing informants and other intelligence-gathering methods to exploit traffickers' greatest fear; (ii) working to build trustworthy governments, justice systems, police and military organizations in source-zone and transit-zone countries to encourage cooperation from all those wishing to escape from fear and coercion, while ensuring certain justice for arrested traffickers; (iii) being persistent, so that traffickers no longer believe they can wait out the counter-drug commitment to achieving and sustaining a strategic effect;

(f) Surge operations should be employed to enhance the impact of limited forces (see the following section).

Limits to drug business adaptability

Evidence has been presented above arguing that most traffickers' business models are trapped by the price-quantity relationship. Also, lack of trust causes trafficker organizations to remain small, while their leaders limit the information available to most subordinates to thwart their ambitions of taking over. These features limit the flexibility and adaptability of individual trafficker

organizations. The adaptability of the cocaine business as a whole is that of the anthill: when a few are lost, others take their place. Furthermore, it takes time to replace an organization after most of its members have been arrested and this creates a law enforcement opportunity to conduct surge operations.

A surge strategy consists of focusing overwhelming pressure on one area until those traffickers are put out of business or forced into a risky move to a new method or location. It is probably impractical for trafficker groups to simply close down for a few months in response to focused law enforcement pressure because they must continually turn over capital rapidly, pay suppliers, avoid competition, pay corrupt officials for protection and so forth. For example, after the effective interception of western Caribbean go-fast-boat lanes, the major smuggling organization operating those lanes immediately attempted to relocate to the Pacific coast, but the police exploited the forced change and were able to arrest the principals. In this case, the smuggling connections took more than a year to reconstitute, providing law enforcement an opportunity to focus elsewhere. Another surge operation, Operation Frontier Shield, was directed against trafficking into Puerto Rico. It quickly deterred much of the go-fast-boat smuggling and levels have remained lower to this day [9]. In preparation for a surge, law enforcement needs to monitor trafficker operations to identify the typical delays between successive trafficking events or any seasonal pattern or characteristic, thus enabling the interception surge to cause the most damage and to sustain the pressure until the traffickers are forced to react.

Measures of effectiveness for counter-drug efforts

The degree of effectiveness of counter-drug efforts should be gauged by the degree of damage inflicted on traffickers' businesses either locally or throughout the entire distribution chain. The principal quantification of risk from the traffickers' perspective is the price mark-up per pure gram necessary to stay in business. For example, Peruvian cocaine-base prices plunged below break-even levels after the implementation of the force-down or shoot-down interception policy for flights over the air bridge to Colombia. Such a drop is clear evidence of damage to the cocaine business and four years later it was found that the excess coca cultivation beyond historical levels in Peru had dropped by 80 per cent. Often, the real price mark-up is expressed as a significant drop in purity because traffickers cover their shortages by adulterating the higher grade product. Street purity may be the best estimate of shortage because it varies more than price during supply shortages. Countries therefore need to collect and report on the purity and transaction quantity associated with drug prices at each trafficking level.

A common indicator of supply-control effectiveness is the seizure rate. Unfortunately, long-term growth in seizures by themselves typically indicate more trafficking rather than less narcotic being delivered [8]. In the short term, the seizure rate is difficult to measure accurately because traffickers hide the true volume of traffic, which is in the denominator of the ratio. Nonetheless, approximate estimates might be sufficient to check consistency with observed price

mark-ups, since a 10-15 per cent seizure rate should be associated with a 2.5 mark-up. Significant and rapid changes in seizure rates should induce corresponding increases in price mark-ups or cause observable changes to trafficking practices. Very high seizure rates and associated arrests are likely to deter traffickers from continuing, hence seizures can begin to fall although trafficking is being damaged. This happened after the implementation of the force-down or shoot-down policy: traffic plunged as did coca prices, but a one-month relaxation of interception pressure enabled trafficking and prices to recover sharply and interception was quickly reinstated [5]. Since seizures are a poor indicator by themselves, a better measure would be arrest rates, along with the consequences of arrest, because arrests are much more likely to deter traffickers [5, 7]. Below a deterrence threshold, traffickers ignore risks, but above this threshold deterrence can cause four to eight times as many to quit as are arrested [5, 9].

Other measures might provide early warning of traffickers gaining advantage over law enforcement: for example, the willingness of major traffickers in Colombia and Mexico after 11 September 2001 to cooperatively assemble large 10-metric-ton-plus loads for smugglers indicated growing horizontal integration resulting from reduced law enforcement pressure. Similarly, the greater number of customers per marijuana dealer compared to cocaine, or cocaine compared to heroin, indicates relatively greater law enforcement effort for the latter drugs.

Some indicators directly measure the defection of users from cocaine abuse. The SBCL/Quest positive test rate data did this on a monthly basis and quickly revealed significant changes among the mostly casual users. The DAWN data clearly reveal the impact of effective supply-control operations; however, the systematic rise in hospital emergencies while abuse rates have been declining calls for a clear interpretation. Unfortunately, these measures at the street-use level lag four to five months behind the initiation of operations in the source zone. Their principal value is to verify the strategic impact and calibrate more local measures.

A common analytical framework for counter-drug strategies

These models and associated methods offer a set of working hypotheses for characterizing the illicit narcotics business worldwide. These working hypotheses could assist researchers, the intelligence community, law enforcement and other counter-drug operational planners and policy makers who need a common analytical framework to measure, compare and express their specialized knowledge and interests. Such a framework facilitates cooperative counter-drug efforts at different steps along the distribution chain, as well as among different agencies and countries, who often have divergent goals and employ measures of performance that cannot be readily compared or related to one another.

To be effective, a common framework would have to be capable of addressing the variety of situations in drug trafficking and be empirically verifiable. The models and methods developed in the course of the present research provide

the beginnings of such a framework. Three models form the backbone of the framework: the generic model of trafficker organizations resulting from the simplifying constraints, the price-quantity relationship and associated multiplicative market price dynamics and the user function and associated validating measures of abuse. A complementary set of methods deals with the wide variation in trafficker and user behaviour and the fragmented data representing what is known about that behaviour. For example, taking medians or other percentiles of many sub-samples yields useful parameters for characterizing the long-tailed distributions of cocaine consumption or price normalized by purity. These parameters are always well defined, handle pathological cases (such as infinite price for zero purity), remain stable with the addition of more data and are well behaved when analysed by the familiar statistical analysis methods. Since price mark-ups are ratios, as are seizure rates and the breakdown of purchased quantities into those sold, such data are plotted on logarithmic scales. When a logarithmic variable is plotted against another, one might discover a scaling relationship such as that between normalized price and transaction quantity. While such plots suppress much detail and compress wide variations, they clarify underlying regularities that motivate and constrain the narcotics trade. Variations in these regularities can then take on significance and the structures they reveal point to vulnerabilities and consequences for traffickers. These structures can be empirically validated and relate the efforts of most counter-drug efforts all along the distribution path from farm gate to street. Finally, these patterns and structures can be related to the trafficker's perspective, especially considerations of risk, competition and lack of trust.

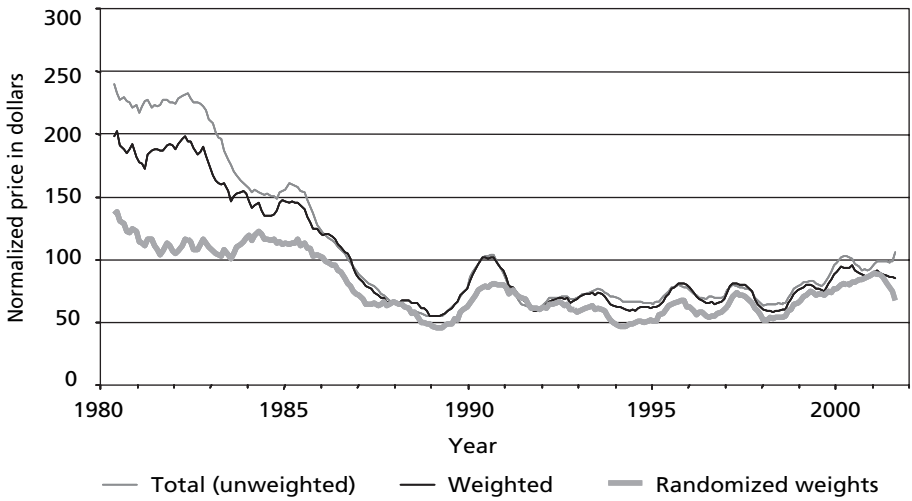
While specific information on trafficker activity tends to be very sensitive and often not shared by the originating agency or country, this framework implies that even consolidated listings or samplings of events described by a few key characteristics can be useful. Although the analytical methods and models used here do not substitute for detailed operational intelligence, they do provide a verifiable and dynamic map of the worldwide cocaine trade and possibly a modelling approach for other illicit narcotics of mass distribution. Such a map is useful in recognizing the strategic vulnerabilities of narcotics trafficking and should encourage broad-based public and political support for joint efforts, effective planning, sustained support and widely accepted measures of performance.

Annex A. Robustness of the normalized price index

As noted above, the STRIDE data collection process reflects local priorities and there is no effort to orchestrate a rigorously balanced statistical survey of all United States markets. Here the robustness of the STRIDE-derived normalized price index for cocaine is explored for purposes of identifying major data trends. The potential impact of applying standard statistical survey techniques in pursuit of precisely estimating, over time, the true national average price of street-level cocaine transactions is addressed.

As a simple illustrative exercise, figures A.I and A.II are considered. The pairs of thin-lined curves are identical in the two figures. Derived from STRIDE, the upper (lighter) curve depicts monthly median normalized cocaine prices, with each median computed across the entire United States. The lower (somewhat darker) curve, similarly based on STRIDE, also presents a monthly measure of United States normalized cocaine prices, calculated as a weighted average of the monthly medians associated with each state and Washington, D.C., with the weights matching the corresponding actual sampling frequencies that appear in STRIDE. Clearly, there is no practical difference between the pairs of curves.

Figure A.I. Alternative cocaine price index construction methodologies: random factors x prices and randomized weights



More rigorous methodologies, however, would argue that the Drug Enforcement Administration sampling is not representative of actual market purchase frequencies and seek to replace, at great time and expense, the implicit Drug Enforcement Administration weights by some measure of total cocaine consumption levels. Figure A.I addresses what the potential impact of such an approach would be, by considering the extreme case of arbitrarily random weights for each reporting jurisdiction in each month (that is, a random number between 0 and 1, properly normalized by the sum of all of the random numbers). One typical realization of this process is given by the thick (lowest) curve in figure A.I. It should be noted that there is some consistent deviation in the normalized price values, with the thick (lowest) curve generally taking on smaller numerical values. This ranking results because the randomly chosen weights tend to de-emphasize those states with relatively more Drug Enforcement Administration sampling, precisely the ones that generally have higher normalized prices. However, as far as fundamental trends and specific excursions in normalized price are concerned, the thick (lowest) curve captures these extremely well. If the focus is indeed on trends and features, the simple problem considered here indicates that it may not be cost-effective to attempt to obtain and incorporate excessively precise consumption figures into the analysis.

Figure A.II. Alternative cocaine price index construction methodologies: random factors x prices and "proportional" randomized weights

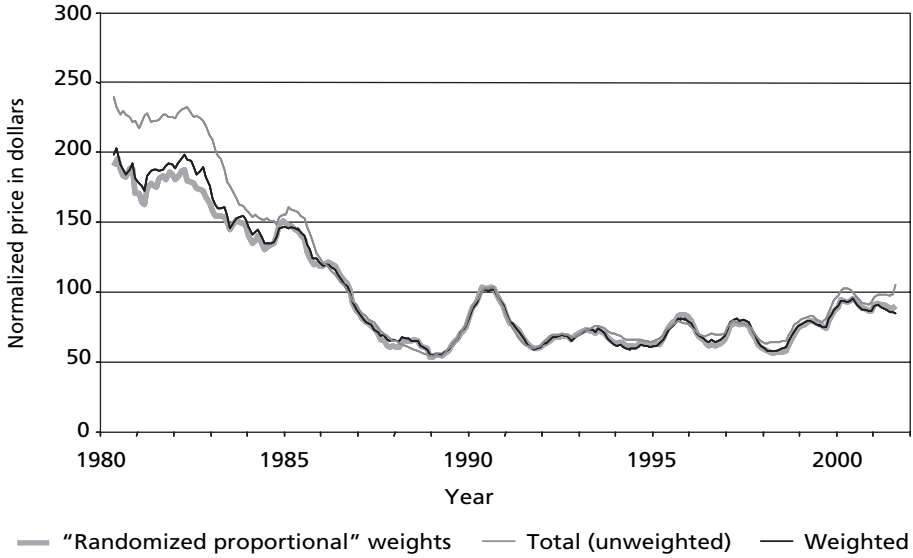


Figure A.II extends the simulation study by assuming that the Drug Enforcement Administration sampling frequencies are probably not too unrealistic, that is, they would naturally focus more on higher-consumption areas. Rather than using completely random weights, each reporting jurisdiction's weight is now computed by beginning with the Drug Enforcement Administration sampling count, multiplying by a random number between 0 and 1 and then normalizing all of these products accordingly. The particularly thick (lowest) curve shown in figure A.II is a typical realization of this process. It should be observed that it essentially matches the other curves, a result that further strengthens the conclusion of the preceding paragraph.

Finally, it was noted that an additional randomization had been applied to the determination of the thick (lowest) curves in figures A.I and A.II. Every STRIDE price was multiplied by a random factor, taking on values between 0.5 and 1.5. Thus, these figures also address the issue of how much effort should be devoted to collecting precisely representative cocaine prices. The robustness of the curves is consistent with the notion that substantive cocaine price and purity trends can be detected even when the available data do not conform perfectly with stratified sampling theory.

Annex B. Detecting trends: sample mean vs. sample median

For extremely heavy-tailed distributions lacking theoretical moments, typical of STRIDE normalized price data, the sample mean is extremely unstable (for example, it does not converge with increasing sample sizes) and is not an insightful measure of central tendency. Comparing individual sample means in an attempt to detect underlying population trends is a completely meaningless exercise. The wild variability of the sample

mean probably disguises trends, even when they are profound in actual magnitude and duration. However, the sample median is an insightful distributional characterization and a powerful tool for detecting trends.

These points are illustrated by the following simple simulation study. Let us assume that price data are sampled daily over a five-week period, with the underlying theoretical distribution of prices adhering to Pareto distributions with systematically changing medians: constant within any given day, but increasing by 10 per cent each day, that is, essentially doubling every week. Suppose that 33 data values are collected daily, generating a weekly sample of 231 points, along with an associated sample mean and sample median. The entire five-week sampling process is iterated repeatedly to obtain the following characterizations: *(a)* the probability that the weekly sample means or medians portray the proper ordering, that is, Week 1 < Week 2 < Week 3 < Week 4 < Week 5 and *(b)* the probability that the weekly sample means or medians have Week 1 < Week 5.

The sample means portray the proper five-week ordering with a probability of only 0.03, while the sample median figure is 0.98. Similar results hold for the second measure of performance. The sample means indicate Week 1 < Week 5 with a probability of 0.84, that is, one-sixth of the time the sample means reverse the ordering, even though the actual difference is a factor of $2^4 = 16$. The sample median, on the other hand, reflects the proper ordering essentially all of the time.

Annex C. Consumption and seizures by trafficking zone

Where appropriate, the amounts seized by country are aggregated into regions or zones, as indicated in table C.1. The columns of table C.1 parallel the steps for estimating consumption. Population from an atlas scaled by United Nations prevalence yields total users in thousands. Assuming that all users consume the same amount, total consumption can be expressed. Combined with seizures, this should balance total production. Given total production, it is possible to calculate the consumption per user that balances the flows.

For total production, the United States estimate of Colombian production also reported by the United Nations is adopted [6].* The rationale for this is to approximately compensate for two opposing adjustments: scaling downward for counting immature crops in the Colombian surveys and for inefficiencies plus traditional use in Peru and Bolivia versus scaling up for market purity, which is assumed to be about 80 per cent.** Since these upward and downward adjustments are of similar size, they approximately cancel each other out.

Cocaine seizure totals for Canada, Western Europe and the United States need to be adjusted because seizures of lower purity street-grade cocaine remove less from the flow than seizures of wholesale kilogram bricks. For Europe, it is assumed that one half of all seizures, two steps of four, are of street-grade cocaine and total seizures are adjusted downward from 44 to 39 metric tons. Similarly, for the United States, it is

*The joint Colombian and United Nations coca survey effort yielded a much larger estimate of production: 680 metric tons versus 520 for the United States coca survey. Without going into the details of the differences between the two surveys, choosing the lower estimate is justified because a large portion, between 30 and 40 per cent, of the Colombian crop must be immature as a result of the recent rapid expansion and replacement of eradication losses.

**Here, the United Nations estimate is taken rather than the STRIDE value for 2000 of 70 per cent.

assumed that two thirds of seizures are street-grade cocaine, which adjusts 134 metric tons down to 112. For source-zone and transit-zone countries, the amounts seized at the consumer level are considered trivial and are therefore ignored. This is justified because, in the source-zone and transit-zone countries and regions, seizures exceed consumption by factors of two to four. However, in consumer-zone countries, consumption exceeds seizures by large percentages.

Table C.1. Seizures and estimated consumption for countries, regions and zones

Country or region	*Population (Thousands)*	*Prevalence (Percentage)*	*Users (Thousands)*	*Consumed (Metric tons)*	*Seized (Metric tons)*	*Consumed (Metric tons*	*Seized (Metric tons)*
Source zones							
Colombia	42 300	1.2	508	13.0	63.9	13.0	63.9
Peru	25 700	1.0	257	6.6	11.3	6.6	11.3
Bolivia	8 300	0.7	58	1.5	7.7	1.5	7.7
Transit zones							
Central America	36 200	1.0	358	9.2	16.7	29.3	63.7
Mexico	98 900	0.5	495	12.7	34.6		
Venezuela	24 200	1.2	290	7.5	12.4		
Ecuador	12 600	1.5	189	4.9	10.6	10.9	22.7
Caribbean	25 620	0.9	236	6.1	12.1		
Consumer zones							
Brazil	170 100	0.8	1 361	34.9	7.6	65.0	12.1
Chile	15 200	2.1	319	8.2	2.9		
Argentina	37 000	2.3	851	21.8	1.6		
Africa	380 600	0.3	1 314	33.7	0.5	33.7	0.5
Western Europe	314 000	0.7	2 200	56.5	44.1	56.5	44.1
Adjusted seizures							39
Canada	30 200	0.7	211	5.4	1.7	216.3	134.0
United States	273 800	3.0	8 214	210.9	132.3		
Adjusted seizures							112
Total	1 494 720	1.1	16 861	432.8	360.0	432.8	332.2

Total seizures	332
Total consumption	433
Total production	765
Consumption per user per year	26 grams

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