DTIC FILE COPY

(4)

A RAND NOTE

AD-A198 338

The Interdictor's Lot: A Dynamic Model of the Market for Drug Smuggling Services

Jonathan A. K. Cave, Peter Reuter

February 1988

DTIC
ELECTE
SEP 0 8 1988
S D
D

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

40 Years 1948-1988

RAND

88 9 7 043

The research described in this report was sponsored by the Office of the Under Secretary of Defense for Policy under RAND's National Defense Research Institute, a Federally Funded Research and Development Center supported by the Office of the Secretary of Defense, Contract No. MDA903-85-C-0030.

The RAND Publication Series: The Report is the principal publication documenting and transmitting RAND's major research findings and final research results. The RAND Note reports other outputs of sponsored research for general distribution. Publications of The RAND Corporation do not necessarily reflect the opinions or policies of the sponsors of RAND research.

Published by The RAND Corporation
1700 Main Street, P.O. Box 2138, Santa Monica, CA 90406-2138

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
N-2632-USDP

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
The Interdictor's Lot: A Dynamic Model of the Market for Drug Smuggling Services

5. TYPE OF REPORT & PERIOD COVERED
Interim

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
Jonathan A.K. Cave, Peter Reuter

8. CONTRACT OR GRANT NUMBER(s)
MDA903-85-C-0148

9. PERFORMING ORGANIZATION NAME AND ADDRESS
The RAND Corporation
1700 Main Street
Santa Monica, CA 90406

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS
Assistant Secretary of Defense
Office, Under Secretary of Defense for Policy
Washington, DC 20301

12. REPORT DATE
February 1988

13. NUMBER OF PAGES
61

14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)

15. SECURITY CLASS. (of this report)
Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)
Approved for Public Release; Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)
No Restrictions

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Economic Models
Economic Analysis
Smuggling
Drugs
Narcotics
Interdictions
Law Enforcement

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

See reverse side

DD FORM 1 JAN 73 1473

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

This Note presents a stylized dynamic model of the market for drug smugglers' services. The model is based on the observation that experienced smugglers may benefit from learning by doing, although the information (and the resulting cost advantage) may be subject to obsolescence. The authors analyze the effects of several variables, including different law enforcement strategies on smugglers of varying degrees of experience, the degree of competitiveness in the supply of smugglers' services, and the conditions governing entry of novice smugglers. The theoretical analysis is supplemented by a Lotus-based simulation model, which is included with the Note, and illustrated by several numerical examples. (See also R-3594, N-2680.)

A RAND NOTE

N-2632-USDP

The Interdictor's Lot: A Dynamic Model of the Market for Drug Smuggling Services

Jonathan A. K. Cave, Peter Reuter

February 1988

Prepared for
The Office of the Under Secretary of Defense for Policy

DTIC COPY INSPECTED 1

Accesion For
NTIS CRA&I ☑
DTIC TAB ☐
Unannounced ☐
Justification
By
Distribution/
Availability Codes
Dist | Avail and/or Special
A-1

40 Years 1948-1988

RAND

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

PREFACE

Rising concern with drug use in the United States has led to increased emphasis on the interdiction of drugs before they reach this country. The military services are now being asked to assume a substantial share of the burden of this interdiction.

In light of this development, the Office of the Under Secretary of Defense for Policy requested that RAND analyze the consequences of further military involvement in drug interdiction efforts, particularly examining how this involvement might influence the consumption of cocaine and marijuana.

This Note has been prepared for the Office of the Under Secretary of Defense for Policy, by RAND's National Defense Research Institute, a Federally Funded Research and Development Center supported by the Office of the Secretary of Defense. It is a product of RAND's program in International Security and Defense Policy and should be of interest to researchers concerned with efforts to control drug smuggling and to economists interested in modeling market evolution where firms' costs fall with experience. The Note presents the technical statement of a model of the drug smuggling market, where smugglers' costs decline as they acquire experience about interdiction. Of related interest are:

- Peter Reuter, Gordon Crawford, and Jonathan Cave, *Sealing the Borders: The Effects of Increased Military Participation in Drug Interdiction,* R-3594-USDP, January 1988.
- Gordon Crawford and Peter Reuter, *Simulation of Adaptive Response: A Model of Drug Interdiction,* N-2680-USDP, February 1988.

SUMMARY

In recent years, increased interdiction efforts seem to have increased the pressure against the cocaine market. Quantities seized have risen sharply, as have arrests; prison terms have increased somewhat. Despite this, the import and retail prices of cocaine have fallen dramatically over the same period, and the quantity successfully imported has risen sharply. These observations motivate our study of the response of the drug smuggling market to interdiction and other forms of law enforcement activity.

Conventional static models of smuggling activity cannot reconcile these divergent observations. Increased interdiction raises the smugglers' expected costs, which leads to higher prices and diminished quantities. However, those models ignore the opportunities for "learning-by-doing" created by law enforcement activities. If learning is important, experienced smugglers will have lower expected costs than novices, immediately altering the behavior expected of the market. Prices will be higher than they were in the absence of law enforcement but will drift down over time if the active smugglers' collective experience increases. Success or failure of interdiction or other particular strategies must be measured in terms of this baseline price path.

Success should not be measured simply by the current price level. Although high current prices imply low current quantities, they may also signal high profits for experienced (low-cost) smugglers. These profits can induce entry, as novices will be willing to operate at a current loss to secure future profits.

The model developed here analyzes the evolution of the smugglers' market. Smugglers attempt to maximize the present value of future profits. Previous experience acts to lower current costs. Therefore, the adjusted marginal cost used to choose current quantity operation equals current marginal cost minus the amount by which current experience lowers future costs.

In discounting the past as well as the future, our model goes beyond the conventional "learning curve" treatment of experience. Because law enforcement activity is the source of learning, the lessons of experience may become obsolete. We represent experience as a weighted sum of previous activity levels, with the most weight placed on the most recent activity, allowing us to parametrically vary both the strength and the durability of learning effects.

The analysis considers several ways in which active and potential smugglers choose their activity levels.[1] In the purely competitive model, active smugglers take the future trajectory of prices as given and choose the quantity that equates current price and adjusted marginal cost. In the noncooperative model, active smugglers take the quantity decisions of others as given and equate adjusted marginal cost and current residual marginal revenue. Finally, we describe a cooperative model in which smugglers act together to maximize collective profit: Each smuggler operates at the point where adjusted marginal cost equals current total marginal revenue.

We also consider several entry conditions. Currently inactive smugglers may decide to enter if (a) current price exceeds their minimum average cost, (b) they can operate profitably in the face of the active smugglers' current total output, or (c) if the post-entry equilibrium offers them positive profits. Under condition (a) equilibrium may not exist. Under condition (b) equilibrium always exists, but there may be many equilibria. Under condition (c) there is usually a unique equilibrium.

We model law enforcement in several ways. Law enforcement strategies differ in their effects on smugglers of varying degrees of experience. Some activities increase the costs of all smugglers by the same amount. Others increase only the costs of active smugglers, or raise the costs of novice smugglers by more than those of experienced smugglers. Still other aspects of law enforcement activity (such as randomization) can reduce the strength and durability of learning.

---

[1]These differences could be incorporated into a single model with appropriate "conjectural variations."

The analysis proceeds in three steps. First, we examine the optimizing behavior of individual smugglers. We then consider the equilibrium corresponding to a given set of active smugglers and conclude by analyzing the pattern of entry and exit that determines which smugglers are active at each stage. All of these elements are essential to understanding the evolution of the market. Changes in law enforcement strategy that increase cost functions will reduce supplies by active smugglers. The consequent price increase will attract new entrants. It is only through a complete analysis that we can determine the long-term effect on price and quantity.

For individual smugglers, supply decreases as the smuggler becomes more myopic (as the interest rate rises). Similarly, increases in the strength or durability of learning increase levels of activity. Finally, increases in the importance of either the future or the past will lower the price at which a given smuggler exits from the market. Learning and farsightedness act together to increase supply, even when current operations are unprofitable. Smugglers will operate at a short-term loss to invest in experience.

For a given set of active smugglers, pure competition leads to the highest level of output and the lowest level of price. Next comes noncooperation, followed by cooperation or collusion. In the special case where smugglers are entirely myopic, equilibrium prices will necessarily fall over time. If smugglers care sufficiently about the future, this conclusion can be modified; but it is still reasonable to conclude that prices will tend to fall over time unless the law enforcement environment changes. This means that a successful policy may still lead to falling prices.

When entry and exit are taken into account, the policy implications become clearer. Because law enforcement activity is the primary source of learning effects, changes in policy may increase or decrease active smugglers' costs and alter their distribution of current costs, affecting the evolution of experience across the market. Measuring the success of a policy depends on evaluating the tradeoff between current quantity restriction (as measured by high prices) and long-term entry

deterrence (as measured by low profits). Changes in the law enforcement environment may induce changes in market concentration that further alter the pattern of prices.

Interdiction may stabilize a "cartel" of experienced producers. If the burden of interdiction falls most heavily on novices, experienced smugglers will earn high levels of pure profit. The experienced group is protected from entry, because law enforcement reduces both the number of surviving novices and the rate at which any novice acquires experience. The large profits earned by the "cartel" will attract a continual flow of new novices.

If the flow of novices dried up, law enforcement pressure on experienced smugglers would increase, leading to falling prices and a sharp reduction in profits. Alternatively, if the burden of law enforcement were distributed more evenly, more novices would accumulate significant experience. Whether the experienced group is purely competitive, noncooperative, or overtly collusive, such expansion would diminish each member's profits.

In principle, the model allows us to distinguish between different types of law enforcement activity. In the theoretical development, we show that prices may be almost completely insensitive to certain types of policies that heavily influence profits, and *vice versa*. For example, consider a policy that removes an experienced active smuggler. One can show that removal always reduces total profits; but it is unlikely to affect price, if less-experienced smugglers are active. The greater the experience of the removed smuggler, the greater the effect on profits and the smaller the influence on prices. A policy that increases the costs of the least-experienced smuggler may even (in some circumstances) cause a fall in price, which can slow market expansion.

The simulation results point up some additional conclusions. A policy that increases costs across the board may raise or lower the future path of prices, or may even trigger fluctuations. The ranking of different policies may be highly sensitive to the degree of cooperation among active smugglers and to such empirical questions as the shape of the demand curve. For instance, with a linear demand curve, the best policies concentrate on experienced smugglers and encourage the entry of

novices. If the demand curve is exponential (e.g., isoelastic), however, policies that concentrate on discouraging entry of novices obtain more substantial and sustained results. Finally, policies that encourage competition by reducing the durability of learning work better when elasticity is highly variable (linear demand).

ACKNOWLEDGMENTS

The study was inspired by a conjecture of Mark Kleiman of Harvard University. The authors wish to thank Herman Quirmbach of the University of Southern California for his careful reading of the manuscript and generous comments. They would also like to acknowledge the comments of Stephen Salant of the University of Michigan and RAND colleagues Arthur Alexander, James Hosek, and Emmett Keeler. Responsibility for any errors remains with the authors.

CONTENTS

PREFACE iii

SUMMARY v

ACKNOWLEDGMENTS xi

FIGURES xv

TABLES xv

Section

I. INTRODUCTION 1

II. CONCEPTUAL FOUNDATIONS 2
- Costs and Experience 2
- Market Structure and Dynamics 7
- Law Enforcement Objectives 11

III. THE MODEL 13
- General Remarks 13
- Individual Quantity Decisions 13
- Market Clearing and Entry 19
- Dynamic Behavior of Price-taking Equilibrium 25
- The Effects of Law Enforcement 30

IV. COMPUTER SIMULATION 37
- Mathematical Structure of the Model 37
- Simulation Results 38

Appendix: USER'S GUIDE TO THE COMPUTER MODEL 53

REFERENCES 61

FIGURES

1. Comparison of profit-maximizing conditions 20
2. Falling costs may not mean falling prices 22
3. Market supply 23
4. Supply and experience 26
5. Dynamic evolution of price and quantity 30
6. Effect of cost increase 35
7. Baseline quantity and price trajectories 40
8. Difference between competition and Nash equilibrium 41
9. Policy effects on quantity--linear quantity-taking model 42
10. Policy effects on quantity--linear price-taking model 43
11. Policy effects on quantity--exponential quantity-taking model 44
12. Policy effects on quantity--exponential price-taking model 45
13. Menus in Model A 55

TABLES

1. Comparison of Legal and Illegal Markets 12
2. Simulated Policies 39
3. Total Quantity Trajectory: Linear Demand Price-taking Model 49
4. Total Quantity Trajectory: Linear Demand Quantity-taking Model 49
5. Price Trajectory: Linear Price-taking Model 50
6. Price Trajectory: Linear Quantity-taking Model 50
7. Total Quantity Trajectory: Exponential Price-taking Model 51
8. Total Quantity Trajectory: Exponential Quantity-taking Model 51
9. Price Trajectory: Exponential Price-taking Model 52
10. Price Trajectory: Exponential Quantity-taking Model 52
11. Description of Top-level Menu Choices 56
12. Description of Econ Menu Choices 57
13. Description of Policy Menu Choices 58
14. Description of Display Menu Choices 59

I. INTRODUCTION

This Note discusses the smuggling of drugs into the United States for domestic consumption. The few previous analyses of this issue (e.g., Reuter and Kleinman, 1986) have assumed that the drug import market can be viewed in terms of static equilibrium. That assumption is likely to bias the results for at least three reasons. First, demand and supply are likely to shift over time in ways that reflect past experience. Second, large-scale smugglers are undoubtedly aware of this and plan their activities with an eye to future as well as present profits. Finally, any analysis of the effects of law enforcement activities should consider both the immediate and long-term effects of such activities on prices and quantities. The analysis presented here examines dynamic effects and is designed to shed light on the role of such law enforcement strategies as interdiction and incarceration in determining the quantities imported and the import prices.

The first section describes the underlying assumptions and the conceptual framework, and summarizes the major results. Subsequent sections develop the formal analysis for various assumptions about the nature of the supply market and the degree to which smugglers take the future into account. This theoretical development is complemented by a computer simulation model designed to illustrate the possibilities highlighted by the formal model.

II. CONCEPTUAL FOUNDATIONS

COSTS AND EXPERIENCE

Our analysis assumes that smugglers are differentiated by experience. We base the assumption on intuition, a reading of accounts of smuggling operations (Warner, 1986) and some interviews with smugglers of varying levels of experience. Increasing experience lowers smuggler's cost of delivering particular quantities to market. This effect is summarized in the individual *cost function*:

$C_t(q:x)$; where (1)

q is current (expected in period t) delivery to market; and

$x = (x_0,\ldots,x_{t-1})$ is experience (shipments and deliveries in all previous periods).

$C_t(0:0,\ldots,0) \equiv 0$; this says that a smuggler can always incur 0 cost by remaining inactive.

We assume that all novices (active or potential smugglers with no experience) have the same cost curve at any moment. Experience lowers costs through learning-by-doing and through the creation of implicit long-term contracts.[1] We assume that the smuggler treats law enforcement as enforcement as a direct source of higher costs, whether such costs reflect:

- The value of seized shipments,
- The loss of experienced agents,
- Legal and time costs associated with criminal trials and incarceration,

[1]If law enforcement activity successfully targets experienced smugglers, costs may increase with experience, reversing the usual "learning curve" effect. For reasons given below, we doubt that characterization of drug interdiction efforts.

- Costs associated with seeking and using "safe" routes for smuggling drugs,
- Costs associated with continual changes of route, or
- Deviations from previous delivery levels that inconvenience customers or suppliers (or both), and thus expose the smuggler to increased probabilities of detection, interception, and betrayal.[2]

Experience may not be adequately represented by any single variable. Some cost savings reflect past shipments (including those lost), and others reflect the smuggler's history of successful deliveries. Normally, neither shipments nor deliveries can be observed, so data limitations do not guide the choice of variable. We assume that smugglers form expectations about the risks they face, so that the choice between shipments or expected throughput (deliveries) as a current decision variable does not limit the generality of the model.[3]

The model presented below uses delivered quantities both as a decision variable and as the basic measure of experience. There are several reasons for this choice: (1) a large portion[4] of the smuggler's supply cost is contingent on successful delivery; (2) market prices reflect successful deliveries; and (3) although seizures may improve both smugglers' and law enforcement officials' information, successful deliveries are more likely to unambiguously reduce smugglers' expected future costs. However, this is not an essential feature of the model at the present level of generality.

---

[2]Experienced smugglers may reduce costs through the creation of extensive "networks" of suppliers and customers. Therefore, adjustment costs, which increase with the number of people affected by changes in shipment rate, may increase with experience.

[3]In other words, the entire model could be recast in terms of experience without affecting the qualitative results.

[4]A common contract between suppliers and smugglers calls for the smuggler to pay the supplier 20 percent of the price when the drugs are transferred to him and the balance upon successful delivery.

Single-number measures of experience, such as cumulative deliveries [$X_t = x_0 + \ldots + x_{t-1}$] or the previous period's delivery [x_{t-1}] can serve as proxies for detailed experience histories but may obscure important elements of the influence of experience on costs. This limits the applicability of the conventional learning curve model.

We suggest three reasons why the cumulative deliveries variable (X_t) fails as a measure of experience. First, long experience at low levels may be more valuable than brief experiences with large-scale operations, even if cumulative throughput is the same. Second, to the extent that cost savings reflect either learning about law enforcement practices or the development and maintenance of a reputation for reliability, recent experience may count more heavily than past experience. Finally, cost-reducing information may be specific to a given rate of flow, so that experience with small quantities is not readily transferable to large-scale operations and vice versa.

The previous period's delivered quantity variable (x_{t-1}) suffers from some of the same drawbacks. It cannot distinguish length of experience. Learning and reputation effects may require more than one period to fully manifest themselves. In addition, last period's delivered quantity might be a deviation from a historical trend.[5] Although this measure provides some information on the scale of a smuggler's operation, it says nothing about the depth of his experience with operations of this size. It also completely ignores the smuggler's experience with other scales of operation, which may provide an important indication of flexibility.

A better one-dimensional measure of experience as it relates to costs is a discounted sum of previous deliveries that places greater weight on more recent experience:

---

[5]This motivates the use of expected levels for current throughput in the cost function rather than an explicitly stochastic model of the relation between shipments and deliveries. Such a model is conceptually more satisfactory but is necessarily far more complex. It also depends heavily on assumptions about the distribution of risk over time that are impossible to verify from existing data. The current model should be viewed as a qualitatively accurate proxy for a more detailed presentation.

$$E(t:\delta,x) = \sum_{s=0}^{t-1} \delta^{t-s} x_s \ , \tag{2}$$

where δ is a discount factor representing (inversely) the obsolescence of information gleaned from experience. As written, $\delta = 0$ represents a situation in which experience is unimportant [$E(t:0,x) = 0$ for all t], and $\delta = 1$ represents the cumulative deliveries measure [$E(t:1,x) = X_t$]. A related measure is $F(t:\delta,x) \equiv E(t:\delta,x)/\delta$, which varies from $F(t:0,x) = x_{t-1}$ to $F(t:1,x) = X_t$. The value of δ reflects changes in the law enforcement environment, among other things.

Experience acquired by one smuggler may affect the perceived cost functions of others. One smuggler's operations may affect conditions of supply and demand. New fields may be planted, officials may be corrupted, and more resources devoted to smuggling. The economic benefits of these adaptations cannot easily be confined to a single smuggler and will diffuse through the operation of market forces, gradually lowering the resource prices that determine other smugglers' costs.

Safe routes for shipment of drugs may be subject to congestion externalities. The short- and long-run directions of these externalities may be different. If route A, say, has more smuggler activity than available law enforcement resources can deal with, increases in one smuggler's current activity may reduce risks faced by others using route A. In the long run, this increase in activity is likely to attract law enforcement resources toward route A and away from other routes. Another smuggler using route A will notice increasing law enforcement pressure, and smugglers using other routes may notice a reduction in risk. Thus the local externality is cost reducing for current activity and cost increasing for experience (past activity). The "spillover" externality between route A and other routes is cost reducing for experience. The net effect on smugglers' cost functions will depend on their ability to respond to changing patterns of law enforcement pressure with changes in route, method, etc.

Information about safe routes, like other commercially valuable information, is subject to "free rider" problems. The extent of information transfer depends on both how well it can be kept secret and the effect of one person's use of information on its value to another. If information can be inferred from observation or is "embodied" in the smuggler's experienced agents, it may be impossible to prevent others from acquiring information through "research" or bidding for the services of knowledgeable agents. Secondary markets for information may not be viable. Moreover, the value of information to different people is strongly interdependent, so that it may be extremely difficult to sell information for its "true" value.[6] Law enforcement strategies that encourage smugglers to provide information about each other's operations to officials may be instrumental in slowing the dissemination of information about ways to reduce the risk of capture.

Finally, resources used jointly by successful smugglers (corrupt officials, "mules," pilots and ship owners, etc.) may be sufficiently scarce that they are not supplied competitively. This strengthens the linkage between the previous activities of one smuggler and the current costs of another.

One special feature of these "market failures" is that routes etc. must be constantly varied to avoid detection. Risk reduction attendant on accumulated experience may take the form of a compromise between risks associated with known routes, methods of operation, and individuals and those associated with unknown new alternatives. Similar problems of risk-balancing arise as a consequence of strategic choices that involve large numbers of people.[7]

---

[6]Thus weakening the incentive to collect such information, leading to "underprovision" (from the smugglers' point of view).

[7] This depends on the drug in question. Marijuana shipments cannot be increased in size without involving more people. Throughput of drugs with high profit margins per unit size, such as heroin or cocaine, can be increased without greatly expanding the number of people involved either as agents or as customers of the smuggler.

These features can be incorporated into the model, but only at the cost of considerably increased complexity. In this Note, they are largely ignored. We simply assume that experience lowers unit costs.

MARKET STRUCTURE AND DYNAMICS

At any moment, there is a distribution of experience levels (cost functions) among potential smugglers resulting in a distribution of current delivery levels, which gives rise to a market-clearing price and quantity. The next period begins with a different distribution of experience. The model elaborated below discusses the implications of this dynamic process for the evolution of market outcomes. The results vary according to the way active smugglers arrive at quantity decisions, the criteria by which potential smugglers decide whether to enter the market, and how law enforcement affects the evolution of experience.

Each smuggler has one of two notional marginal cost schedules:

- A *myopic* schedule MC, which measures current marginal cost, or
- A *farsighted* schedule AMC, which includes an adjustment for the effect of current q on future costs.

The farsighted marginal cost schedule must take account of future quantity decisions. Future costs are discounted at a risk-adjusted rate; inexperienced smugglers will therefore discount the future at a generally steeper rate than experienced smugglers.[8]

Smugglers may entertain different views of their strategic interaction:

- *Pure competitors* (price-takers) take prices as given,
- *Noncooperative competitors* (quantity-takers) take the quantity decisions of other smugglers as given, and

[8]This discount factor, ρ, is conceptually distinct from the "obsolescence factor," δ, applied to past experience, although they are related through the market model.

- *Cooperative competitors* take the (long-term) strategies of other smugglers as given--in our model, they act as a cooperative cartel.

There is no reason for all smugglers to take the same view. A smuggler's interpretation of the current distribution of experience may reflect his own: it is more likely to find farsightedness, and noncooperative and cooperative competition in experienced than in inexperienced smugglers. Existing theoretical models of learning-by-doing generally take the learning curve as exogenous and limit themselves to a more-or-less competitive environment.[9] We know of no model that integrates experience and "solution concept." The only models that allow heterogenous points of view are:

- Stackelberg equilibrium models of oligopoly, in which one smuggler acts as a (special case of a) cooperative competitor and the others act as noncooperative competitors;
- Price leadership models in which a few smugglers (or a cartel) act as noncooperative (cooperative) competitors and the other smugglers act as pure competitors; and
- Reputation models, in which smugglers have dispersed expectations about other smugglers' behavior and behave as noncooperative competitors. These may be reinterpreted in terms of our analysis by representing information in terms of other smugglers' presumed strategies.[10]

However active smugglers view their interaction, they are constrained by the entry decisions of potential rivals. Such inactive

---

[9]Exceptions include recent papers by Spence (1981), Fudenberg and Tirole (1983), and Mookherjee and Ray (1986).

[10]A discussion of this interpretation can be found in Haltiwanger and Waldman (1986). They consider a world in which individuals may be described as "responders" or "nonresponders" according to whether they react strategically to the choices of others.

smugglers may be novices or they may be experienced smugglers who find operation currently unprofitable. The decision to begin or resume production may be:

- *Price-taking:* all potential smugglers whose minimum average cost is below the current market price will become active,
- *Quantity-taking:* the potential entrant takes the current quantity decision of active smugglers as given and enters if the residual demand curve allows profitable operation, or
- *Sophisticated:* the potential entrant decides whether to enter on the basis of profits earned in the post-entry equilibrium.

The strategic choices of a given set of active smugglers determine the associated quantity and price. Entry conditions such as those described above determine both the existence and the uniqueness of equilibrium active sets.

The formal model partitions the set of active smugglers into three subsets: price-takers, quantity-takers, and a cartel.[11] The computer simulation considers pure cases corresponding to each model of the quantity determination process. All active smugglers share the same strategic outlook, and all potential entrants use the same entry criterion.

Law enforcement activities affect the evolution of experience in various ways. The seizure of drugs can inform smugglers about law enforcement strategies. The loss of agents may reduce the smuggler's store of experiential capital, some (indeed all) of which may be held by agents. Incarceration of smugglers (as distinct from their agents) can also directly censor the distribution of experience.

Interdiction has further indirect effects on prices and quantities. Higher seizure rates increase risks and in some circumstances may reduce optimal throughput for all individual smugglers. We assume that more experienced people's optimal throughput per unit time is larger; this does not necessarily mean larger loads. For the most part, we assume

[11]The "competitive fringe," the "noncooperative body," and the "cartelized core."

that greater interdiction affects inexperienced smugglers most sharply, thus increasing the cost advantage of experienced smugglers.[12] The effects on market price depend on the distribution of experience and on the market structure. Below we illustrate the major results.

In a world of myopic pure competitors, price is set by the intersection of the current demand curve (itself a function of the customers' experience) and market supply, which is the horizontal sum of marginal cost curves (above minimum average or variable cost), adjusted for changes in factor prices[13] and free entry at the (inexperienced) margin. Free price-taking entry makes the supply curve horizontal at the minimum average cost of novice smugglers (c^*). With few experienced smugglers relative to the total and a large pool of potential entrants, market price will equal c^*, and increases in interdiction will only affect price to the extent that they increase c^*--for example, by raising inexperienced smugglers' perceptions of the risks of participation. More experienced smugglers earn pure profits (Ricardian rents).

If there are few experienced smugglers and a small fringe of potential entrants, increased interdiction may eliminate or greatly restrict the horizontal portion of the supply curve, thus increasing prices.

With a large pool of experienced smugglers, demand and supply may intersect below c^*. In that case the market is serviced only by the relatively experienced, and interdiction will affect price to the extent that it shifts the cost curves of these participants. As the effects of interdiction on cost may differ with the experience of those affected, the nature of the marginal participant may strongly influence predictions of policy effects.

---

[12]The model is more flexible than this suggests, allowing any pattern of correlation between experience and law enforcement pressure.

[13]The factor price adjustment reflects the fact that individual smugglers treat input prices as fixed when computing their marginal costs. If all smugglers change the scale of their operations at once, input prices will change and marginal costs will be different. As long as supply curves for inputs are rising, this adjustment will make market supply less elastic.

Consider a law enforcement strategy such as technical interdiction, which falls disproportionately on the low end of the experience distribution. Over time, it will retard entry into the group of more-experienced smugglers. In the normal course of events, such expansion would reduce both market price and profits of experienced smugglers. Therefore, as long as price remains high enough to attract a steady stream of entrants, the experienced group may actually benefit from law enforcement activity.[14]

Interdiction strengthens incentives for experienced smugglers to cooperate in keeping prices high. Their individual profits are higher in the short term. Moreover, fewer novices survive to acquire much experience, slowing long-term expansion of the implicit cartel, which reduces collective profit. Indeed, if the pool of experienced smugglers were to expand, the resulting decline in price would choke off the flow of new entrants and sharpen the pressure of law enforcement activity on the experienced group. This suggests that law enforcement may stabilize or enhance cartelization of the experienced smugglers.

LAW ENFORCEMENT OBJECTIVES

In conventional market structure analysis, efficiency is desirable and deadweight loss is to be avoided. Intervention in "failed" markets for legal products is generally limited to the supply side, and is guided by the principle that greater consumption is always good up to the point where marginal (social) benefit equals marginal (social) cost. Success is measured directly by total surplus and indirectly by quantity consumed. Profits are important only for distributional reasons, or as indirect evidence of deadweight loss.

In markets for illegal goods, the collective interest is generally identified with quantity abatement. Profits earned by experienced smugglers are also considered harmful, because they encourage rent-seeking entry, which at best wastes resources and at worst increases

[14] That is, their profits may be higher than in the absence of interdiction, even when adjusted for increased risk to themselves, as long as inexperienced smugglers bear the brunt of interdiction efforts.

consumption. Intervention may be directed toward the demand side, although it is unclear whether this is cost effective. Total surplus is unimportant. Table 1 summarizes these static comparisons.

Dynamic welfare analysis is also different. Analysis of legal markets begins with consumer sovereignty and favors increases in demand and supply over time. Analysis of illegal markets reverses these presumptions.

Table 1

COMPARISON OF LEGAL AND ILLEGAL MARKETS

	Value	
Increase in	Legal	Illegal
Quantity	good	bad
Price (> MC)	bad	good
Deadweight loss	bad	good
Consumer surplus	good	neutral
Producer surplus	good	bad
Total surplus	good	neutral

III. THE MODEL

GENERAL REMARKS

The model developed here rests on four elements: (1) strategic interaction between active smugglers, which determines individual quantities; (2) market clearing, which determines current price; (3) entry, which determines the number and identities of active smugglers; and (4) learning, which determines the evolution of costs over time. Law enforcement will be modelled as part of the learning process, as outlined above.

INDIVIDUAL QUANTITY DECISIONS

We limit strategic choice by individual smugglers to amounts delivered to market. Actual decisions involve quantity shipped rather than amount delivered, but given smugglers' rational expectations, the two variables are simple monotone transformations of each other. Market prices, profits, etc. are modelled in terms of delivered quantities, and this choice avoids a confusing proliferation of nomenclature.

A *quantity trajectory* q is an array of amounts q_{it} delivered by smuggler i at date t. Inactive smugglers are represented by $q_{it} = 0$. Given a quantity trajectory q, the present value of smuggler i's future profits from date t onward can be written:

$$\pi_{it}(q) = \sum_{s=t}^{T} \rho^{t-s}\{P(\sum_{j=1}^{n} q_{js})q_{is} - C(q_{is}:q_{i0},\ldots,q_{is-1})\} , \qquad (3)$$

where P(Q) is the inverse demand function, and ρ is the discount factor applied to future profits. Associated with any quantity trajectory are sequences P_t, Q_t, and π_{it} of market-clearing prices, total delivered quantities, and individual profits, respectively.[1]

[1]We shall use the term "trajectory" indiscriminately to refer to any of the outcomes associated with a quantity trajectory.

A trajectory is an *internal equilibrium* if each smuggler i active at date t picks q_{it} to maximize π_{it}, subject to some assumptions.

The trajectory is an *external equilibrium* if the maximum profit π_{jt} expected under certain assumptions by any smuggler j inactive at date t is nonpositive, and if the profit π_{it} earned by any active smuggler i is nonnegative.

An internal and external equilibrium is an *equilibrium* trajectory $q^* = (q^*_1,\ldots,q^*_n)$. We consider three ways for q^*_i to be chosen:

1 *Price-taking:* to maximize π_{it} subject to the fixed sequence P^*_t of prices

2 *Quantity-taking:* to maximize π_{it} subject to the fixed sequence Q^*_{-it} of amounts supplied by all other smugglers:

$$\sum_{j \neq i} q^*_{jt} \equiv Q^*_{-it} , \tag{4}$$

3 *Cooperative:* to maximize $\Sigma\, \pi_{it}$.

In principle the profit-maximizing trajectories chosen by smuggler i at distinct dates t and t' may prescribe different amounts for delivery at the same subsequent date $t'' > \max\{t, t'\}$.

This problem of "time inconsistency" arises naturally if, for example, price-taking smugglers presume that the current market price will prevail forever. Because cost curves shift through learning, the optimal trajectories chosen by individual smugglers will not be stationary. Neither will the resulting prices. Therefore, if smuggler i reexamines his choice at a later date, he will use a different "fixed price" and will select a different (nonstationary) trajectory. In our formulation, consistency is ensured by rational expectations about the future course of prices or quantities.[2]

[2]Of course, unforeseen changes in law enforcement strategies will cause rational smugglers to reevaluate their actions.

The cooperative solution is also ambiguous. We have described no way to enforce cooperation in the face of short-term incentives to expand throughput. If perfect collusion cannot be secured,[3] the price and quantity trajectory selected by a cartel will depend on details of its reward and punishment mechanisms. As smuggling is already illegal, sidepayments can be used to redistribute profits throughout the group. This eases the "cartel instability" problem, if quantities delivered can be monitored. If they cannot, the quantity-taking model is more appropriate.

Price-takers

A price-taking smuggler i confronted with a trajectory P_t of prices will choose quantities q_{it} to maximize:[4]

$$\sum_{t=0}^{T} \rho^t \{P_t q_{it} - C(q_{it}:q_{i0},\ldots,q_{it-1})\} \text{ subject to} \tag{5}$$

$$q_{it} \geq 0 \text{ all } t \ .$$

This leads to the following first-order condition:

---

[3]Under some conditions, there are no repeated-game equilibria which maximize total profits. Under weaker conditions, there are no perfect equilibria which do so.

[4] [illegible] that the smuggler can always earn 0 profits by remaining inact[illegible]

$$P_t = MC_{it} + \sum_{r=t+1}^{T} \rho^{r-t}\lambda_{irt} \equiv AMC_{it} \text{ , where} \tag{6}$$

$$MC_{it} = \partial C(q_{it}:q_{i0},\ldots,q_{it-1})/\partial q_{it} \text{ , and}$$

$$\lambda_{irt} = \partial C(q_{ir}:q_{i0},\ldots,q_{ir-1})/\partial q_{it} \text{ .}$$

This says that a price-taker equates *adjusted marginal cost* (AMC) and current *price*. This solution is clearly time consistent.

Strictly speaking, the smuggler will solve a dynamic programming problem. To Eq. (6) we must append a shut-down condition that the smuggler will choose not to operate in any period where expected future profits are negative. Letting $h_{it} = (q_{i0},\ldots,q_{it-1})$, define

$$V_t(P:h_{it}) = \max_{q_{it}} \{P_t q_{it} - C(q_{it}:h_{it}) + \rho V_{t+1}(P:h_{it},q_{it})\} \text{ .} \tag{6a}$$

We then say that i is *active at t* iff $V_t(P:h_{it})$ is achieved at a positive value of q_{it}. This can also be written in terms of current price as $P_t \geq AAC_{it}$, where:

$$AAC_{it} = \{C(q_{it}:h_{it}) + \rho V_{t+1}(P:h_{it}, q_{it})\}/q_{it} \text{ .} \tag{6b}$$

This is an abuse of notation, because AAC reflects future prices as well as costs, but it allows us to specify exit-inducing levels of current price.

If i's experience at date t lowers costs at date r, $\lambda_{irt} < 0$, so quantities chosen by a price-taking smuggler generally increase with the discount factor ρ. As ρ is inversely related to the interest rate:

- Supply is a decreasing function of the interest rate.

By the same token, amount supplied increases as the learning effect strengthens (λ_{irt} becomes more negative):

- Supply increases with the strength of the learning effect.

With the weighted-average formula for experience given in Eq. (2) above:

$$AMC_{it} = MC_{it} + \sum_{s=t+1}^{T} (\rho\delta)^{s-t} C_{iEs} \text{ , where} \tag{6c}$$

$$C_{iEs} = \partial C(q_{is}:E(s:\delta))/\partial E(s:\delta) \text{ .}$$

From Eq. (6a):

- Supply increases with the durability of knowledge (δ).

Durable learning (high δ, very negative λ) and farsightedness (high ρ) act synergistically to reduce the marginal cost of an active smuggler. This applies to the person's shut-down price as well:

- Farsightedness or durable learning reduces the exit-inducing level of current price.

In other words, to secure lower future costs such a smuggler is more likely to continue operating when current profits are negative.

To summarize, the supply curve of an individual price-taking smuggler is that portion of adjusted (for the present value of learning effects) marginal cost that exceeds adjusted average cost. Increases in δ or ρ act to shift both of these curves down, thus increasing amounts supplied.

The amounts supplied by a price-taker i who faces a trajectory $P = \{P_t\}$ of prices, and discounts the future at rate ρ will be denoted $q_i^P(P,\rho) = \{q_{it}^P(P,\rho):t = 1,\ldots,T\}$.

Quantity-takers

If each smuggler takes the others' quantity decisions as given, the first-order condition corresponding to Eq. (6) is:

$$P_t + P'_t q_{it} \equiv RMR_{it} = AMC_{it} \ . \tag{7}$$

This says that a quantity-taking smuggler equates *adjusted marginal cost* (AMC) and *residual marginal revenue* (RMR)--the marginal revenue obtained by considering only that portion of the original demand curve lying to the right of the cumulative throughput of the other smugglers.

Residual marginal revenue is always less than price, so a quantity-taker supplies less than a price-taker facing the same situation. In most other respects, the responses of such smugglers are similar, and the observations made above continue to hold.

The amounts supplied by a quantity-taker i who faces a trajectory $Q_{-i} = \{q_{jt}: j \neq i,\ t = 1,\ldots,T\}$ of amounts supplied by other smugglers and discounts the future at rate ρ will be denoted $q_i^q(Q_{-i},\rho) = \{q_{it}^q(Q_{-i},\rho): t = 1,\ldots,T\}$.

Cooperative Behavior

If the active smugglers maximize collective profits, each smuggler's first-order condition is altered by the addition of a (negative) term representing the spillover effect of i's production on the profits of the others.

$$P_t + P'_t[\sum_{j=1}^{n} q_{jt}] \equiv MR_t = AMC_{it} \tag{8}$$

In other words, the cooperative solution sets each smuggler's *adjusted marginal cost* equal to *(total) marginal revenue*. Marginal revenue always lies below residual marginal revenue, so the cooperative solution involves the smallest total output and the highest total profits.

The amounts supplied by a smuggler i who cooperates with the other active smugglers, all of whom discount the future at a common rate ρ, will be denoted $q_i^c(\rho) = \{q_{it}^c(\rho): t = 1,\ldots,T\}$. These amounts may well be zero for less-experienced members of the cartel.

The cooperative case differs from the price- and quantity-taking situations in that each smuggler i believes that he can profitably deviate from the planned trajectory q_i^c by increasing production. In general, such cartels require more-or-less explicit stabilizing mechanisms. These may take the form of sidepayments (cost- or profit-sharing arrangements, coinsurance, etc.), internal threats (e.g., most-favored customer clauses that automatically match or exceed any unilateral price cut) or external threats (e.g., violence). If threats are costly to execute, they may be incredible unless their execution is automatic or the parties invest in reputations making their fellow cartel members believe that defections from q_i^c will be met with sufficient punishment. These issues go beyond the scope of the current analysis.

Comparison

The relation of the three solutions is shown in Fig. 1. Law enforcement policies that increase costs, either directly or by means of the learning curve, will reduce individual quantities. Without extra assumptions, it is generally impossible to determine which type of smuggler will have the most elastic response to a given policy.

If supplies decrease in response to law enforcement activity, does it follow that aggregate supply will decrease, and thus that price will rise? To answer this question even for a single period we must take account of the market-clearing and entry processes.

MARKET CLEARING AND ENTRY

Here we combine the profit-maximizing responses to determine the equilibrium price and quantities for a particular set of active smugglers. The identity of the active set will reflect the entry decisions of potential smugglers.

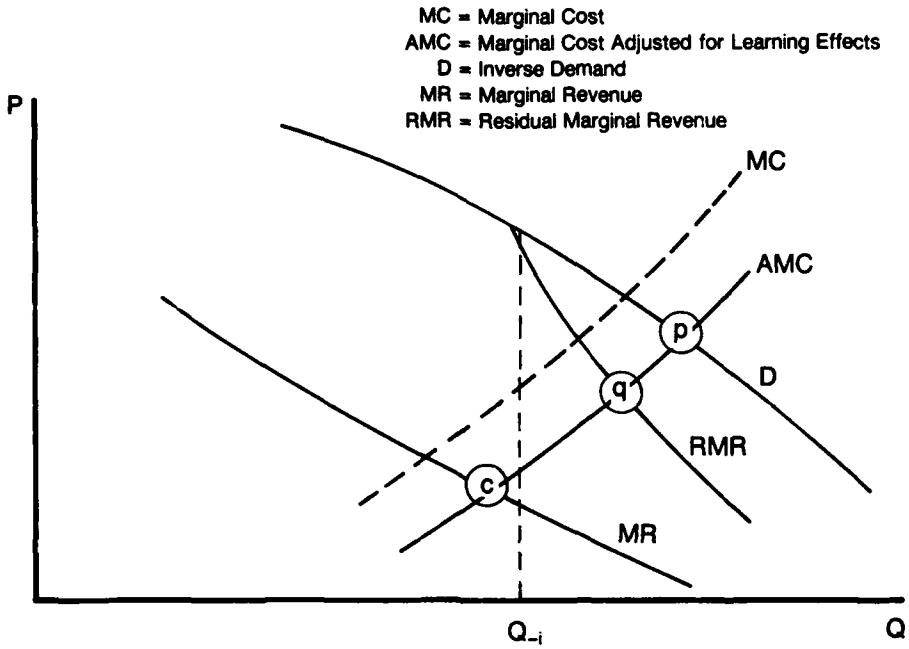

Fig. 1--Comparison of profit-maximizing conditions

Price-takers will produce at the point where AMC equals current price, provided that price exceeds adjusted average cost (AAC). We can therefore describe the behavior of a particular set of active price-takers by the horizontal summation of the relevant portions of the AMC curves. Due to scale effects, adjustment costs, and lump-sum transactions (risk) costs, quantity supplied is unlikely to be a continuous function of price.

A *price-taking equilibrium* for a given set A of active smugglers is a trajectory of quantities $q^* = \{q_{it}^*: i \varepsilon A, t = 1,\ldots,T\}$ such that:

$$q_{it}^{*} = q_{it}^{P}(P(q^{*}),\rho) \text{ , where} \tag{9}$$

$$P(q^{*}) = \{P(\sum_{j\varepsilon A} q_{jt}^{*}): \quad t = 1,\ldots,T\} \text{ .}$$

Similar definitions can be given for the quantity-taking and cooperative cases. Most of the subsequent discussion concerns the price-taking case, but we indicate differences when important.

One immediate general observation is the following:

- If smugglers ignore the future [$\rho = 0$], the equilibrium trajectory of quantities increases (weakly) over time.

This means that in the absence of entry, prices will fall over time, a direct result of the fact that increasing experience lowers current costs. However, if smugglers take the future into account, equilibrium quantity trajectories need not rise. This can be seen in Fig. 2: although the MC curve is falling (shifting to the right) over time, the AMC curve may rise if the learning effect tapers off rapidly. In that case, the "gap" between AMC and MC diminishes faster than MC falls, and market prices will rise.[5]

This carries the further implication that law enforcement activities which alter the importance of the future (e.g., by changing internal rates of return) can either increase or decrease prices compared with "baseline" trajectory expected in the absence of such activity.

Perverse effects are unlikely, and the presumption is that the first-order effect of cost increases raises prices relative to the baseline. However, as the baseline is likely to involve falling prices, observed prices may still fall over time.

---

[5]For example, consider a two-period model in which h is average previous quantity, and $MC(q: h) = a - b(q - h)$. In the first period, $h = 0$, so $MC_1 = a + bq_1$, and $AMC_1 = a + b(1 - \rho)q_1$. For the second period, $MC_2 = AMC_2 = a - b(q_2 - q_1)$. As long as $q_1 < \rho q_2$, we will have the situation depicted in Fig. 2.

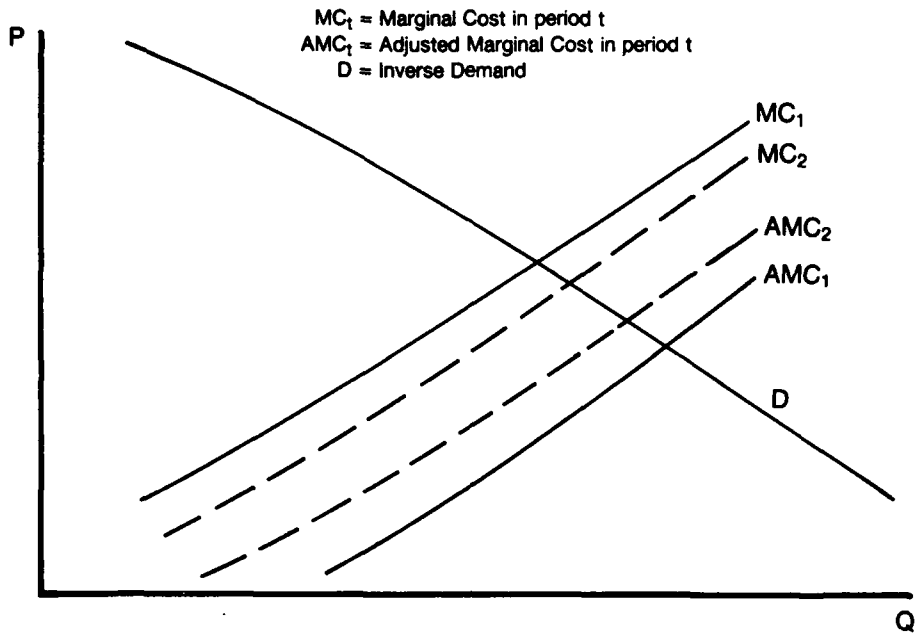

Fig. 2--Falling costs may not mean falling prices

A sample market supply curve is shown in Fig. 3. This curve will shift over time in response to the two learning effects just discussed: The direct effect of accumulated experience (which unambiguously lowers costs and thus increases supply) and the effect of current production on future costs (which may move in either direction).[6]

Entry at the novice level is assumed to be costless. The "novice entry price" is the minimum average cost of an inexperienced smuggler, and is denoted c^*.

The market supply schedule consists of alternating increasing and horizontal portions. Along increasing portions, the number of active smugglers is constant, while horizontal supply marks the entry of new smugglers. In particular, the supply curve becomes horizontal at c^*.

[6]The quantity-taking and cooperative cases do not give rise to supply curves. However, the qualitative points made in the text retain their validity when they are applied to equilibrium values of price and quantity.

The larger the pool of potential entrants, the longer the horizontal segment at c^*.

The length of a horizontal segment reflects the combined minimum optimal scale of all entrants at that price, and current market price and quantity are given by the intersection of supply and demand.

Since the supply curve is discontinuous along its horizontal segments, there may be no intersection with the demand curve. From the market-clearing point of view, this would lead to complementary price and inventory cycles. In general, whether such cycles are accompanied by entry and exit of firms depends on the conditions of entry.

Regardless of whether active firms are price-takers, quantity-takers, or cooperative, we can distinguish between "naive" entrants, who base their decisions on current conditions, and "sophisticated" entrants, who consider the profitability of post-entry equilibrium. Naive entrants may be further subdivided between those who enter whenever the current price exceeds their minimum average cost and those who take current throughput trajectories as given. These differences are the subject of much recent work in industrial organization theory, which we shall not attempt to summarize. However, under mild and usual assumptions[7] some general propositions are easy to demonstrate:

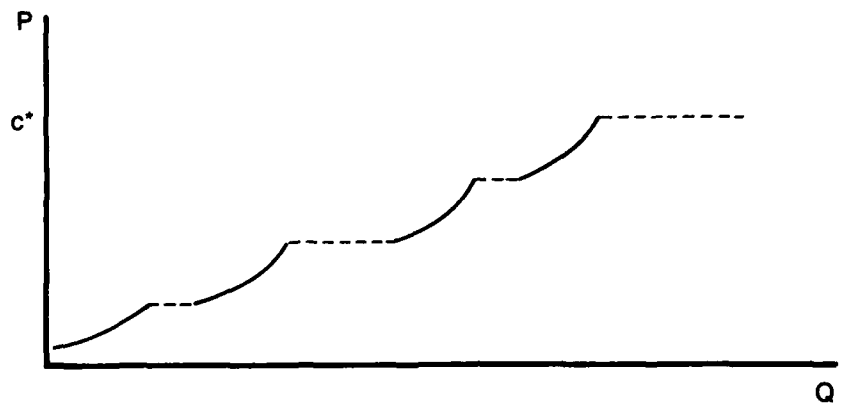

Fig. 3--Market supply

[7]For example, if Marginal Revenue is everywhere decreasing and AMC is nondecreasing.

- If active smugglers are price-takers and potential entrants are naive price-takers, there will be no equilibrium unless the demand curve crosses the market supply curve where the latter is rising.
- If active smugglers are price-takers and potential entrants are sophisticated or naive quantity-takers, there will always be equilibrium.
- If active smugglers are price-takers and demand intersects a rising portion of the market supply curve, all three entry conditions lead to the same equilibrium.
- If active smugglers are quantity-takers and potential entrants are naive quantity-takers, there will typically be many equilibria. There may be one equilibrium for every interval,[8] provided only that the equilibrium profits of the marginal active smuggler (k) are nonnegative.
- If active smugglers are quantity-takers and potential entrants are either sophisticated or naive price-takers, there will typically be a unique equilibrium in which the set of active smugglers (and the total quantity produced) is the largest of the equilibria in the observation above.
- If active smugglers cooperate, they will produce at the intersection of MR and the horizontal summation of the AMC curves. If demand is inelastic, that may well mean that the marginal members of the cartel will be "sleeping partners," producing nothing. They may be a source of extra supply to protect the cartel from entry by high-cost novices. If entrants are price-takers or quantity-takers, the cooperative equilibrium will be very close to the price-taking equilibrium.

---

[8]The active set is an interval if it takes the form {1,2,...,k-1,k} where 1 denotes the most experienced smuggler, and the smugglers are labelled in decreasing order of experience. The important qualification is that there cannot be any inactive smugglers who are more experienced than an active smuggler.

The last observation illustrates a "contestability" feature of the model. Cost advantages stem from accumulated experience rather than protected assets, and thus fringe firms will almost always earn low profits. Any additional barrier to entry--such as law enforcement, which falls most heavily on novice smugglers--will lead to progressive differentiation of price-taking, quantity-taking, and cooperative markets. In the absence of such barriers, entry conditions are the greatest determinant of actual behavior. For this reason, the price-taking analysis below depicts law enforcement effects accurately unless they are heavily skewed toward new entrants. However, one exception does merit discussion.

If the "usual" conditions on demand and cost are not met, or if active smugglers are quantity-takers, the model admits multiple equilibria, adding an interesting dimension to the analysis. Suppose each possible equilibrium corresponds to a certain set of active firms. At any moment, one of these equilibria will prevail. By changing the costs of active and potential smugglers or the distribution of experience among active firms, law enforcement activity can alter the set of possible equilibria. This may generate a "small" shift in the existing equilibrium, or destroy it altogether. If the existing pattern of activity becomes untenable, the market will move to a new equilibrium. Theory does not predict whether the new equilibrium will involve a larger or smaller set of active smugglers, and thus cannot tell us whether prices, quantities, profits, etc. will increase or decrease. It is possible for cost increases to destroy a concentrated equilibrium with a small set of active firms and lead to a more competitive equilibrium with a large number of firms. The new equilibrium price may be less than the old one.

DYNAMIC BEHAVIOR OF PRICE-TAKING EQUILIBRIUM

Here we examine the equilibrium trajectories of prices, quantities, and profits. We have already seen that individual supply curves are likely to shift out over time.[9] (Observation E) However, we cannot

[9]Although they need not do so, as shown in Fig. 2.

therefore conclude that market prices will fall over time. To interpret empirical price observations, we must make specific assumptions about:

- The rate at which demand shifts as a function of experience;
- The effect of experience on the elasticity of individual supply curves;
- The effect of experience on the minimum optimal scale; and
- The differential effect of law enforcement strategies on demand, current supply schedules, discount rates, learning curves (including the obsolescence factor δ), and the distribution of experience levels among active smugglers.

This Note neglects shifts in demand. On the supply side, we assume that the adjusted marginal cost (supply) curve of a more-experienced smuggler i lies everywhere below that of a less-experienced smuggler j: At any price at which i and j both produce positive quantities, i produces more than j, restricting the relative ranking of minimum optimal scales and shut-down prices. It is impossible for the more-experienced smuggler i to have a smaller minimum optimal scale than j unless i's shut-down price is also less than j's. However, if i has a larger minimum optimal scale, his shut-down price may be more or less than that of j. These possibilities are illustrated in Fig. 4.

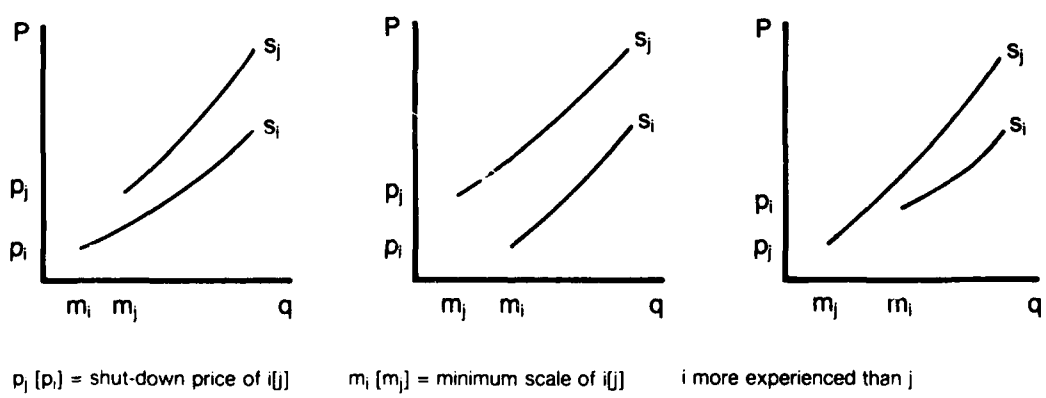

Fig. 4--Supply and experience

Our model assumes that more-experienced smugglers have lower shut-down prices (the first two diagrams in Fig. 4).[10] In this *canonical case*, lower portions of the market supply curve correspond to more-experienced smugglers, who enjoy higher rents. The model ignores fixed costs unless they do not rise with experience. The ranking of smugglers by experience persists over time (unless upset by law enforcement activity): At any price, more-experienced smugglers will ship larger quantities and thus maintain their advantage.

Over time, the supply schedules of individual active smugglers will shift. In addition, they may be linked by "network externalities." These spillover effects can be positive or negative, and it is difficult to go beyond casual empiricism in evaluating them. A partial listing includes:

- *Input price effects*: Increased demand for inputs by experienced smugglers may raise costs in the short run and raise or depress costs in the long run as scale economies in production etc. are realized.
- *Information effects*: Costs associated with inexperience may reflect ignorance. As with any commercially valuable information, novices may learn about safe routes etc. through inference, observation, transfer of skilled personnel, and other "diffusion" processes, as well as by direct experience. This is a positive externality; increased experience lowers the costs of inexperienced smugglers as well, albeit by a smaller amount.
- *Congestion and detection effects*: Risks associated with particular techniques, routes, etc. depend on the extent to which the authorities are aware of and wish to target them. A safe route may be one that the authorities are unaware of, or one that is regarded as having a sufficiently low volume

[10]This follows directly from the assumption that more-experienced smugglers have lower total (as opposed to simply marginal) costs at every level of output.

relative to the cost of interdiction. To minimize costs associated with "choice of technique," experienced smugglers must take account of the activities of inexperienced smugglers and authorities. Detailed modelling of the minimization process goes beyond the scope of the model, but we can identify its effects. As volume grows in a channel, so do the common risks of all who use it. To the extent that novices are easier to detect than experienced smugglers, they may attract law enforcement attention to a route, forcing experienced smugglers to vary routes etc. more than they would in the absence of inexperienced competition and therefore raising costs.

- *Enforcement resource effects*: Limited enforcement resources introduce another strategic interaction between smugglers of different degrees of experience. If law enforcement officers can be "kept busy" arresting novices, they pose less risk to experienced smugglers. Similar considerations influence amounts shipped. In certain circumstances, increases in the number and total amount of shipments may minimize risk costs. The external benefits are local public goods and cannot be appropriated by a single smuggler. In this connection, it would be interesting to see whether experienced smugglers prefer systematically smaller shipment sizes than novices.

For any fixed level of law enforcement activity, the dynamics of price reflect the rate at which supply and demand curves shift out. If supply increases faster than demand, price will fall. If demand increases faster than supply, price will rise. In either case, the equilibrium quantity of drugs consumed will increase. The quantity of drugs seized might increase over time without any change in the costs of individual smugglers if seizures represent a constant fraction of an expanding total. A pattern of increasing seizures, arrests, and market price is consistent with an underlying expansion of both market size and profits, which means they are not good proxies for the law enforcement objectives of reduced quantity and profit.

In fact, the market supply curve may not shift out uniformly over time for various reasons. If a smuggler's marginal cost declined uniformly while his fixed costs increased, perhaps as a result of increased bribes and other overhead expenses, we would obtain the "noncanonical case" shown in panel 3 of Fig. 4. The rising portion of the old supply curve would cross the horizontal portion of the new supply curve. Depending on the extent to which fixed costs rise and marginal costs fall, and on the level of demand, price could either rise or fall. The first panel of Fig. 5 illustrates this: With the high demand curve (D_h) price falls and quantity rises with experience; with the low demand curve (D_l), price rises and quantity falls as the least-experienced firm becomes marginal. Such rising fixed costs may reflect the appropriation of monopoly profits by other agents (suppliers, corrupt officials, etc).

Alternatively, one could imagine a situation in which fixed costs were constant or declining but marginal costs became steeper by pivoting about a smaller quantity than is currently being sold. For example, a smuggler may discover by unhappy experience that his exposure on a given route is a rapidly increasing function of experience, and he may therefore decide to retreat to a lower quantity. This possibility is illustrated in the second panel of Fig. 5. As before, price (quantity) will rise (fall) only for certain levels of demand. The difference is that high demand leads to price increases in contrast to the fixed-cost situation. Marginal costs associated with particular shipment volumes reflect *expected* costs. Experience of risks leads both to risk-reducing expenditures (which increase the deterministic component of costs) and to revised expectations about losses (which may either increase or decrease the stochastic component of costs).

In both cases, the number of active smugglers remains constant. Changes in their cost curves can lead to countervailing changes in their number. For example, cost decreases leading to price decreases may induce sufficient exit (of "slow learners") to shrink total supply and thus raise future prices.

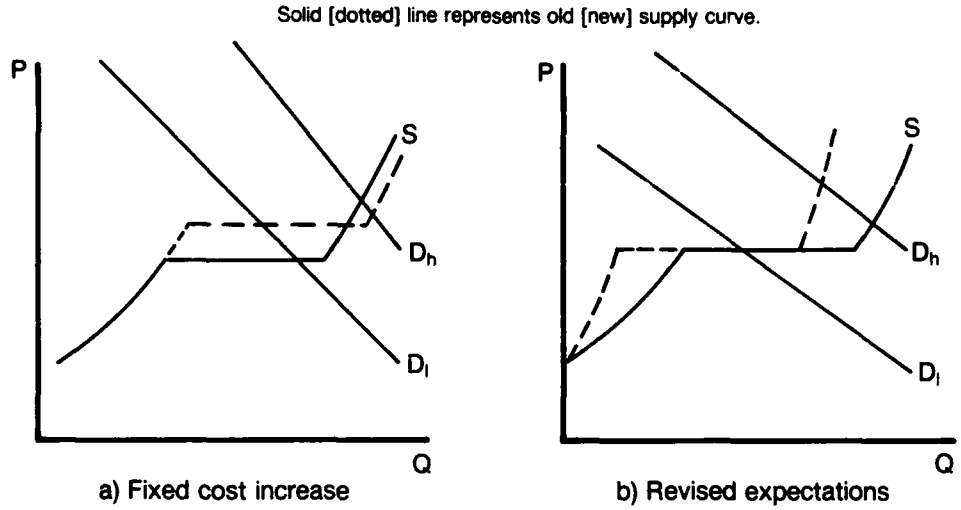

Fig. 5--Dynamic evolution of price and quantity

In summary, although the effects of learning on individual cost curves may point unambiguously in the direction of gradually increasing supplies, prices may increase, decrease, or move cyclically when market-clearing and entry phenomena are taken into account.

One additional point that is obscured by the price-taking assumption is the effect of market concentration on quantity decisions. Falling numbers of active smugglers may decrease competitiveness and thus increase prices and profits.

THE EFFECTS OF LAW ENFORCEMENT

General Observations

Market evolution with learning is controlled by several interacting effects, and proper analysis of the effects of law enforcement must take careful account of them. Generally, learning lowers the costs of experienced smugglers. Barring changes in the number of active smugglers, this typically leads to falling prices and expanding quantities. Profits may increase or decrease.

Falling prices may induce exit of marginal smugglers who do not learn fast enough. This tends to reduce total quantities and raise prices once again. Therefore, entry and exit phenomena can lead to a "baseline" pattern of oscillations in price. Entry also determines the number of active smugglers and the profits earned by marginal (less-experienced) smugglers. Changes in industry concentration may be accompanied by changes in market price and quantity. A highly concentrated industry may act like a cartel in restricting quantity.

Market evolution is determined by the rate and durability of learning and the rate at which smugglers discount the future. The pattern described above is strongest when firms are farsighted (low internal rates of return) and learning effects are strong.

Law enforcement activities are the principal source of learning externalities. One way to analyze them considers the type of cost imposed on smugglers.

Seizures result in private (specific to the affected smuggler) costs that vary directly with current market price and increase costs of delivery. The degree to which a given smuggler's costs increase may reflect the contractual terms under which the drugs were acquired for shipment. These in turn may reflect the smuggler's experience. For instance, an experienced smuggler may have long-term contracts that can cushion the effect of a single seizure.

Risk expenses may be direct or indirect, private or public (general to the industry), financial or psychic, and depend indirectly on current price. They include insurance types of expenditures determined by overall levels of law enforcement (bribes, retainers, contingency funds), and direct risk-management expenses (personnel and legal costs, etc.) that depend on acual outcomes. Risk expenses may also alter supply prices in a manner that reflects contractual relations among suppliers, smugglers, and domestic retailers.

Arrest and imprisonment costs are usually private and either financial or informational. They reflect the opportunity cost of the services of imprisoned personnel (including the value of lost knowledge) and possible increase in authorities' knowledge of the affected

smuggler's activities. Arrest and imprisonment may have socially harmful spillover if they drain scarce law enforcement resources. Over the long run, they may yield socially beneficial (bad for smugglers) externalities in the form of increased awareness of the activities of a particular network of smugglers by authorities.

Law enforcement strategies can also be differentiated by their effect on individual cost curves. Strategies that stress technical means of interdiction (e.g., patrol) are likely to be most effective against novice smugglers. Rapid learning may taper off quickly as experience accumulates, but it is likely to be fairly durable. Such strategies restrict current quantities but allow high levels of profit among the experienced.

Strategies that stress "police work"--investigations aimed at uncovering or destabilizing the extensive networks associated with experienced smugglers--offer good long-term results because the present value of learning is reduced. Learning effects may even be negative if the increased exposure of an experienced smuggler outweighs his ability to predict and evade interdiction. This strategy offers a smaller short-term payoff, because resource expenditures per unit of drugs seized are relatively high. However, the long-run effect is to produce a competitive, high cost, low profit industry.

In general, learning by smugglers reduces the cost burden imposed by law enforcement. It follows that enforcement strategies should be designed to limit the scope of learning; otherwise, the benefits of law enforcement will be eroded over time. In addition, the social costs of the drug market are diminished by reductions in quantity and by lower levels of profitability. Strategies that concentrate cost increases on the relatively experienced may be preferred. If the profits of experienced smugglers are high and the expectations of potential entrants sufficiently optimistic, the capture of novice smugglers will offer few benefits. The quantities intercepted are easily replaced. Fewer novices survive to reap the rewards of experience, so entry into the group of experienced smugglers is retarded. This enhances their profitability, and ensures a steady supply of potential entrants. In brief, strategies that concentrate on the inexperienced are unlikely to

have sustained effects on either the amount of drugs imported or the profits earned by smugglers.

Other things equal, law enforcement strategies should aim to make learning by smugglers less durable. Random variations in the pattern of interdiction efforts are likely to reduce the value of long experience and spread the burden of interdiction more evenly across smugglers with different levels of experience. This fosters competition, which reduces profit rates in the long run.

Because demand shifts in response to experience, the "correct" tradeoff between reductions in current supply and long-run growth may not be obvious. Members of a profitable, concentrated industry may have more incentive to stimulate demand than pure competitors. To the greatest extent possible, potential competition should be encouraged and actual entry frustrated.[11]

Finally, law enforcement strategies should concentrate on arrest and imprisonment rather than interdiction or seizure. Enforcement resources are scarce and supply prices are fairly low. Unless they are prohibitively expensive, strategies that reduce the stock of experiential capital--by imprisoning either principal smugglers or their most-experienced agents--are to be preferred over those that merely result in seizures of drugs and imprisonment of inexperienced personnel.

The reasoning is straightforward: Imported drugs are produced using at least the two inputs of drugs and experience. Drugs are cheap and experience is costly to acquire and strictly limited in supply. Other things being equal, importation will be more affected by reductions in experience than by seizures.

---

[11]This assumes that potential entrants lack "rational expectations." Given an accurate assessment of their expected risk costs, they would enter only it if were profitable for them to do so. However, accurate information about even aggregate shipments and deliveries seems unlikely. In any event, those best able to supply such information to the "supply side" have strong incentives not to do so. The authorities wish to portray smuggling as an unprofitable enterprise; unsuccessful smugglers have neither the desire nor the means to reveal the nature of their failures, and successful smugglers have strong incentives to guard information. An interesting question is whether the flow of information to potential entrants could be manipulated to distort smugglers' expectations.

Specific Enforcement Activities

In this model, arrest and imprisonment (removal of a smuggler from the active population) always reduce the supply curve (shift it to the left). Although that may not affect current price or quantity, it reduces total surplus.

Incarceration of a novice smuggler will have no long-term effect unless the pool of potential entrants is sufficiently small that the market price exceeds c^* (the minimum average cost of a novice smuggler). In that case, active novices will accumulate experience at a greater rate than before, and future falls in price (increases in quantity) become more likely.

If the pool of entrants is sufficiently large that the market price remains at c^*, the only effect of incarcerating a novice is to slow the increase of supply by removing the novice's experience from the market. The long-term effect is negligible.

The dynamic effect of incarceration (slowing the expansion of supply due to learning effects) will reflect the accumulated experience of the smuggler involved. Removal of an experienced smuggler will reduce the stock of experience and thus the supply of drugs represented by active smugglers. However, after this one-time reduction in supply, the rate at which supply expands may be increased; the novice smugglers who replace the incarcerated expert have a lot to learn, and thus may be able to reduce their costs quite rapidly. Whether such a removal has an immediate effect on price depends on the extent to which it reduces total supply. This is linked to experience through both the minimum optimal scale and the elasticity of supply of an experienced smuggler. If the marginal (least experienced) smuggler in the pre-incarceration equilibrium made zero profits, and if the same person remains marginal after removal of a more experienced smuggler, current price will be unaffected.

Another important effect of removing experienced smugglers is to greatly reduce producer surplus. If market price lies below c^*, this has both good and bad aspects: Pure profits are smaller but will persist for a longer time.

In the price-taking model, incarceration's effects are unambiguous. Price may rise or stay the same (relative to where it would have been without incarceration), but it cannot fall.[12] Similarly, quantity and producer surplus may fall or remain constant, but they cannot rise.

The situation is different as regards seizure, which we view as an increase in cost. Figure 6 shows a change in law enforcement activity that increases the shut-down price of a particular smuggler. As in Fig. 5, the level of demand determines whether the equilibrium price will rise or fall.

For the situation depicted in Fig. 4 to arise:

- The supply elasticity of the affected smuggler or more experienced smugglers must also increase, or
- The minimum optimal scale of the affected smuggler must increase by more than the amount predicted by his "old" marginal cost curve.

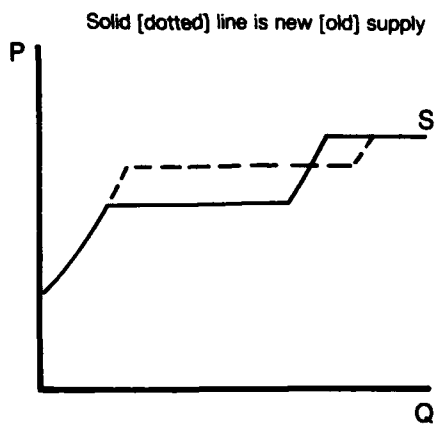

Fig. 6--Effect of cost increase

[12]Because the baseline trajectory of prices and quantities may not be constant over time, price may still fall over time while incarceration increases. The drop in price is not an effect of incarceration, however.

The first of these might occur if the cost increase reduced risks for more experienced smugglers, or if the cost increase represented a conversion of variable to fixed cost for the affected smuggler. The latter situation may occur if economies of scale (and experience) shift the new supply schedule far enough to the right. Alternatively, anticipation of increased seizure efforts may force shipment increases that result in random, but nonetheless observed, increases in quantity delivered.

Seizure activity that increases costs in one segment (by experience level) of the market may actually reduce costs in another, especially if such increases reflect reallocation rather than increases in the resources alloted to antidrug activity. Over the long run, enhanced seizure may even increase the value of experience, as smugglers learn new ways to evade detection. This erosion of effectiveness selectively favors more-experienced smugglers, thus increasing their profits. At the same time, the costs of novices might increase: The end result is a steeper market supply curve. Once again, the aggregate size of demand determines whether market price rises (high demand) or falls (low demand).

In the case of enforcement strategies that selectively target experienced smugglers, the arguments presented above are largely reversed. Seizure directly reduces total rents and thus indirectly shrinks the pool of entrants. The immediate effect on prices (relative to the baseline) is likely to be modest, but long-term expansion of supply is greatly impeded. Finally, the experienced group's power and stability are directly attacked, as their more-experienced members are targeted and new members are added.

IV. COMPUTER SIMULATION

This section describes the functional forms used in the computer simulation, and discusses the results of computations designed to illustrate the importance of various parameters of the model. A user's guide to the Lotus-based model included with this document is given in an Appendix.

MATHEMATICAL STRUCTURE OF THE MODEL

The model uses a fairly general specification of demand. Market price P as a function of current (delivered) quantity Q is given by:

$$P = A + BQ^{-C} , \tag{10}$$

where A, B, and C are constants, and B and C have the same sign. For computational simplicity, the model is limited to two values of C. When C = -1, the demand curve is linear, and when C = 1, demand is an (inverse) exponential. One important special case is given by A = 0; in that case demand is isoelastic.

Smuggler i is assumed to have a U-shaped average cost curve. The total cost to smuggler i of delivering the quantity q is:

$$C_i(q) = (\alpha/2)(q - \mu)^2 + \phi_i q , \tag{11}$$

where α is a constant common to all firms, and ϕ_i is a variable reflecting smuggler i's experience. The parameter μ represents the common minimum optimal scale of all firms--the quantity at which average cost is minimized. If smuggler i is a price-taker, he will produce exactly μ when the market price is ϕ_i and will shut down at any lower price.

This specification provides the smuggler with a linear marginal cost curve:

$$MC_i(q) = \alpha(q - \mu) + \phi_i . \tag{12}$$

Now consider smuggler i at date t, and suppose that it has a history of shipments q_s at earlier dates s. The current experience level of smuggler i is denoted E(i,t), and is given by:

$$E(i,t) = \sum_{s=0}^{t-1} \delta^{t-s} q_s \ , \tag{13}$$

where $\delta \varepsilon (0,1)$ is a discount factor common to all firms. δ measures the rate at which information gained during previous shipments becomes obsolete. If $\delta = 0$, experience is irrelevant, because E(i,t) is always 0. If we replace E(i,t) with $f(i,t) = E(i,t)/\delta$, then at $\delta = 0$ only last period's shipment affects current cost. However, if $\delta = 1$, experience is total cumulative throughput, and we have a conventional learning curve model.

The constant term ϕ_i is given by:

$$\phi_i = (1 + L_{it})\{1 - S\ln[1 + E(i,t)]\}C_{i0} \tag{14}$$

where S is the slope of the learning curve, C_{i0} is smuggler i's initial minimum average cost--as of the date of policy change, and L_{it} represents the law enforcement pressure on smuggler i at date t. In this model L_{it} is a parametric function:

$$L_{it} = \lambda_C + \lambda_E E(i,t) + \lambda_F t E(i,t) \ . \tag{15}$$

The computer model works only for myopic firms [$\rho = 0$], because the forward-looking model does not offer a closed-form solution.

SIMULATION RESULTS

This section discusses the results of several sample computations performed to illustrate the effects of six policies, denoted A through F. The following tables describe the policies and show their effects on total quantity and price for linear and exponential demand and for price-taking and quantity-taking behavior.

Table 2

SIMULATED POLICIES

Policy	C	E	ExT[a]	Description
A	1	0	0	Independent (constant) MC Increase
B	1	.5	0	Mild Experience Penalty
C	1	5	0	High Experience Penalty
D	2	-.5	0	Mild Inexperience Penalty
E	1	-.5	.5	Mild Inexperience, Long-run Experience Penalties
F	1	0	0	Reduced Durability of Learning

[a]C, E, ExT are parameters 1, 2, and 3, respectively, defined in Table 13 below.

The simulations consider four possible market conditions. Demand is either linear or (inverse) exponential, and market structure is either price-taking or quantity-taking. Entry is always sophisticated, which eliminates problems associated with nonexistence or multiplicity of equilibria. We do not present results for the collusive case, because we do not find arguments for the viability of effective collusion particularly compelling in light of the difficulty of policing a cartel in an illegal market.

The results of the policy simulations are illustrated in Figs. 7-12. Figure 7 shows the base case trajectories of quantity and price for the four market conditions. Figure 8 concentrates on the effect of market structure, showing the difference between competitive and Nash equilibrium price and quantity for the linear and exponential demand curves. Figures 9-12 each compare the baseline and policy-affected quantity trajectories for different market situations.

The base case trajectory of prices in the linear competitive model falls monotonically over time, albeit at a decreasing rate. This pattern is repeated in the other variants (quantity-taking behavior, exponential demand). The price premium due to quantity-taking behavior is considerably higher with linear demand than with exponential demand, but price falls much more rapidly in the exponential case.

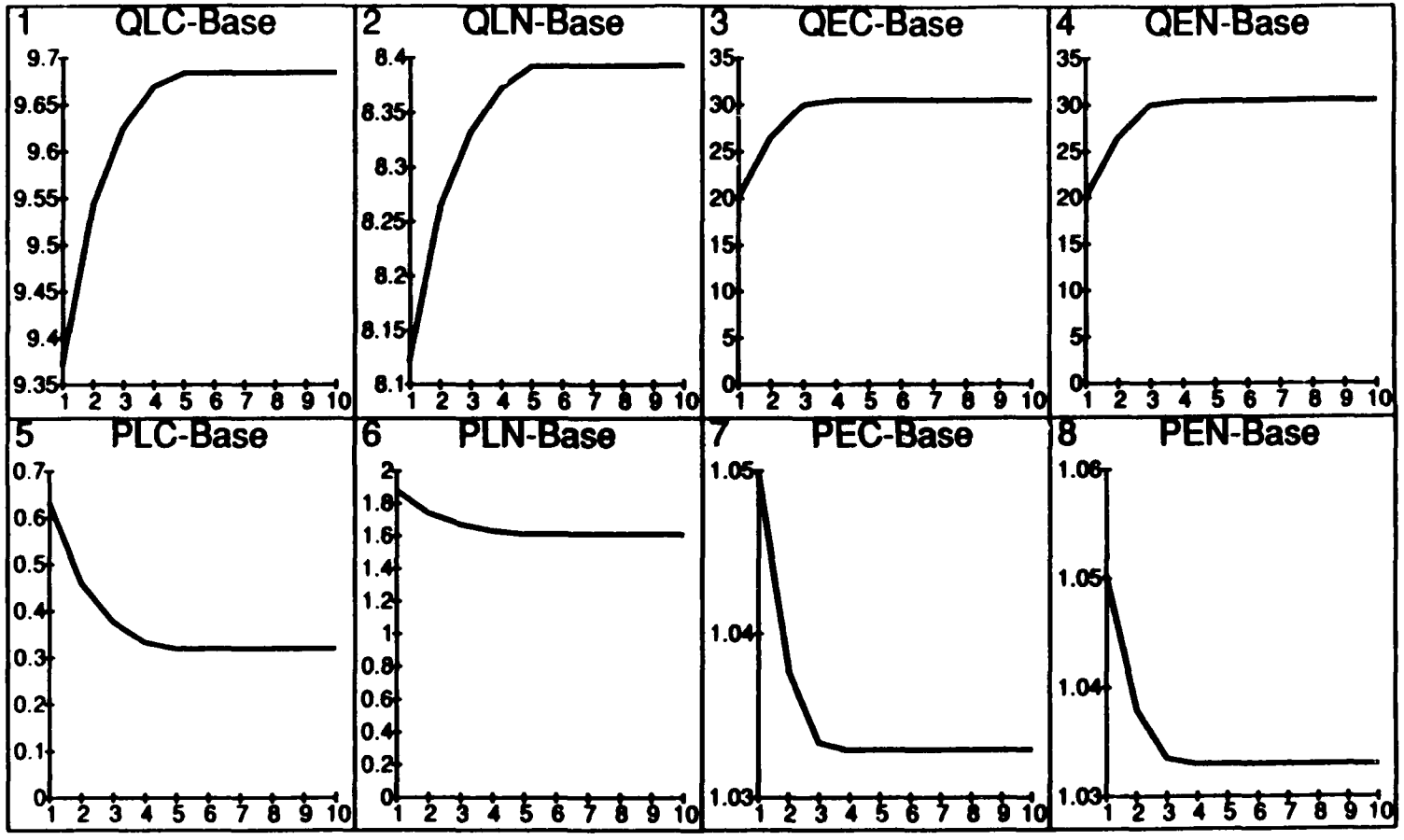

Fig. 7--Baseline quantity and price trajectories

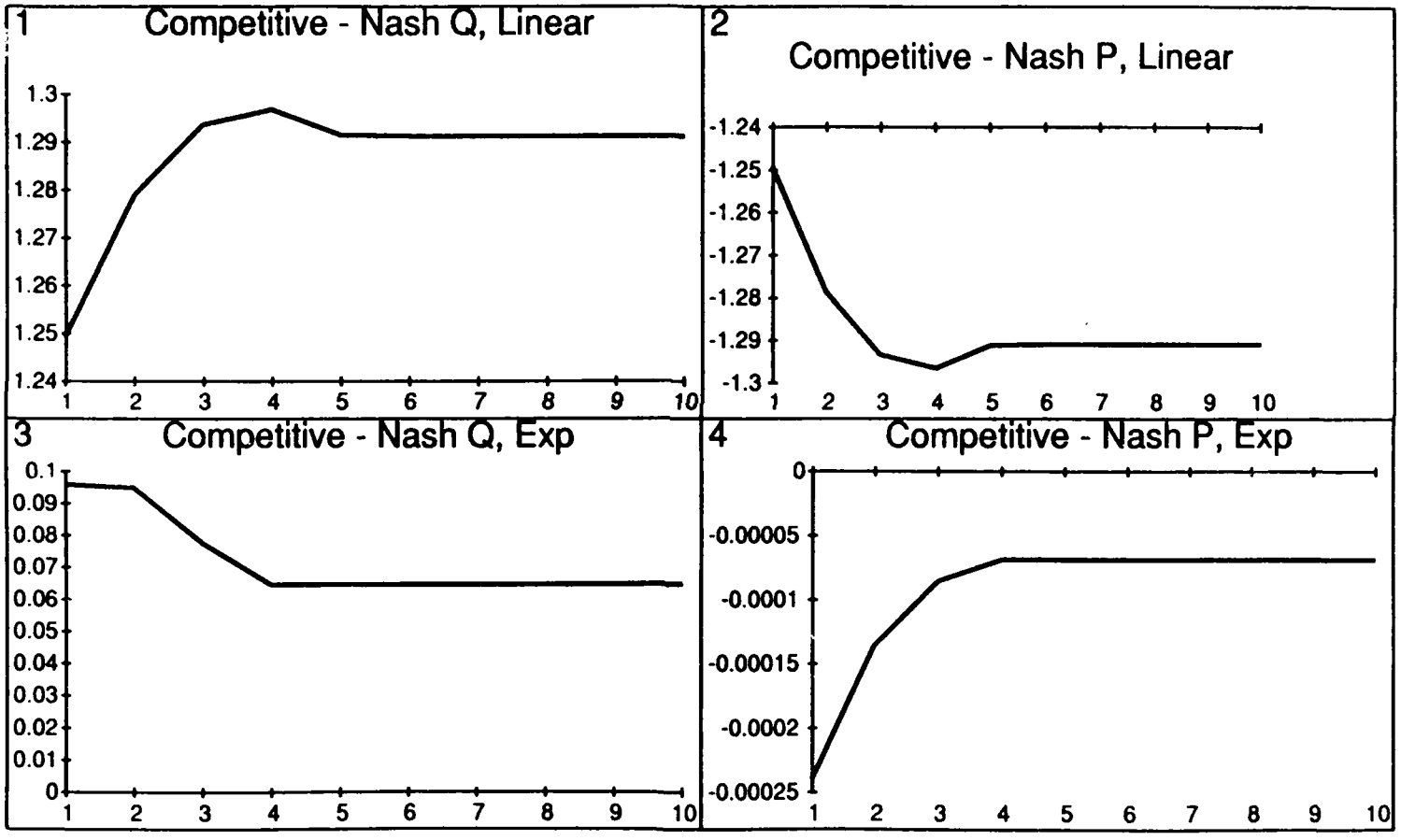

Fig. 8--Difference between competition and Nash equilibrium

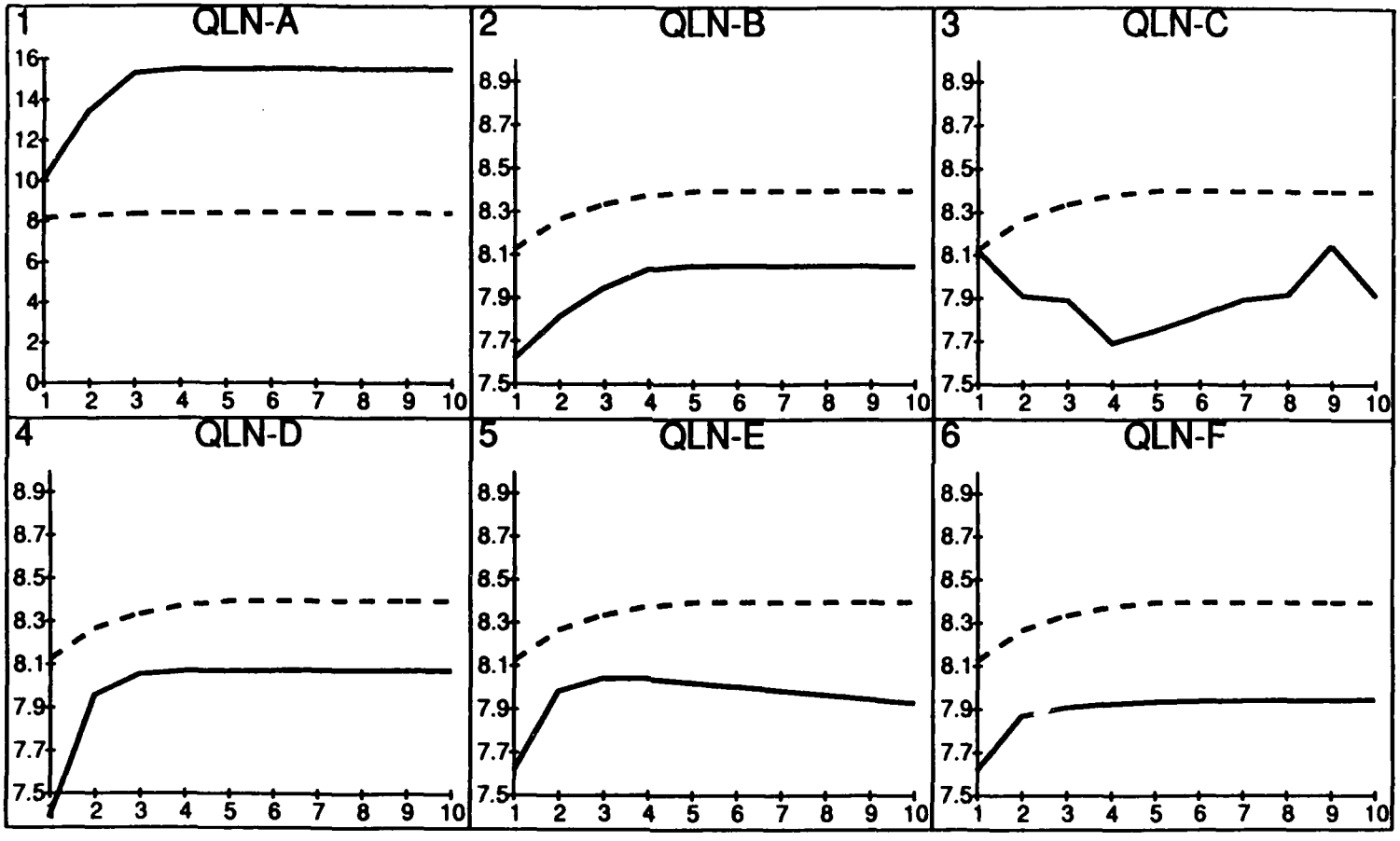

Fig. 9--Policy effects on quantity--linear quantity-taking model

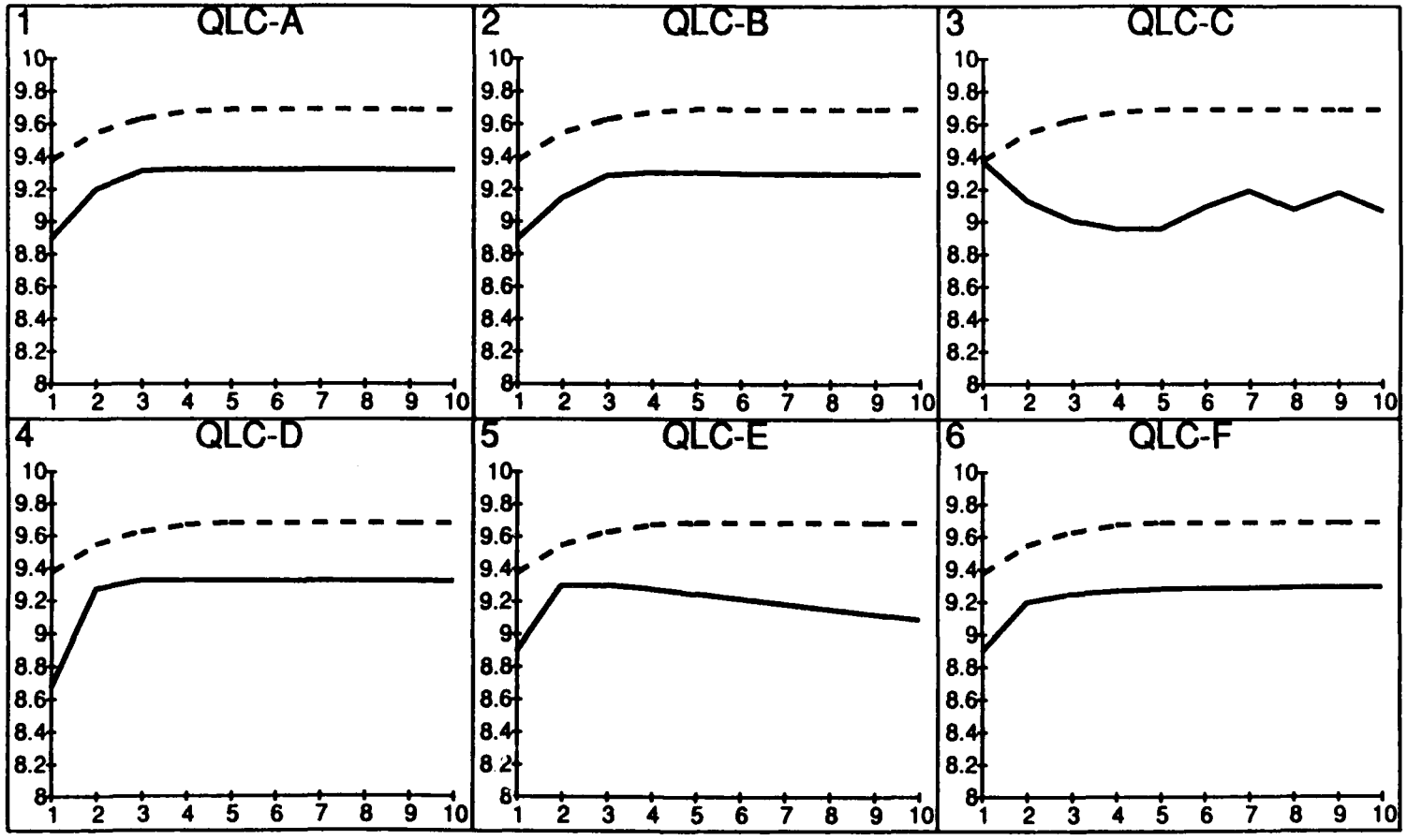

Fig. 10--Policy effects on quantity--linear price-taking model

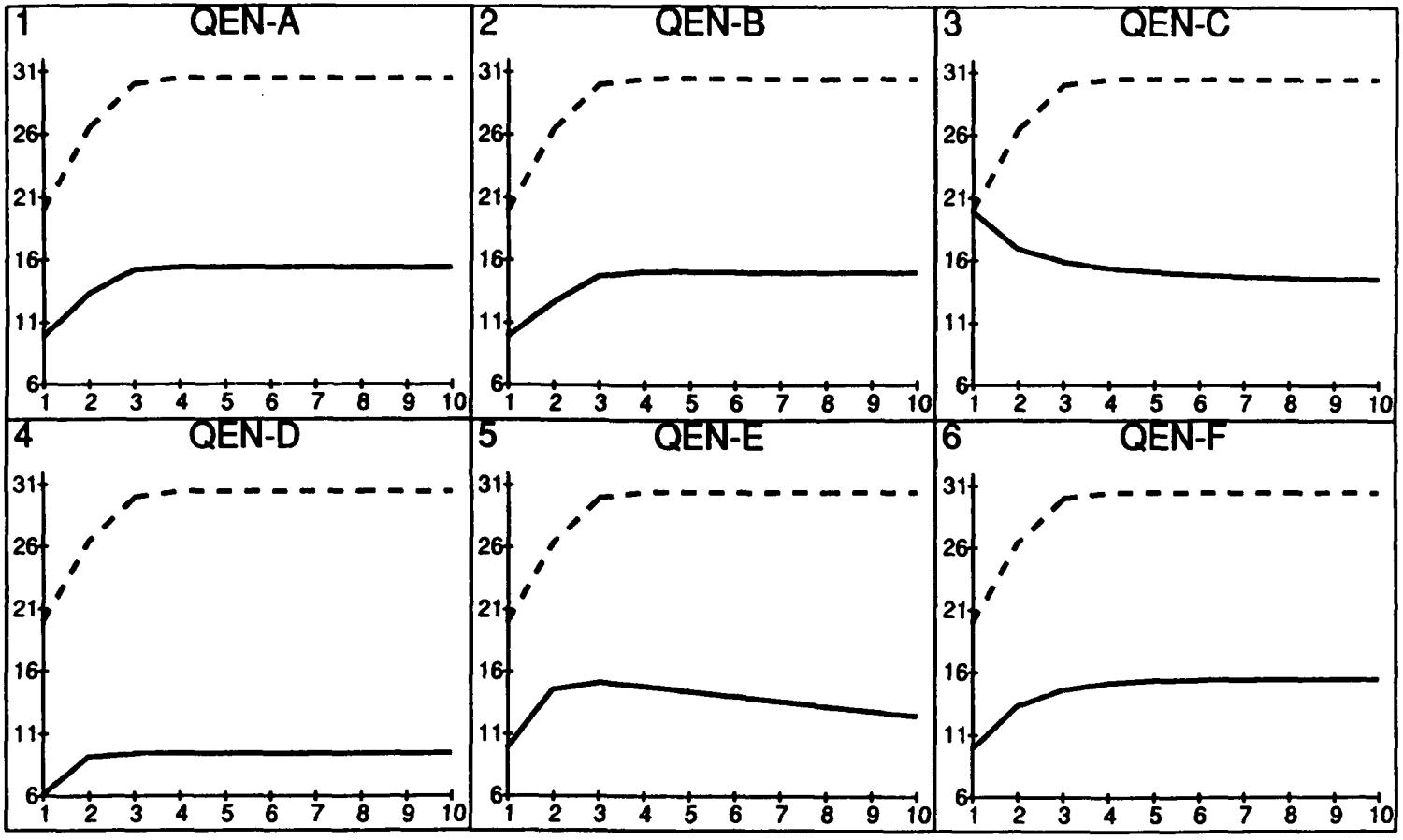

Fig. 11--Policy effects on quantity--exponential quantity-taking model

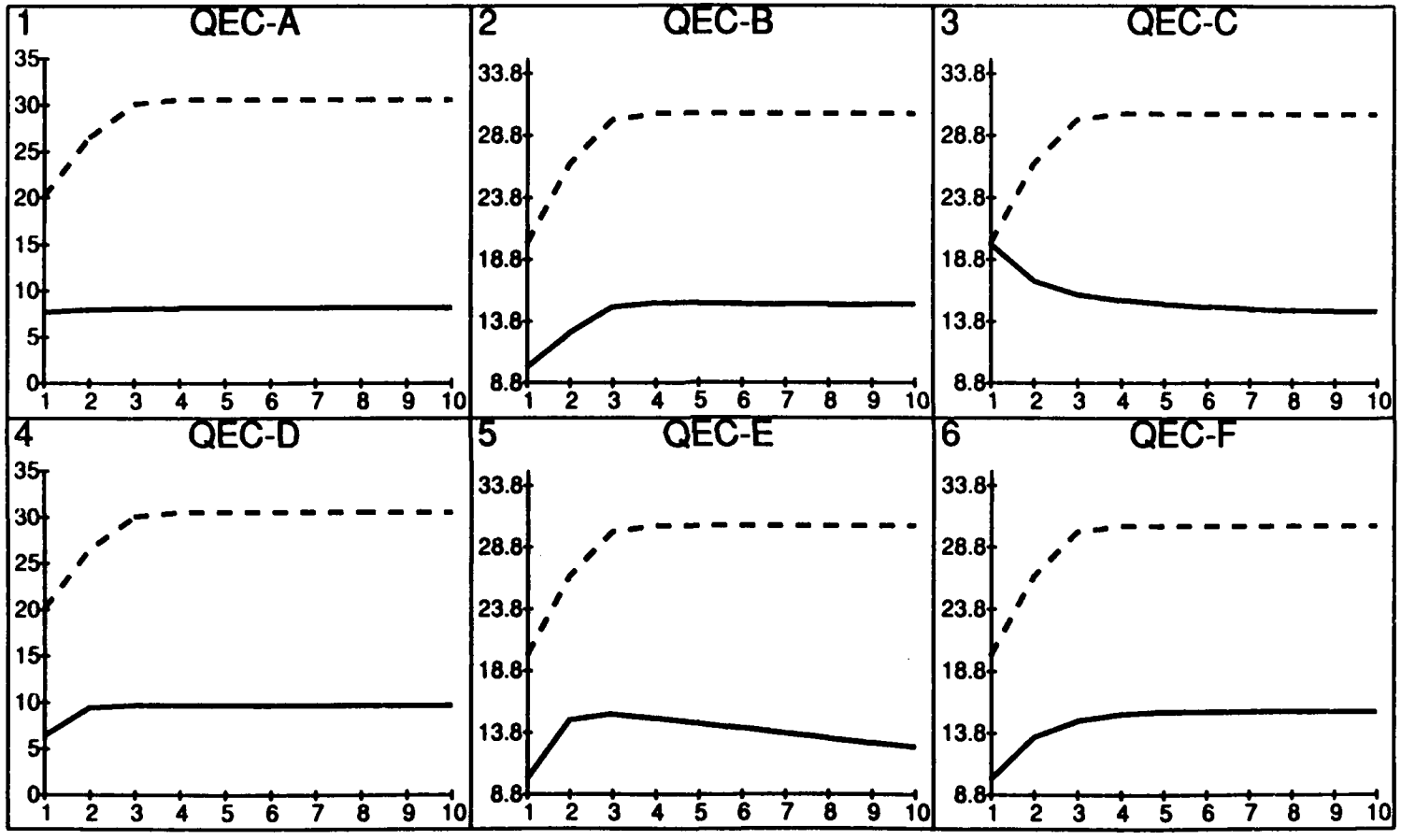

Fig. 12 --Policy effects no quantity--exponential price-taking model

Policy A uniformly increases marginal cost. Relative to the baseline, it produces a strong short-term price increase, which diminishes rapidly before increasing to a slightly higher long-term price level. The long-term effect is less than the short-term effect. Quantity-taking smugglers achieve persistently higher prices than price-takers in the exponential demand model. In the linear model, the gap between the two types of behavior develops over time: Quantity-takers are much more successful in avoiding a long-term cut in price, although they begin at similar levels.

Policy B places a mild penalty on experience. In its relation to the base case, it resembles policy A, except that the initial narrowing of the gap between policy-adjusted and baseline price is less rapid, and the long-term price increase is higher. In the exponential demand model, price-takers and quantity-takers are almost identical. In the linear model, the price level is systematically higher for quantity-takers. The price-takers' price trajectory is persistently lower and broadly declining, with a slight periodicity.

Policy C places a heavy penalty on experience, producing very different effects, mostly due to the continual entry and exit of smugglers. Compared with the baseline, a damped cycle rises broadly in the linear price-taking case, converging to a long-term increase in prices. The exponential price-taking case is similar, except that price increase is monotonic rather than cyclical. The quantity-taking model is almost identical to the price-taking model when demand is exponential. With linear demand, quantity takers have higher prices, which vary according to a lower-frequency, higher-amplitude cycle than their price-taking counterparts.

Policy D offers a higher general cost increase, the brunt of which is borne by the inexperienced. In the price-taking linear model, this leads to a big initial price increase, which quickly disappears: The long-term elevation in price is the lowest of the simulated policies. By contrast, in the price-taking exponential model the near-term behavior is the same, but this policy leads to a sustained long-term pattern of price increase that makes it one of the best policies. This

policy is not heavily affected by the nature of the strategic interaction between active smugglers.

Policy E offers a general cost increase, a mild penalty for inexperience, and a penalty for long-term experience. The big initial price rise disappears rapidly, but price rises again in the long term, when the experience penalty leads to a market whose active firms all have similar (and low) levels of experience. The sustained price rise makes this uniformly the most effective long-term policy.

Policy F is not measured in terms of a cost increase, because it reflects more rapid obsolescence of experience. In the price-taking models and the exponential quantity-taking model, it produces a damped cyclical convergence to a constant long-run price elevation. In the linear quantity-taking model, however, less durable learning is highly effective in producing a sustained increase in price.

These results demonstrate several important features of the model:

- The pattern of prices that follows the implementation of a policy need not have any simply predictable relation to the course of prices in the absence of such a policy: Even if the policy increases costs across the board, prices may rise, fall, or even fluctuate in response.
- It is important to evaluate policies in terms of the baseline that would have resulted had the policies not been followed: A policy that is accompanied by declining prices may still be judged a success if it offers a slowed rate of price decrease.
- The ranking of different policy options may be highly sensitive to the nature of the demand curve and the type of strategic interaction between active smugglers. It must be stressed that we are talking here about qualitative variables: whether demand is exponential or linear; and whether smugglers are price-takers or quantity-takers. These questions that cannot be answered by estimating the parameters of a model that prespecifies functional forms. However, there are nonparametric empirical tests that can be used. Our point here is that such tests should be done.

- Policies that differentially affect the costs of smugglers with differing degrees of experience can markedly affect the evolution of the market. In particular, long-term effects may differ from immediate ones. Under certain circumstances e.g., linear demand, the best policies concentrate on experienced smugglers, encouraging entry of novices. Under other circumstances, e.g., exponential demand, concentrating on preventing entry of novices achieves more substantial and sustained results.
- Finally, one can imagine policies that aim at making the market more purely competitive by frustrating information flows among smugglers. If elevation in market price is the measure of success, such policies are more likely to be effective when elasticity is highly variable (linear demand) than when it is not (exponential demand).

The simulation results provide much more information: detailed histories of individual smugglers, trajectories of profit and consumer surplus, etc. However, the assumptions are sufficiently difficult to verify that subjecting the data to exhaustive analysis seems unnecessary.

Table 3

TOTAL QUANTITY TRAJECTORY: LINEAR DEMAND PRICE-TAKING MODEL

Date	Base	A	B	C	D	E	F
0	9.37	8.89	8.89	9.37	8.67	8.89	8.89
1	9.54	9.19	9.14	9.13	9.27	9.29	9.19
2	9.63	9.30	9.28	9.00	9.32	9.30	9.24
3	9.67	9.32	9.30	8.95	9.32	9.27	9.26
4	9.68	9.32	9.29	8.95	9.32	9.25	9.27
5	9.68	9.32	9.29	9.09	9.32	9.21	9.28
6	9.68	9.32	9.29	9.19	9.32	9.18	9.28
7	9.68	9.32	9.29	9.07	9.32	9.15	9.28
8	9.68	9.32	9.29	9.17	9.32	9.12	9.28
9	9.68	9.32	9.29	9.06	9.32	9.09	9.29

Table 4

TOTAL QUANTITY TRAJECTORY: LINEAR DEMAND QUANTITY-TAKING MODEL

Date	Base	A	B	C	D	E	F
0	8.12	10.00	7.62	8.12	7.38	7.62	7.62
1	8.26	13.44	7.81	7.91	7.95	7.98	7.87
2	8.33	15.27	7.95	7.89	8.05	8.04	7.91
3	8.37	15.45	8.03	7.69	8.07	8.04	7.92
4	8.39	15.45	8.05	7.75	8.07	8.02	7.93
5	8.39	15.45	8.05	7.82	8.07	8.00	7.94
6	8.39	15.45	8.05	7.89	8.07	7.98	7.94
7	8.39	15.45	8.05	7.91	8.07	7.96	7.94
8	8.39	15.45	8.04	8.14	8.07	7.94	7.94
9	8.39	15.45	8.04	7.91	8.07	7.92	7.94

Table 5

PRICE TRAJECTORY: LINEAR PRICE-TAKING MODEL

Date	Base	A	B	C	D	E	F
0	0.63	1.11	1.11	0.63	1.33	1.11	1.11
1	0.46	0.81	0.86	0.87	0.73	0.71	0.81
2	0.37	0.70	0.72	1.00	0.68	0.70	0.76
3	0.33	0.68	0.70	1.05	0.68	0.73	0.74
4	0.32	0.68	0.71	1.05	0.68	0.75	0.73
5	0.32	0.68	0.71	0.91	0.68	0.79	0.72
6	0.32	0.68	0.71	0.81	0.68	0.82	0.72
7	0.32	0.68	0.71	0.93	0.68	0.85	0.72
8	0.32	0.68	0.71	0.83	0.68	0.88	0.72
9	0.32	0.68	0.71	0.94	0.68	0.91	0.71

Table 6

PRICE TRAJECTORY: LINEAR QUANTITY-TAKING MODEL

Date	Base	A	B	C	D	E	F
0	1.88	1.10	2.38	1.88	2.62	2.38	2.38
1	1.74	1.07	2.19	2.09	2.05	2.02	2.13
2	1.67	1.07	2.05	2.11	1.95	1.96	2.09
3	1.63	1.06	1.97	2.31	1.93	1.96	2.08
4	1.61	1.06	1.95	2.25	1.93	1.98	2.07
5	1.61	1.06	1.95	2.18	1.93	2.00	2.06
6	1.61	1.06	1.95	2.11	1.93	2.02	2.06
7	1.61	1.06	1.95	2.09	1.93	2.04	2.06
8	1.61	1.06	1.96	1.86	1.93	2.06	2.06
9	1.61	1.06	1.96	2.09	1.93	2.08	2.06

Table 7

TOTAL QUANTITY TRAJECTORY: EXPONENTIAL PRICE-TAKING MODEL

Date	Base	A	B	C	D	E	F
0	20.00	7.62	10.00	20.00	6.35	10.00	10.00
1	26.43	7.87	12.79	17.03	9.37	14.73	13.44
2	30.01	7.99	14.89	15.93	9.57	15.22	14.73
3	30.46	8.05	15.23	15.44	9.57	14.88	15.26
4	30.46	8.06	15.18	15.13	9.57	14.50	15.45
5	30.46	8.06	15.13	14.91	9.57	14.09	15.45
6	30.46	8.06	15.10	14.76	9.57	13.69	15.45
7	30.46	8.06	15.08	14.65	9.57	13.29	15.45
8	30.46	8.06	15.06	14.57	9.57	12.91	15.45
9	30.46	8.06	15.05	14.52	9.57	12.56	15.45

Table 8

TOTAL QUANTITY TRAJECTORY: EXPONENTIAL QUANTITY-TAKING MODEL

Date	Base	A	B	C	D	E	F
0	19.90	9.82	9.82	19.90	6.06	9.82	9.82
1	26.34	13.25	12.59	16.86	9.13	14.56	13.25
2	29.94	15.12	14.72	15.83	9.37	15.10	14.56
3	30.39	15.32	15.11	15.33	9.37	14.76	15.11
4	30.39	15.32	15.05	15.02	9.37	14.38	15.31
5	30.39	15.32	15.01	14.81	9.37	13.97	15.32
6	30.39	15.32	14.98	14.65	9.37	13.56	15.32
7	30.39	15.32	14.96	14.54	9.37	13.17	15.32
8	30.39	15.32	14.94	14.47	9.37	12.79	15.32
9	30.39	15.32	14.93	14.42	9.37	12.43	15.32

Table 9

PRICE TRAJECTORY: EXPONENTIAL PRICE-TAKING MODEL

Date	Base	A	B	C	D	E	F
0	1.05	2.38	1.10	1.05	1.16	1.10	1.10
1	1.04	2.13	1.08	1.06	1.11	1.07	1.07
2	1.03	2.01	1.07	1.06	1.10	1.07	1.07
3	1.03	1.95	1.07	1.06	1.10	1.07	1.07
4	1.03	1.94	1.07	1.07	1.10	1.07	1.06
5	1.03	1.94	1.07	1.07	1.10	1.07	1.06
6	1.03	1.94	1.07	1.07	1.10	1.07	1.06
7	1.03	1.94	1.07	1.07	1.10	1.08	1.06
8	1.03	1.94	1.07	1.07	1.10	1.08	1.06
9	1.03	1.94	1.07	1.07	1.10	1.08	1.06

Table 10

PRICE TRAJECTORY: EXPONENTIAL QUANTITY-TAKING MODEL

Date	Base	A	B	C	D	E	F
0	1.05	1.10	1.10	1.05	1.17	1.10	1.10
1	1.04	1.08	1.08	1.06	1.11	1.07	1.08
2	1.03	1.07	1.07	1.06	1.11	1.07	1.07
3	1.03	1.07	1.07	1.07	1.11	1.07	1.07
4	1.03	1.07	1.07	1.07	1.11	1.07	1.07
5	1.03	1.07	1.07	1.07	1.11	1.07	1.07
6	1.03	1.07	1.07	1.07	1.11	1.07	1.07
7	1.03	1.07	1.07	1.07	1.11	1.08	1.07
8	1.03	1.07	1.07	1.07	1.11	1.08	1.07
9	1.03	1.07	1.07	1.07	1.11	1.08	1.07

Appendix

USER'S GUIDE TO THE COMPUTER MODEL

This appendix describes the structure and operation of the Lotus-based simulation model accompanying this Note. The model examines the dynamic behavior of a smuggler's market under a variety of parametric conditions. These conditions, which can be altered by the user, include:

- the market demand curve,
- individual smugglers' cost curves,
- the rate at which experience becomes obsolete,
- the rate at which experience lowers costs,
- the structure of the smugglers' market (pure competition, Cournot-Nash noncooperative behavior, or collusive cartel),
- the rationale for entry decisions (current price, current quantity, or post-entry profits), and
- various law enforcement parameters.

The model must be run in conjunction with Lotus release 2.1 (or higher). In what follows, keyboard entries are enclosed in quotation marks ("keyboard entry"). The Return key is denoted ~.

To begin using the model:

- Use the "123" command to bring up a blank spreadsheet.
- Use either "/fd" or "/wgdd" to change the source directory to the drive containing the model files. These files are named A and B.
- Use the command "/frA~" to recall model A and begin execution. If you wish to interrupt model execution, use the command "ctrl+break." Here the "+" symbol means that the indicated keys are to be pressed simultaneously. If you use the "ctrl+break" command when the model is computing, you will be

returned to the top-level menu. If you use this command when in a menu, you will be returned to Ready mode. If you wish to return to automatic operation in any of the models, use the command "alt+a".

The screen display has been adjusted to provide maximum information and also to minimize processing delays caused by the need to redraw the screen. The display is broken into two windows, and several columns are hidden. To modify hidden data, such as the initial cost vector C(0), or to modify formulae, return to Ready mode (using "ctrl+break" or the Quit option in the top-level menu) and clear the display using "ctrl+c". To return the display to its normal mode and reinvoke the top-level menu, use "ctrl+r".

When model A has been retrieved, you will see a menu at the top of the screen. If you use the directional arrows to move the highlight to a given menu option, you will see a short decription of what that option does. To select an option, either type "~" (Return) when your choice is highlighted or type the first letter or number of the desired menu item.

Some menu items cause the model to do certain calculations. Others lead to subordinate menus. Still other options allow the user to adjust certain parameters of the model. If you select such an option, simply type in the value you wish and hit the return key. Figure 15 shows the tree structure of the menus for Model A.

Tables 11-14 describe the menu entries in more detail.

OTHER ADJUSTMENTS

One set of data is not menu-adjustable: the vector of initial costs c_i with which the simulation begins. This can be modified by returning to Ready mode (by selecting "Quit" from the top-level menu), typing "alt+c" to clear the windows and display hidden data, and entering the new values by hand in the column labelled Ci0. To reset the display and resume execution, type "alt+r".

```
                                                                                  Menu
                                                                                  Number
 ____________________________________________________________________
|      :        :     :         :       :       :      :        |
| Econ : Policy : Run : Dry Run : Clear : Graph : Keep : Quit   |      I
|__|___:___|____:_____:_________:_______:___|___:__|___:________|
   |       |                                |      |. . . . . . . .
+. | ......|                                |...................  |
|  |                                                              |  |
|  V_____________________________________________________         |  |
| |      :     :    :      :     :        :     :      |        |  |
| |1 Type:2 Int:3 P':4 Disc:5 MC':6 Min MC:7 MOS:Return|        |  |   II
| |___|__:_____:____:______:_____:________:_____:______|        |  |
|     |     ________________                                    |  |
|     +--->|      :           |                                  |  |
|          |Linear:Exponential|                                  |  |   IIA
|...       |______:___________|                                  |  |
   |                                                              |  |
   V_____________________________________________________________  |  |
  |       :     :          :        :     :     :      :      |  |  |
  |1 Const:2 Exp:3 ExpxTime:4 Regime:5 LC':6 Sim:7 Mode:Return|  |  |   III
  |_______:_____:__________:____|___:_____:_____:__|___:______|  |  |
                                |                  |             |  |
   _______ _____________________V______            |        ....|  |
  |           :              :         |           |        |     |
  |Competitive:Noncooperative:Collusive|           |        |     |   IIIA
  |___________:______________:_________|           |        |     |
                                                   |        |     |
        ____________________________               |        |     |
       |     :        :              |<------------+        |     |
       |Price:Quantity:Sophisticated|                       |     |   IIIB
       |_____:________:______________|                       |     |
                                                             |     |
   ____________________________________________________      |     |
  |        :     :     :       :       :         :      |<--+     |
  |Quantity:Price:Indiv:Numbers:Surplus:Each Rent:Return|         |   IV
  |________:_____:_____:_______:_______:_________:______|         |
                                                                  |
                                                                  |
   ____________________________________________________           |
  |        :     :     :       :       :         :      |<--------+
  |Quantity:Price:Indiv:Numbers:Surplus:Each Rent:Return|            V
  |________:_____:_____:_______:_______:_________:______|
```

Fig. 13--Menus in Model A

Table 11

DESCRIPTION OF TOP-LEVEL MENU CHOICES

Name	Description
Econ	"Demand, Cost, and Experience Functions"--invokes menu II.
Policy	"Enforcement Strategy, Learning Curve, Simulation Length" --invokes menu III.
Run	"Compute Dynamic equilibrium"--performs the simulation.
Store	"Store Output File"--stores the output data (see below) in another worksheet file.
Clear	"Clear Output Table and Reset for Next Run"
Graph	"Display Output Graphs"--invokes menu IV.
Keep	"Save Output Graphs"--invokes menu V.
Quit	"Return to Ready Mode"--See "Other Adjustments" heading below.

Table 12

DESCRIPTION OF ECON MENU CHOICES

Name	Description
1 Type	"$P = A + BQ^{-C}$"--invokes submenu IIA, which allows selection of linear or inverse exponential demand function and automatically adjusts A and B.
2 Int	"$P = A + BQ^{-C}$"--allows the user to set the P-intercept of the demand function.
3 P'	"$P = A + BQ^{-C}$"--allows the user to set the slope of the demand function.
4 Disc	"Rate at which previous experience is discounted (0 = only last time counts)"--controls the obsolescence of learning-by-doing. The conventional learning curve is represented by the value 1.
5 MC'	"Common slope of marginal cost curves"--in this model, smuggler i's total cost is $(\alpha/2)(q - \mu)^2 + q_{Ci}$. This option allows the user to adjust α.
6 Min MC	"Limiting shut-down cost of experienced firm"--allows the user to adjust the minimum average cost of a "completely experienced" firm.
7 MOS	"Common minimum optimal scale"--allows the user to adjust μ, the quantity at which average cost is minimized.
Return	Return to menu I.

Table 13

DESCRIPTION OF POLICY MENU CHOICES

Name	Description
1 Const	"Fixed Increment to Marginal Cost"--allows the user to set the level of across-the-board law enforcement pressure, affecting all firms independently of history.
2 Exp	"Rate at which increment to marginal cost changes with experience"--allows the user to select either a positive (more experienced smugglers face higher pressure) or negative (inexperienced smugglers face higher pressure) level.
3 Exp x Time	"Rate at which increment to marginal cost changes with ExT"--mimics the effect of learning by the authorities.
4 Regime	"Price-taking, Cournot, or Collusive Behavior"--leads to submenu IIIA, and allows the user to select pure competition (each smuggler takes price as given), noncooperation (each smuggler takes the others' quantities as given), or collusion (all smugglers act to maximize their collective profits) for active smugglers.
5 Mode	"Entry: current price, current quantity, post-entry profit" --allows the user to select the degree of sophistication shown by new entrants.
6 LC'	"Slope of the Learning Curve"--controls the rate at which the logarithm of experience decreases costs.
7 SIM	"Length of Simulation"--allows the user to set the number of periods for which equilibria are computed and also adjusts the display of the results. To perform a T period simulation, select this option, type the number T, then (Ret), then the number T-1, then (Ret) again.
Return	"Return to Main Menu"

Table 14

DESCRIPTION OF DISPLAY MENU CHOICES

Name	Description
Quantity	"Display (Save) Graph of Total Quantity versus Date"
Price	"Display (Save) Graph of Price versus Date"
Individual	"Display (Save) Graph of Individual Quantities versus Date"
Number	"Display (Save) Graph of Number of Active Smugglers versus Date"
Surplus	"Display (Save) Graph of Producer and Consumer Surplus versus Date"
Each Rent	"Display (Save) Graph of Individual Profits versus Date"
Return	Return to Main Menu

NOTE: The options are the same for both the "Display" and "Keep" Menus: the former merely shows selected graphs on-screen, and the latter also saves the results for later printing. Once the output files have been processed (Model B), these and other graphs can be reproduced.

OUTPUTS

The model computes various data for each date, including:

- the total quantity produced,
- the market price,
- the number of active smugglers,
- the quantity shipped by each smuggler,
- the average quantity shipped by the "fringe" (the active smugglers, if any, whose costs are at least fifth from the lowest)--this number is used in the graph cf individual quantities,

- the number of equilibria, if there are more than one--the results reported in the model correspond to the equilibrium with the largest total shipments and number of active smugglers,
- the profits earned by each smuggler,
- the total profits (producer surplus) earned by all smugglers,
- the average profit earned by active fringe smugglers, and
- the consumer surplus.

These data are contained in the output file produced by the "Store" command. To prepare them for easy access and comparison, "/fr" (retrieve) the file named "B.wk1". You will see a menu with three entries:

- **More**--this allows you to process output files.
- **Graph**--this allows you to see, in succession, the standard graphs (as in Table 14) of the current output file.
- **Quit**--this returns you to Ready mode and is used when you wish to exit.

REFERENCES

Fudenberg, D. and J. Tirole, "Learning-by-doing and Market Performance," *Bell Journal of Economics, 14*, No. 2, August 1983, pp. 522-530.

Haltiwanger, J. and M. Waldman, "Responders Versus Nonresponders: A New Perspective on Heterogeneity," University of California at Los Angeles, October 1986 (mimeo.).

Mookherjee, D. and D. Ray, "Dynamic Price Games and Learning-by-doing," Stanford University, March 1986 (mimeo.).

Reuter, P. and M. Kleinman, "Risks and Prices: An Economic Analysis of Drug Enforcement," M. Tonry and N. Morris (eds.), *Crime and Justice: An Annual Review of Research, 7*, 1986.

Spence, A. M., "The Learning Curve and Competition," *Bell Journal of Economics, 12*, No. 1, Spring 1981, pp. 49-70.

Warner, Roger, *Invisible Hand: The Marijuana Business,* William Morrow, New York, 1986.