Web Appendix

In this web appendix we publish the extended discussion and extensions mentioned in section 4. We also publish the Tables from that originally appeared in the Appendix.

Extension: crackdowns persist if citizens' utility function is nonlinear

The model developed in this paper assumes that the utility function was linear in the benefit, x, from committing a crime. The linearity assumption can be relaxed. Suppose citizens have a utility function u that is increasing in x. Then they will commit a crime iff

$$(1-p)\,u(x) + pu(x-T) > u(0)\,.$$

Consider the set of values of x such that the inequality is satisfied, and denote by $H(p)$ the measure of this set. The function $H(p)$ represents the crime rate. Note that since u is increasing, the left hand side is increasing in x and, also, $u(x) > u(x-T)$ whereby the left hand side is decreasing in p. Therefore, the set of values of x such that the inequality is satisfied decreases as p increases. This means that $H(p)$ is decreasing in p. The analysis of Sections 2 and 2.3 can then be carried out replacing F with H.

Extension: crackdowns persist if the crime decision is continuous

Suppose that instead of a binary problem (committing a crime or not), each citizen solves a more complicated problem involving not only whether to commit a crime, but also the degree to which to commit it. For example, a motorist may choose whether to speed and how much to speed. Suppose that the penalty for driving at s miles per hour above the speed limit is an non-decreasing function $T(s)$ (which could be equal to zero below the speed limit) and that the agent's utility from exceeding the speed limit by s is an increasing function $x(s)$. We allow different individuals to have different functions $x(s)$.

Given a certain level of interdiction p, an agent with a given function $x(\cdot)$ solves

$$\max_s x(s) - pT(s).$$

Denote with $s^*(p)$ the maximizer of this problem. Denote by $\widetilde{F}(s|p)$ the fraction of individuals who choose to travel at or below speed s for given p. The quantity $\widetilde{F}(s|p)$ will depend on the distribution of the functions $x(\cdot)$ that is present in the population. It is easy to see, however, that the optimal speed $s^*(p)$ is decreasing (or at least not increasing) in $p: s'(p) = T'/(x'' - pT'')$ is negative by the concavity of $x - pT$ at the maximum. This means that any motorist, regardless of his or her $x(\cdot)$, will decrease his or her optimal speed as the probability of being monitored increases. The function $\widetilde{F}(s|p)$ is therefore increasing in p.

If police cared not only about the fraction of people who exceed the speed limit, but also about their speeding levels, the police's objective function would be represented by the function

$$D(p) \equiv \int K(s)\, d\widetilde{F}(s|p),$$

where $K(s)$ is some non-decreasing function. The function $K(s)$ represents the disutility that the police receives from having one motorist travel at speed s. Because $\widetilde{F}(s|p)$ is increasing in p, the function $D(p)$ is decreasing in p. Now, rewrite problem (2) replacing $1 - F(p)$ with $D(p)$. This yields a mathematical formulation of the problem in which motorists can choose the amount of speeding and police care not only about the fraction of speeders but also about their speed. From a formal viewpoint this new formulation is similar to the original problem. Therefore, all the qualitative features of the solution to the original problem carry over, including the optimality of crackdowns when the function $D(p)$ exhibits non-convexities.

Other Applications

The ideas developed in this paper have potential applications beyond speeding. In this section, we consider some of them.

Tax Evasion and Drug Interdiction

Suppose the principal cares about reducing the crime of drug production, but the principal can only observe the drugs that make it to the market without being intercepted. In that case, police performance will have to be evaluated based on undetected crime. Sometimes, minimization of undetected crime may even arise as a first-best option. For example, a principal may find it optimal to give incentives to the police based on *undetected* crime when detection removes the social cost of the crime. This is the case for example with illegal firearms, where if a firearm is intercepted it is taken off the street. The same is true for tax evasion. The objective of the tax authority is to minimize undetected crime.

When a group is monitored with intensity p, the fraction of crime in the group that goes undetected is $(1-p)(1-F(pT))$. Given a policing strategy μ, undetected crime is given by

$$\int_0^{\overline{p}} \mu(p)(1-p)(1-F(pT)) \; dp. \tag{9}$$

The police chooses a policing strategy μ to minimize expression (9) subject to the budget constraint (3).

This programming problem is very similar to the one studied in Section 2.1; there as well as here, the objective function is decreasing in p. This was the only property of the objective function that was used in Section 2.1, so it is immediate that Propositions 1 and 2 continue to hold in this setting.

Whether crackdowns are optimal depends, as before, on the convexity of the objective function. In the present case, it is the convexity of undetected crime that matters. If undetected crime is convex in p then crackdowns are never optimal (see Remark 1.) It is simple to verify that undetected crime is "more convex" than crime, in the sense that if $(1-F(pT))$ is convex then $(1-p)(1-F(pT))$ is also convex. Therefore, if F is such that police minimizing overall crime rates never finds it optimal to engage in crackdowns, then crackdowns are also not optimal if the objective is to minimize undetected crime.

Collecting TV-license Fees in Sweden

Under Swedish law everyone who owns a television set is required to pay the licence fee. The fee is collected by Radiotjänst, a private corporation that administers the TV-fee as well as checks out that people are actually paying the fee. The controls are carried out throughout the year. In addition, there are *special fee-controls.* These are stricter controls in 3-5 predetermined areas every year. According to the law on the TV license fee, everyone should be informed of their area being subjected to special fee-control. Among other things, this is done by postcards being sent out to all households in the area. Information is also given in advance through the media and radio, and through the TV-detecting films that are shown on TV. The special fee-controls can be interpreted as crackdown.

Consumers differ according to their taste for TV net of the cost of purchasing it, captured by x, and their psychological cost of being fined, captured by h. The two parameters are realizations from a joint probability distribution (so we allow for correlation between X and H). For all consumers, the scalar d represents the monetary cost of the fee, and the value of not having a TV is zero.

In our setup, the socially optimal outcome is for all consumers with $x > 0$ to receive the TV. However, consumers with $x < \min\{ph, d\}$ will opt not to get a TV. Thus, interdiction (increasing p) entails inefficiencies due to exclusion of some consumers. On the other hand, interdiction reduces cheating and thus increases the receipts from the fee. We want the regulated firm who collects the fine to set interdiction so as to balance fee receipts with the inefficiencies generated by interdiction.

Given an interdiction level p, the fraction of consumers who actually pay the fee are those who prefer paying the fee to not having a TV at all, and who are also more afraid to cheat than they dislike paying the fine. The fraction

$$\varphi = \Pr(X > d)$$

prefers paying the fee to not having a TV at all. So the fraction of fee-paying consumers is

$$\varphi \cdot \Pr(pH > d | X > d)$$

Let us now turn to the social cost of interdiction. While we can be sure that a fraction φ of consumers will get a TV—if necessary, by paying the fee—the remaining $(1 - \varphi)$ may actually choose not to get a TV. Those consumers will chose not to get a TV when their payoff from cheating is smaller than zero. So the fraction of consumers who do not get a TV is given by

$$(1 - \varphi) \cdot \Pr(X - pH < 0 | X < d).$$

This fraction is a measure of the social loss due to interdiction (which is increasing in p).

Denote

$$\begin{aligned} F_H(y) &= \Pr(H \leq y \,|X > d) \\ F_{X/H}(y) &= \Pr\left(\frac{X}{H} \leq y|X < d\right). \end{aligned}$$

Then the objective function is

$$\max_{\mu} \int_0^{\bar{p}} \left[d \cdot \varphi \cdot \left(1 - F_H\left(\frac{d}{p}\right)\right) - \alpha \cdot (1 - \varphi) \cdot F_{H/X}(p) \right] \mu(p)\, dp.$$

The first addend in brackets accounts for the receipts from the fee (increasing in p). The $(-\alpha)$ coefficient represents the weight assigned to the social loss. If the term in bracket is convex as a function of p then we have the possibility that crackdowns, such as are observed in Sweden, are optimal.

Appendix B: Additional Tables

Table B1
Number of Announced and Unannounced Monitoring
Events by Month and Year on all Highways†

	2000		2001		2002		2003 (first half of year)	
	Ann	Unann	Ann	Unann	Ann	Unann	Ann	Unann
January	3	7	10	12	15	17	41	3
February	10	12	7	9	17	9	45	9
March	5	6	5	3	19	26	32	24
April	3	18	6	4	24	21	36	24
May	3	10	6	8	29	11	64	21
June	4	14	4	11	27	8	57	20
July	7	13	6	10	31	6	*	*
August	8	7	7	8	32	1	*	*
September	4	9	6	7	29	6	*	*
October	3	18	5	5	41	12	*	*
November	3	17	6	13	36	6	*	*
December	13	21	7	16	37	3	*	*
Total	66	152	75	106	337	126	275	101

†Sample includes all monitoring events.

Table B2
Number of Announced and Unannounced Monitoring
Events by Day of Week and Year on all Highways†

	2000		2001		2002		2003 (first half of year)	
	Ann	Unann	Ann	Unann	Ann	Unann	Ann	Unann
Saturday	8	38	23	27	40	19	36	6
Sunday	17	29	10	34	64	31	29	20
Monday	8	17	6	11	24	12	48	11
Tuesday	7	15	12	8	68	17	40	17
Wednesday	10	16	13	9	58	14	37	20
Thursday	6	19	7	9	39	22	43	11
Friday	10	18	4	8	44	11	42	16
Total	66	152	75	106	337	126	275	101

†Sample includes all monitoring events.

Table B3
Estimated Logistic Model for the Probability of Monitoring
when there is no announcement, by Year and by Road†
Dep. Var: Indicator for Whether Monitoring Occurred

	Highway		
Variables*	A10	A14	R4
Intercept	-2.50	-2.43	-4.36
	(0.36)	(0.36)	(0.58)
quarter 1	0.37	-0.12	0.45
	(0.25)	(0.44)	(0.45)
quarter 2	-0.19	0.44	0.55
	(0.28)	(0.20)	(0.43)
quarter 3	-1.90	-0.47	0.11
	(0.49)	(0.22)	(0.44)
announced last week	0.15	-0.12	0.04
	(0.35)	(0.20)	(0.49)
announced yesterday	-0.22	-0.29	…
	(0.41)	(0.23)	
monitored last week	0.78	1.95	2.11
	(0.40)	(0.36)	(0.34)
monitored yesterday	0.37	0.48	-1.21
	(0.36)	(0.19)	(0.64)
some announcement same	0.71	-0.84	-1.34
day on any road	(0.23)	(0.20)	(0.50)
year 2001	-0.15	-0.67	0.28
	(0.29)	(0.20)	(0.34)
year 2002	-0.10	0.27	-0.26
	(0.32)	(0.20)	(0.54)
year 2003	-0.01	0.41	…
	(0.31)	(0.24)	
Number of observations	1273	1302	1451
% Correctly classified	76.1%	73.4%	80.7%

† The sample consists of three potential monitoring events for each day of the year, excluding those events during which an announcement was made. The covariates are used to predict whether there was monitoring during events when there was no announcement.

* The specification also includes fixed effects for day of week.

Table B4
Expected Length of Time Spent Monitoring, by Year and By Road
Dep Var: Hours Spent Monitoring During a Given Event†

	Highway					
	A10		A14		R4	
	Ann	Unann	Ann	Unann	Ann	Unann
Intercept	0.56	0.16	0.25	0.14	0.40	0.32
	(0.22)	(0.08)	(0.24)	(0.07)	(0.19)	(0.08)
quarter 1	0.07	-0.03	0.01	-0.01	0.29	-0.04
	(0.06)	(0.05)	(0.06)	(0.04)	(0.23)	(0.04)
quarter 2	-0.06	-0.06	-0.10	-0.01	0.05	-0.09
	(0.05)	(0.05)	(0.06)	(0.03)	(0.20)	(0.04)
quarter 3	-0.06	-0.06	-0.01	0.06	0.34	0.001
	(0.06)	(0.09)	(0.06)	(0.04)	(0.18)	(0.04)
year 2001	0.12	0.04	0.12	0.03	…	0.002
	(0.11)	(0.05)	(0.08)	(0.03)		(0.04)
year 2002	-0.09	0.07	-0.02	0.07	…	0.02
	(0.10)	(0.06)	(0.07)	(0.03)		(0.06)
year 2003	-0.13	0.14	-0.04	0.10	…	…
	(0.10)	(0.06)	(0.08)	(0.04)		
announced last week	-0.11	-0.0002	-0.04	-0.004	-0.15	0.04
	(0.11)	(0.06)	(0.07)	(0.03)	(0.17)	(0.04)
announced yesterday	-0.004	0.01	0.03	0.01	…	…
	(0.07)	(0.06)	(0.06)	(0.03)		
monitored last week	-0.01	0.002	0.22	-0.03	-0.03	0.01
	(0.06)	(0.06)	(0.11)	(0.05)	(0.16)	(0.03)
monitored yesterday	-0.004	-0.04	-0.04	0.01	…	-0.007
	(0.07)	(0.06)	(0.05)	(0.03)		(0.05)
some announcement same day on any road	…	-0.03	…	-0.05	…	-0.04
		(0.03)		(0.03)		(0.05)
Medium traffic density	…	…	…	0.02	-0.02	-0.24
				(0.15)	(0.23)	(0.08)
Moderate traffic density	-0.10	-0.06	…	0.07	0.03	-0.21
	(0.36)	(0.18)		(0.15)	(0.13)	(0.06)
Light traffic density	-0.19	0.002	0.08	0.11	…	-0.19
	(0.18)	(0.06)	(0.21)	(0.06)		(0.06)
Holiday	0.06	0.02	0.02	-0.03	…	0.03
	(0.07)	(0.05)	(0.07)	(0.03)		(0.04)
Number of observations	346	122	394	309	10	51
R-squared	0.12	0.11	0.07	0.07	0.84	0.45

† This regression is used to predict the length of time spent monitoring. The sample includes all monitoring event, with and without announcements.
* All specifications also include fixed effects for day of week. The variable "holiday" was not included in the above specifications because of too few observations.

Table B5
Average Predicted Probability of Monitoring

Year	highway	no-announcement	no-announcement this sector, announced other sector	Announcement
2000	A10	0.004	0.009	0.27
	A14	0.011	0.003	0.26
	R4	0.009	0.002	0.29
2001	A10	0.004	0.007	0.30
	A14	0.011	0.003	0.30
	R4	0.014	*	0.35
2002	A10	0.008	0.010	0.20
	A14	0.027	0.007	0.24
	R4	0.001	0.001	*
2003	A10	0.011	0.018	0.19
	A14	0.030	0.020	0.23
	R4	*	*	*

* Too few observations in the cell.

Table B6
Estimated Logistic Model for the Probability of Announcement by Highway†
Standard errors shown in parentheses
Dep. Var: Indicator for Whether Announced During Given Event

Variables*	Highway A10		A14		R4	
Intercept	-3.76	-4.07	-4.94	-4.90	-2.65	-3.20
	(0.36)	(0.61)	(0.40)	(0.41)	(0.82)	(1.46)
quarter 1	0.08	0.10	-0.004	0.02	-1.18	-1.19
	(0.21)	(0.22)	(0.20)	(0.21)	(1.18)	(1.18)
quarter 2	0.22	0.17	0.02	0.03	-0.20	-0.91
	(0.21)	(0.22)	(0.20)	(0.19)	(0.89)	(1.82)
quarter 3	-0.23	-0.23	-0.01	-0.003	0.48	-0.06
	(0.22)	(0.22)	(0.20)	(0.20)	(0.84)	(146)
Holiday	2.23	2.13	0.98	0.99	2.50	2.28
	(0.47)	(0.50)	(0.27)	(0.27)	(1.34)	(1.45)
announced last week	0.34	0.26	-0.18	-0.17	-0.06	0.48
	(0.36)	(0.38)	(0.21)	(0.22)	(0.96)	(1.56)
announced yesterday	-0.52	-0.52	0.19	0.19	…	…
	(0.29)	(0.29)	(0.21)	(0.21)		
monitored last week	1.38	1.41	2.65	2.63	-0.35	-0.32
	(0.41)	(0.41)	(0.38)	(0.39)	(0.80)	(0.80)
monitored yesterday	0.25	0.24	-0.31	-0.31	…	…
	(0.27)	(0.27)	(0.19)	(0.19)		
year 2001	0.06	-0.008	0.42	0.45	-2.39	-2.67
	(0.03)	(0.36)	(0.23)	(0.24)	(1.07)	(1.24)
year 2002**	2.13	2.31	1.55	1.53	…	…
	(0.30)	(0.42)	(0.22)	(0.22)		
year 2003	2.12	2.37	2.16	2.15	…	…
	(0.30)	(0.49)	(0.24)	(0.25)		
Fraction speeding if unannounced monitoring	…	0.05 (0.07)	…	-0.01 (0.02)	…	0.14 (0.31)
Number of observations	1620	1620	1697	1697	732	732
p-value from test of joint significance of all covariates, except year indicators	<0.0001	<0.0001	<0.0001	<0.0001	0.9015	0.9116

† The sample includes all monitoring events.
*All specifications include fixed effects for days of week. Some days of week indicators are significant for A10 and A14 in 2000 and for A14 in 2001.
**There is only one announcement day on R4 in 2001 and none thereafter, so the R4 logistic regression only includes years 2000 and 2001.

Table B7
Correlation of Announced Monitoring with Number of Speeders
and with the Proportion of Speeders on the Road
p-value shown in parentheses

	Number of Speeders	Proportion of Cars Speeding
Over all roads	-0.03	-0.26
	(0.31)	(<0.0001)
Road A10	-0.21	-0.32
	(<0.0001)	(<0.0001)
Road A14	0.05	-0.77
	(0.20)	(<0.0001)
Road R4	-0.05	-0.13
	(0.70)	(0.33)