

Private Security: Deterrent or Diversion?

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1. Introduction

Window bars, chain-link fences, and guard dogs are ubiquitous in wealthy Asian homes from New Delhi to Taipei. By contrast, all of these are rare in similar British, Canadian, and U.S. residential districts without the rate of property crime being substantially higher.¹

Generally, private security expenditures have two effects (Clotfelter, 1978; Clarke, 1983; Cook, 1986; and Shavell, 1991). First, they may *deter* some potential criminals, i.e., persuade them not to attempt crime at all. Second, they may also *divert* criminals towards other potential victims.² To the extent that security expenditures divert crime, their marginal effect on crime will be lower, which would be consistent with the contrast between Asia and the West noted above.

Empirical evidence (from Britain) on the diversionary effect, however, is mixed. The installation of additional surveillance cameras in selected London Underground stations appeared not to divert crime to other stations (Mayhew, Clarke, et al., 1979). By contrast, after steering column locks were required on new cars, theft of new cars fell, while theft of older cars rose (Mayhew, Clarke, et al., 1976). Can these two apparently conflicting observations be reconciled?

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¹With regard to institutional expenditures, Cunningham and Taylor (1984) estimated that in 1980 U.S. institutions spent a total of \$21.7 billion on private protective goods and services, compared with a total loss of \$67 billion from economic crime in the same year. Using different methods, Laband and Sophocleus (1992) give a substantially higher estimate of \$157.83 billion for security expenditures in 1985. Tullock (1967) was one of the first scholars to emphasize private security expenditures as an important consequence of crime.

²Strictly, only security expenditures that potential criminals can observe have both effects. By contrast, precautions that cannot be identified with a particular victim have only the deterrent effect (Friedman, 1984; Shavell, 1991). For instance, in British public housing, a major burglary target is coin-fed electricity and gas meters. When these were replaced by conventional billing in some houses, the burglary rate for *all* units in the estate fell. Potential burglars could not tell from outside whether a particular house had a coin meter or conventional billing (Pease, 1992).

Previous theoretical research *assumed* that security expenditures would divert crime, which assumption seems inconsistent with the London Underground study. By contrast, in this paper we seek to explain *when* security expenditures *will* divert crime. We focus on observable precautions against property crimes such as theft and robbery. Our first result is that security expenditures are *strategic complements* in the sense that, if one potential victim raises security, others will spend more as well.³ Second, the more valuable the property at risk or the more easily potential criminals can switch among victims, the more likely it is that security expenditures will divert rather than deter crime. The opposite will be true the less valuable the property or the less easily criminals can switch from one victim to another.

These results are quite consistent with the two British studies. Motorcars are relatively valuable targets, and a car thief has a wide choice of closely substitutable targets on a street or in a parking garage. So it should not be surprising that installing steering locks on some cars would divert criminals to other cars. By contrast, the pickings—handbags, wallets, etc.—at London Underground stations are relatively small. Further, stations have different physical layouts, so a thief who gains expertise at one cannot easily transfer it to another. Accordingly, installing closed-circuit TV cameras in one station will not divert many criminals to other stations.

In Section 2, we present the framework, and in Section 3 we set out the cost of crime to potential victims. Section 4 analyzes equilibrium security expenditures, and Section 5 identifies the factors that determine whether additional security will divert or deter criminals. Section 6 concludes with directions for future research.

2. Setting

Two potential victims (which may be households, retail stores, or factories) have property of identical value, v . Owing to transportation costs or differing access to information, criminals tend to specialize. For instance, workers have a natural advantage in stealing from their respective employers. With this motivation, let the victims be a unit length apart and potential criminals be distributed with uniform density between the victims. “Distance” need not be physical; it simply expresses some difference in the relative attractiveness of the two victims among potential criminals. One potential criminal is drawn at random from the population. He must incur cost t per unit distance to raid a victim.

The victims spend amounts s_i , $i = 1, 2$, respectively, on security against crime. The potential criminal can freely observe the victims’ choices of security. If the criminal targets victim i , he will either succeed and obtain revenue v from selling the stolen property, or he will fail. For simplicity, we ignore the possibility of criminal prosecution; if the criminal fails, he simply gets zero income and suffers no further consequences. All parties are risk neutral.

Let the probability that a criminal will succeed in stealing from victim i be $\rho(s_i)$, where $\rho(0) = 1$ and ρ decreases with the victim’s security, $d\rho/ds_i < 0$. We assume that the marginal return to security is high enough that both victims will choose a positive level of security. Within the range of v and t that we study, a sufficient condition is

³Bulow, Geanakoplos, and Klemperer (1985) develop the concepts of strategic substitutes and complements.

that

$$\frac{d\rho(s_i)}{ds_i} < -\frac{t}{v^2}, \quad i = 1, 2. \quad (\text{A1})$$

Further, let the marginal return diminish monotonically towards zero,

$$\frac{d^2\rho}{ds_i^2} > 0, \quad (\text{A2})$$

$$\frac{d\rho}{ds_i} \rightarrow 0 \text{ as } s_i \rightarrow +\infty, \quad i = 1, 2. \quad (\text{A3})$$

Each potential criminal has an alternative legitimate activity that yields zero expected income. Consider the potential criminal farthest from victim 1, i.e., located a unit distance away. The maximum expected gain that this criminal can attain by raiding victim 1 is $v\rho(0) - t$. For simplicity, we assume

$$v < t, \quad (\text{A4})$$

which implies that $v\rho(0) < t$. This means that, regardless of victim 1's choice of security, there will be some criminals who will always prefer the legitimate activity to raiding victim 1, and likewise for victim 2.⁴

3. Expected Cost of Crime

The prospect of theft imposes two costs on a potential victim—the expected loss of property that he suffers and the security expenditure he incurs to avert loss. Let $p_1(s_1, s_2)$ represent the probability that victim 1 will lose his property. Then his expected cost of crime is

$$E(s_1) = vp_1(s_1, s_2) + s_1. \quad (1)$$

We suppose that victim 1 chooses his security expenditure, s_1 , to minimize (1), while taking victim 2's security, s_2 , as given. Likewise for victim 2.

The first-order condition from (1) is

$$v \frac{\partial p_1}{\partial s_1} = -1. \quad (2)$$

The effect of additional security on victim 1's rate of property loss, $\partial p_1/\partial s_1$, depends on the extent to which potential criminals participate in crime. This, in turn, depends on the attractiveness of crime relative to the legitimate activity. There are two cases: *all* potential criminals attempt theft (AC), or only *some* attempt crime while the remainder take the legitimate alternative (SC).

Suppose that all potential criminals would attempt theft (case AC). Consider one located at a distance ℓ from victim 1. His expected return from attempting theft will be $v\rho(s_1) - t\ell$ from victim 1, and $v\rho(s_2) - t(1 - \ell)$ from victim 2. He will be just indifferent between the two targets if $v\rho(s_1) - t\ell = v\rho(s_2) - t(1 - \ell)$, or

⁴This assumption ensures that each victim's choice of security is a problem with at most two local minima.

$$\ell = \frac{1}{2t} [t + v\rho(s_1) - v\rho(s_2)]. \quad (3)$$

All potential criminals at a distance of less than ℓ will target victim 1. Since each attempt will succeed with probability $\rho(s_1)$, victim 1 will suffer theft at a rate

$$p_1(s_1, s_2) = \int_0^\ell \rho(s_1) dx = \ell\rho(s_1). \quad (4)$$

Notice from (3) and (4) that if victim 2 increases security, he will divert some potential criminals to victim 1 and thereby add to victim 1's crime rate (Clotfelter, 1978).

In Figure 1, curve A represents victim 1's expected cost in this case (AC).⁵ Differentiating (4) and substituting in (2), the minimum point of curve A is given by

$$v \left[\ell + \frac{v}{2t}\rho(s_1) \right] \frac{d\rho}{ds_1} = -1. \quad (5)$$

The alternative possibility is that some potential criminals will avoid crime altogether (case SC). Intuitively, these find *both* victims unattractive relative to the legitimate activity. Let the most distant criminal to target victim 1 be located at a distance ℓ_1 . Since this criminal is just indifferent between attempting theft at victim 1 and the legitimate activity,

$$v\rho(s_1) - t\ell_1 = 0. \quad (6)$$

Hence victim 1's probability of theft is

$$p_1 = \int_0^{\ell_1} \rho(s_1) dx = \frac{v}{t} [\rho(s_1)]^2. \quad (7)$$

In this case (SC), additional security by one victim forces more potential criminals to "go legitimate" and does not divert crime.

Curve S in Figure 1 represents victim 1's expected cost of crime in this case. Differentiating (7) and substituting in (2), the following characterizes the minimum point of curve S,

$$\frac{2v^2}{t} \rho(s_1) \frac{d\rho}{ds_1} = -1. \quad (8)$$

By (6), a potential criminal located at a distance $\ell_1 = v\rho(s_1)/t$ from victim 1 and $\ell_2 = v\rho(s_2)/t$ from victim 2 would be just indifferent among the two victims and the legitimate alternative if $\ell_1 + \ell_2 = 1$, i.e., $t/v = \rho(s_1) + \rho(s_2)$. Define $\bar{s}_1(s_2, v, t)$ by

$$\frac{t}{v} = \rho(\bar{s}_1) + \rho(s_2). \quad (9)$$

If victim 1 chooses s_1 exceeding the critical level, \bar{s}_1 , then some potential criminals would prefer the legitimate activity to attempting theft from either victim. For these potential criminals, the cost of crime is too high relative to the expected gain. If, however, victim 1 chooses $s_1 < \bar{s}_1$, then the two victims' security is low enough that

⁵As explained below, whether all potential criminals attempt crime depends on the magnitude of s_1 relative to s_2 . Please refer to the Appendix for a formal derivation of the curves in Figure 1.

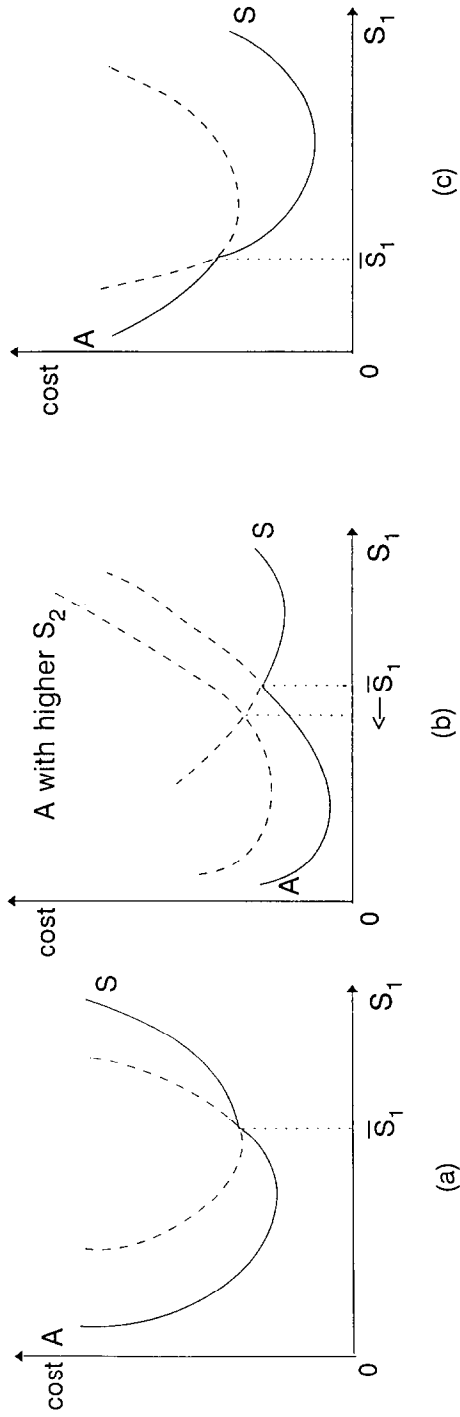


FIG. 1. Expected cost of crime.

all potential criminals will attempt crime. So, given s_2 , victim 1's security $s_1 > \bar{s}_1$ characterizes case SC, while $s_1 < \bar{s}_1$ characterizes case AC.

Thus, beginning with small values of s_1 , victim 1's expected cost of crime follows curve A until $s_1 = \bar{s}_1$. By (1), (3), and (4), victim 1's expected cost of crime along A is

$$E(s_1) = \frac{v}{2t} [t + v\rho(s_1) - v\rho(s_2)] \rho(s_1) + s_1.$$

By (9), at $s_1 = \bar{s}_1$, this cost simplifies to

$$E(s_1) = \frac{v^2}{t} [\rho(s_1)]^2 + s_1,$$

which, by (1) and (7), is victim 1's expected cost along curve S. Accordingly, curves A and S meet at $s_1 = \bar{s}_1$, and victim 1's expected cost follows curve S for all $s > \bar{s}_1$. Figure 1 illustrates the three possible relations between curves A and S.

4. Equilibrium Security

In this section we show that private security expenditures are strategic complements, and consequently, that there may exist multiple equilibria.⁶ Consider the effect of an increase in (victim 1's beliefs about) s_2 . When $s_2 = 0$, victim 1 will, by (A1), choose $s_1 > 0$. By (1), (3), and (4), an increase in s_2 will *raise* the curve A, i.e., assuming that all potential criminals attempt crime, the increase in s_2 will push some criminals towards victim 1 and thereby raise the latter's cost of crime. By (1) and (7), however, an increase in s_2 will have no effect on curve S. So, in general, when s_2 is sufficiently low, victim 1 will choose some $s_1 < \bar{s}_1$, thus inducing case AC, while for sufficiently large s_2 , he will choose some $s_1 > \bar{s}_1$ (case SC).

When s_2 is sufficiently low that victim 1 chooses $s_1 < \bar{s}_1$ (case AC), an increase in s_2 will divert potential criminals toward victim 1. By (1), (3), and (4), the marginal product of victim 1's security

$$v \frac{\partial}{\partial s_1} [\ell \rho(s_1)] = v \left(\ell + \frac{v\rho}{2t} \right) \frac{\partial \rho}{\partial s_1},$$

which is increasing in victim 2's security expenditure, s_2 . Intuitively, when victim 2 raises security, he pushes more potential criminals towards victim 1, so each dollar that victim 1 spends on security reduces the success rate of a larger number of criminals. Hence, the higher victim 2's security, s_2 , the greater will be victim 1's marginal product from additional security. Thus, in case AC security expenditures are strategic complements.

In case SC, an increase in s_2 does not affect the number of potential criminals who target victim 1 and hence will have no effect on victim 1's marginal product of security. Accordingly, we conclude that⁷

⁶If two parties are symmetric, then multiple equilibria can arise only if their strategic variables are strategic complements (Bulow, Geanakoplos, and Klemperer, 1985).

⁷Please refer to the Appendix for detailed proofs of this and the next proposition.

PROPOSITION 1: *Victims' security expenditures are strong strategic complements when all potential criminals attempt theft and are weak strategic complements otherwise.*

Recall that when $s_2 = 0$, victim 1 will choose $s_1 > 0$, hence victim 1's reaction function begins below the 45-degree line (Figure 2). Then, as s_2 rises, victim 1's best-response s_1 rises as well (case AC). So the reaction function slopes upward. Note from Figure 1 that as s_2 rises from 0, causing curve A to rise, there will be some s_2 at which the minimum points of curves A and S will be level. A further increase in s_2 will lead victim 1's choice of security to jump from case AC to case SC. This implies that victim 1's reaction function is discontinuous.

When victim 2's security is sufficiently high (case SC), victim 1's choice of security will be independent of victim 2's, i.e., in terms of Figure 2, victim 1's reaction function turns vertical. Since the two victims are identical, they will have identical reaction functions; hence, in equilibrium, they will choose identical levels of security. Referring to Figure 2, victim 1's reaction function begins below the 45-degree line, slopes upward, and then, at some point, jumps to a vertical portion. Thus the reaction function must cross the 45-degree line, which implies that there always exists an equilibrium.

The contrast between Asia and the West motivates us to consider whether the "arms race" between the potential victims might generate multiple equilibria. We first show that there can be at most one equilibrium of the AC type. Given such an equilibrium, suppose that victim 2 were to raise s_2 . Then, by Proposition 1, victim 1 will raise security. The issue here is by how much? Since $s_1 = s_2$ is a necessary condition for an equilibrium, if s_1 does not keep pace with the increase in s_2 , then there cannot be another AC-type equilibrium. Additional security by victim 1 has two effects: first,

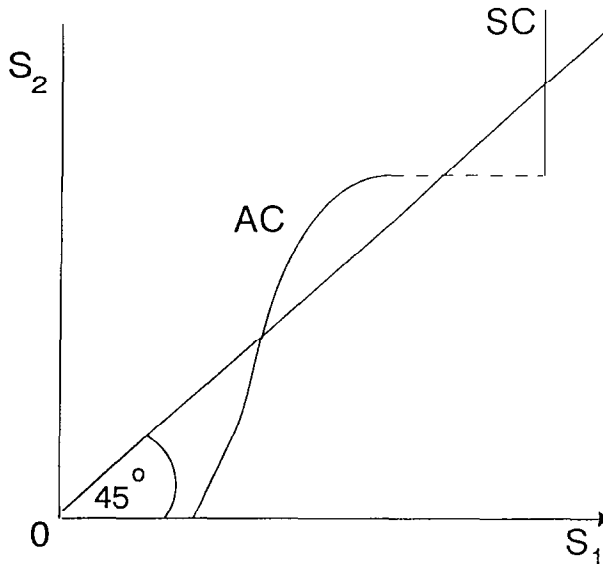


FIG. 2. Equilibrium security expenditures.

it will drive some potential criminals back toward victim 2, and second, it will reduce the success rate of those (inframarginal) criminals who continue to target victim 1. Assumption (A2), however, implies that there are diminishing returns to both effects. Hence, victim 1 will not raise s_1 so much as to *match* the higher s_2 . This proves that there cannot be another AC-type equilibrium.⁸

As we demonstrate in the following example, however, an AC-type equilibrium can coexist with an SC-type.⁹

Example: Let $\rho(s_i) = \exp(-\lambda s_i)$, $t = 2.5/\lambda$, and $v = 2.25/\lambda$, where $\lambda > 0$. In an AC-type equilibrium, all potential criminals attempt crime and $s_1 = s_2$; hence, by (3) $\ell = 1/2$. Substituting in (5), we have $\lambda v \rho(1 + v\rho/t)/2 = 1$, since $d\rho/ds_i = -\lambda\rho$. Hence $\rho = 0.5830$ and $s_1 = s_2 = 0.5396/\lambda$. On the other hand, by (8), at an SC-type equilibrium, $2\lambda(v\rho)^2/t = 1$, where we again use the substitution $d\rho/ds_i = -\lambda\rho$. In this case, $\rho = 0.4969$ and $s_1 = s_2 = 0.6994/\lambda$. Thus, by (6) the proportion of potential criminals that attempt crime is $2v\rho/t = 0.8944$.

Starting from the AC-type equilibrium, the initial effect of additional security is to divert rather than deter potential criminals. Hence, although security expenditure in the SC-type equilibrium is 30 percent higher than in the AC-type equilibrium, the criminal participation rate is only 11 percent lower. This result does not depend on diminishing marginal returns to security: It holds even when λ is small and so ρ'' is close to zero.

5. Diversion *vis-à-vis* Deterrence

Finally, we turn to the central question: When will security expenditure deter criminals, and when will it instead divert crime? If $t = 0$, each potential criminal can steal from victim 1 as easily as from victim 2, i.e., all criminals consider the two victims to be perfect substitutes. In this case, additional security expenditures by one victim surely will divert criminals to the other. At the other extreme, when t is sufficiently large, no potential criminal will switch between the two victims, even when security expenditures are low. Accordingly, we find that the range of t may be divided into three intervals: If t is sufficiently low, there is a unique AC-type equilibrium; over an intermediate range, there are two equilibria (one AC-type and one SC-type); while if t is sufficiently high, there is a unique SC-type equilibrium.

Likewise, potential criminals will find the two victims to be close substitutes when the value, v , of the victims' property is extremely high, and poor substitutes when v is very low. To prove that the range of v divides into just three intervals, however,

⁸Formally, in an AC-type equilibrium, both s_1 and s_2 must satisfy (5) and $s_1 = s_2$. By (3), $s_1 = s_2$ implies that $\ell = 1/2$; substituting in (5), we have

$$\frac{v}{2} \left(\frac{v\rho}{t} + 1 \right) \left| \frac{d\rho}{ds} \right| = 1.$$

The left-hand side of this condition is the marginal product of additional security. This has two parts—the effect on marginal potential criminals and the effect on inframarginal criminals. By (A1) and (A2), the marginal product decreases in s_1 ; hence, there can be at most one s_1 that satisfies the preceding condition.

⁹De Meza and Gould (1992) present a model in which multiple potential victims can make a discrete choice between spending or not spending on security. Assuming that one victim's spending will divert criminals to other victims, the model also yields two equilibria. In one equilibrium, all victims spend on security, while in the other, none do so.

we use a slightly stronger assumption, (A2') as stated below, in place of (A2). Essentially, (A2') requires that the marginal product of security, dp/ds , diminish with s faster than the total product, $\rho(s)$.¹⁰ Obviously, it implies (A2).

PROPOSITION 2: *Assuming that*

$$\rho(d^2\rho/ds^2) \geq (d\rho/ds)^2, \quad (\text{A2}')$$

the more valuable the property at risk relative to potential criminals' cost of switching among victims, i.e., the higher is the ratio v/t , the more likely is the equilibrium to be one in which security expenditures divert crime.^{11,12}

Proposition 2 is consistent with the results of the two U.K. Home Office studies of diversion. The pickings at London Underground stations are relatively small. Moreover, every station has a different physical layout, so a thief who gains expertise at one cannot easily use it at another. Accordingly, Proposition 2 would predict that diversion would be relatively unlikely, as indeed shown by the study of Mayhew, Clarke, et al. (1979).

By contrast, motorcars are relatively valuable targets (v relatively high), and a car thief has a wide choice of closely substitutable targets on a street or in a parking garage (t low). So, it is not surprising that when steering locks were required on new cars, thieves were diverted to older cars (Mayhew, Clarke, et al., 1976). Likewise, laws such as those of Illinois, Massachusetts, and New York that require insurers to offer lower premiums for cars equipped with car alarms may simply be diverting car thieves.^{13,14}

6. Concluding Remarks

We have emphasized that a key determinant of how much one potential victim spends on observable security measures, such as electronic tagging of goods, is other potential victims' expenditures. Bartel (1975) studied businesses' demand for secu-

¹⁰We use (A2') to rule out there being more than three intervals, e.g., a lower range with unique SC-type equilibria, then a range of multiple equilibria (both AC- and SC-types), then another range with unique SC-type equilibria, and finally an upper range with unique AC-type equilibria.

¹¹In the Appendix we actually prove a slightly stronger result. Without using A2', we show that the lower t is, the more likely is the equilibrium to be of the AC-type.

¹²We have also obtained results similar to Propositions 1 and 2 in a setting where a potential criminal's probability of success, p , is fixed, and a victim's security expenditure instead affects the cost of committing crime. Specifically, let $c(s_1)$ represent the cost of targeting victim 1, then a potential criminal at a distance ℓ will obtain expected return $v\rho - c(s_1) - \ell$ from victim 1. In this setting, when victim 1 raises s_1 , he persuades the marginal criminal to choose the legitimate activity or another victim, but the expected loss to each *inframarginal* criminal remains $v\rho$. Accordingly, the impact of *inframarginal* criminals on the victim's welfare is independent of victim 1's choice of security. We believe, however, that, consistent with the model that we present in the main text, security measures such as fences and gates reduce the impact of *both* marginal and *inframarginal* criminals on the victim.

¹³"Laws Encourage Car Alarms, But Din May Not Be Worth It," *New York Times*, February 19, 1991, A1 & A16.

¹⁴Ignoring victims' effort in accumulating wealth and criminals' expenditure on theft, the social value of anti-theft devices that divert criminals is the difference of two differences. The first difference is that between the victim's and the criminal's valuation of a car with steering lock or alarm, while the second is that between the victim's and the criminal's valuation of a car without the anti-theft equipment.

rity guards and protective services but omitted neighbors' security from the explanatory variables. Accordingly, one direction for empirical work is to test the effect of one potential victim's security expenditures on those of others. The other is to test our prediction that the higher the value of property at risk relative to potential criminals' cost of switching among victims, the more likely is it that additional security will divert crime.

As for future theoretical work, we wish to mention several ideas.¹⁵ The first is whether a potential victim should *disclose* his security expenditures. Such disclosures will drive away potential criminals to the extent that they believe that their odds of success are lower. For instance, many Los Angeles residents prominently display security-service signs on their properties. On the other hand, when potential victims have property of differing value, visible security precautions may be taken as a signal of particularly juicy pickings and so attract more criminals.

If one potential victim takes an unobservable security measure, such as installing hidden closed-circuit TV cameras, and does *not* disclose the precaution, then other potential targets will benefit (Friedman, 1984; Shavell, 1991): Since a criminal does not know who has raised security, he will be deterred from the whole group of victims. It is interesting to note that *observable* security measures may also generate positive externalities for the following reason. The opportunity cost of crime may be high enough that a potential criminal needs several victims to make crime worthwhile. So if a sufficient proportion of victims takes precautions, even observable ones, the potential criminal's expected return will be driven so low that he will quit crime.¹⁶

Another important direction for future work is to consider the interaction between public enforcement and private security expenditures.¹⁷ Cook argued that an increase in public enforcement could lead potential victims to *reduce* (private) security expenditures, thereby attenuating the impact of increased public enforcement on crime. Bartel's empirical study, however, found *per capita* state and local police expenditures to have statistically insignificant effect on businesses' demand for guards and protective services, which suggests that private security may be complementary with public enforcement on some important dimensions.¹⁸

Finally, while we assumed that potential victims' wealth was fixed, it in fact depends on the owners' effort. Just as taxation reduces the incentive to accumulate wealth, so does theft (Tullock, 1967). In the context of our model, when one party increases security, so diverting criminals to another victim, the latter will respond *both* by raising his own security and reducing the effort expended in accumulating wealth.

This paper has focused on the investments made by property owners to defend themselves from theft. A similar conflict occurs in the wild: Predatory species develop skills to enhance their ability to seek and acquire prey, while potential prey develop defensive characteristics, such as natural camouflage, thick shell, or speed,

¹⁵We are very grateful to the referees for these suggestions.

¹⁶For instance, improved security at Birmingham's Rag and Open Markets also reduced crime in nearby areas where security had not been changed (Poyner and Webb, 1992).

¹⁷The latter should be distinguished from expenditures, such as those by bounty hunters and private prisons operating under government contract, that aim to assist the *public* law-enforcement system (Becker and Stigler, 1974; Landes and Posner, 1975; Polinsky, 1980; Friedman, 1984).

¹⁸For instance, private alarms and surveillance systems are more effective if connected to police stations and if police have resources to dispatch patrols in response to alarms.

to escape predation. In the wild, however, these developments are more likely the outcome of selection than the processes of optimization posited in this paper.

Nevertheless, certain features of the model have close parallels to the conflict between predator and prey. For instance, predators face a choice between several alternative species of prey. The prey differ in their defensive characteristics, hence predators tend to specialize. Accordingly, it may be possible to draw several analogies from the model of security expenditures. First, if one species of potential prey enhances its defenses, it will lead (by a selection process) other species of prey to respond by developing stronger defenses too. Second, defensive characteristics of potential prey might deter predation in general (reducing the number of predators that a territory can support) or divert predators towards other more vulnerable species in the area. Third, diversion is more likely the more easily the predator can switch from one prey to another.

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Appendix

Derivation of Figure 1

- We first show that both curves A and S are U-shaped. By (1), (3), and (4), along curve A, victim 1's expected cost is

$$E(s_1) = \frac{v}{2t} [t + v\rho(s_1) - v\rho(s_2)]\rho(s_1) + s_1.$$

Hence,

$$\frac{\partial E}{\partial s_1} = \frac{v}{2t} [t + 2v\rho(s_1) - v\rho(s_2)] \frac{d\rho}{ds_1} + 1, \tag{AP1}$$

and

$$\frac{\partial^2 E}{\partial s_1^2} = \frac{v}{2t} [t + v\rho(s_1) - v\rho(s_2)] \frac{d^2\rho}{ds_1^2} + \frac{v^2}{t} \left(\frac{d\rho}{ds_1} \right)^2.$$

Notice that $t + v\rho(s_1) - v\rho(s_2) > 0$, since $t + v\rho(s_1) - v\rho(s_2) \geq t - v\rho(s_2) \geq t - v > 0$, by (A4). Furthermore, by (A2), $d^2\rho/ds_1^2 > 0$, hence $\partial^2 E/\partial s_1^2 > 0$ along curve A. By (A1) and (AP1), $\partial E/\partial s_1 < 0$ when $s_1 = 0$, and by (A3), $\partial E/\partial s_1 \rightarrow 1$ as $s_1 \rightarrow +\infty$. Thus curve A must be U-shaped.

By (1), (6), and (7), victim 1's expected cost along curve S is

$$E(s_1) = \frac{v^2}{t} [\rho(s_1)]^2 + s_1.$$

Hence

$$\frac{\partial E}{\partial s_1} = \frac{2v^2}{t} \rho(s_1) \frac{d\rho}{ds_1} + 1, \tag{AP2}$$

and

$$\frac{\partial^2 E}{\partial s_1^2} = \frac{2v^2}{t} \left[\rho(s_1) \frac{d^2\rho}{ds_1^2} + \left(\frac{d\rho}{ds_1} \right)^2 \right] > 0.$$

Likewise, by (A1) and (AP2), $\partial E/\partial s_1 < 0$ when $s_1 = 0$, and by (A3), $\partial E/\partial s_1 \rightarrow 1$ as $s_1 \rightarrow +\infty$; thus S is also U-shaped.

- Next, we show that if $s_1 < \bar{s}_1(s_2)$, then the slope of curve S will be less than that of curve A, i.e.,

$$\left. \frac{dE(s_1)}{ds_1} \right|_{S \text{ curve}} < \left. \frac{dE(s_1)}{ds_1} \right|_{A \text{ curve}}. \tag{AP3}$$

In general, additional security will reduce a victim's expected loss by (i) reducing the success rate of criminals who continue to raid that victim, and (ii) diverting (curve A) or deterring (curve S) some potential criminals. Consider the number of criminals targeting victim 1: By (3), it is

$$\ell = \frac{1}{2t} [t + v\rho(s_1) - v\rho(s_2)] \quad (3)$$

along curve A, while, by (6) it is

$$\ell_1 = \frac{v\rho(s_1)}{t} \quad (6')$$

along curve S. By (9), if $s_1 < \bar{s}_1(s_2)$, then $t < v\rho(s_1) + v\rho(s_2)$; hence $\ell < \ell_1$. Thus, if $s_1 < \bar{s}_1(s_2)$, more criminals target victim 1 along curve S than along A, which implies that effect (i) will be stronger along curve S.

Moreover, with regard to effect (ii), the marginal diversion along curve A is weaker than the marginal deterrence along curve S: by (3), the marginal diversion along curve A is

$$\frac{d\ell}{ds_1} = \frac{v}{2t} \frac{d\rho}{ds_1},$$

while, by (6') the marginal deterrence along curve S,

$$\frac{d\ell_1}{ds_1} = \frac{v}{t} \frac{d\rho}{ds_1},$$

is twice as large. In sum, additional security will reduce a victim's expected loss by more along A than S. Formally, comparing (AP1) and (AP2), we have

$$\left. \frac{dE}{ds_1} \right|_{S \text{ curve}} - \left. \frac{dE}{ds_1} \right|_{A \text{ curve}} = \frac{v}{2t} [v\rho(s_1) + v\rho(s_2) - t] \frac{d\rho}{ds_1} < 0,$$

since $d\rho/ds_1 < 0$, and by (9), $v\rho(s_1) + v\rho(s_2) > t$ when $s_1 < \bar{s}_1(s_2)$. This proves (AP3).

- Finally, we show that if $s_1 < \bar{s}_1(s_2)$, then curve S will lie above curve A, i.e.,

$$E(s_1)|_{S \text{ curve}} > E(s_1)|_{A \text{ curve}} \quad (\text{AP4})$$

In the main text, we showed that curves A and S meet at \bar{s}_1 . By (AP3), when $s_1 < \bar{s}_1(s_2)$, curve S has smaller slope than curve A. This proves (AP4). Formally,

$$\begin{aligned} E(s_1)|_{S \text{ curve}} - E(s_1)|_{A \text{ curve}} &= \frac{v_2}{t} [\rho(s_1)]^2 - \frac{v}{2t} [t + v\rho(s_1) - v\rho(s_2)]\rho(s_1) \\ &= \frac{v}{2t} [v\rho(s_1) + v\rho(s_2) - t] > 0, \end{aligned}$$

since, by (9), $v\rho(s_1) + v\rho(s_2) > t$ when $s_1 < \bar{s}_1(s_2)$.

- In light of (AP1) – (AP4), there are three possibilities for the relative positions of curves A and S. We depict these in Figure 1.

PROOF OF PROPOSITION 1: We first show that the larger s_2 is, the further right the trough of curve A. Compare two curves A associated with different levels of s_2 , say s_2' and s_2'' , where $s_2' < s_2''$. Differentiating (AP1) with respect to s_2 yields

$$\frac{\partial^2 E}{\partial s_1 \partial s_2} = - \left(\frac{v^2}{2t} \right) \frac{d\rho(s_1)}{ds_1} \frac{d\rho(s_2)}{ds_2} < 0.$$

Since curve A is U-shaped, the above inequality implies that when the curve A associated with s_2' reaches its trough, the curve A associated with (the higher) s_2'' will have a negative slope.

Now consider the effect of changes in s_2 on victim 1's choice of s_1 . Let the trough of curve S occur at security s_1^* and the trough of the curve A associated with s_2 be at $s_1^A(s_2)$. Recall from the main text that curve A rises with s_2 . Above, we have shown that the trough of A shifts rightward as s_2 rises. But curve S remains fixed as s_2 changes. Therefore, referring to Figure 1, when s_2 rises from s_2' to s_2'' , the new best-response s_1 may (i) rise from $s_1^A(s_2')$ to $s_1^A(s_2'')$, (ii) jump up from $s_1^A(s_2')$ to s_1^* , or (iii) remain at s_1^* . From these three cases, we conclude s_1 never decreases with s_2 . Q.E.D.

PROOF OF PROPOSITION 2:

- We first show that if, at some $t = t'$, there exists an AC-type equilibrium, i.e., one in which security expenditures divert crime, then if the transportation cost drops to t'' while v remains unchanged, there will also exist an AC-type equilibrium. By (AP1), in an AC-type equilibrium,

$$\frac{1}{2}v \left(1 + \frac{v\rho}{t} \right) \left| \frac{d\rho}{ds} \right| = 1 \tag{AP5}$$

for both s_1 and s_2 . Let s' be victim 1's equilibrium spending when $t = t'$, then s' and t' must satisfy (AP5). By (A2), $\rho |d\rho/ds|$ decreases with s . Now $t'' < t'$, hence at $t = t''$, we can find some $s'' > s'$ that satisfies (AP5).

For this s'' to be an AC-type equilibrium, more than half of the potential criminals must prefer raiding victim 1 to the legitimate activity, i.e., $v\rho(s'')/t'' \geq 1/2$. By (A2), we have $|d\rho/ds|_{s=s''} < |d\rho/ds|_{s=s'}$, since $s'' > s'$. So, comparing the (AP5) corresponding to t' and t'' , respectively, we infer that $v\rho(s'')/t'' > v\rho(s')/t'$. But $v\rho(s')/t' \geq 1/2$, since s' is an AC-type equilibrium when $t = t'$. Hence the result.

- Suppose that an SC-type equilibrium, i.e., one in which security expenditures deter crime, exists when $t = t'$. We would like to show that an SC-type equilibrium also exists at a larger t'' and the same v . By (AP2), in an SC-type equilibrium,

$$\frac{2v^2\rho}{t} \left| \frac{d\rho}{ds} \right| = 1. \tag{AP6}$$

By applying a similar logic to (AP6) as that used above on (AP5), we can show that there exists some $s''' < s'$ that induces an SC-type equilibrium at $t = t''$.

- Next, we show that if at some $v = v'$ there exists an AC-type equilibrium, then if the value of the victim's property rises to v'' while t remains unchanged, there will also exist an AC-type equilibrium. Let s'' satisfy (AP5) when $t = t'$. This s'' will constitute an AC-type equilibrium if $v\rho(s'')/t > 1/2$. To prove this, differentiate (AP5) with respect to v and s to obtain

$$\frac{ds}{dv} = \frac{\left| \frac{d\rho}{ds} \right| \left(1 + \frac{2v\rho}{t} \right)}{v \left[\frac{d^2\rho}{ds^2} + \frac{v}{t} \left(\frac{d\rho}{ds} \right)^2 + \frac{v}{t} \rho \left(\frac{d^2\rho}{ds^2} \right) \right]}$$

Now

$$\frac{d}{dv} v\rho = \rho + v \frac{d\rho}{ds} \frac{ds}{dv} = \frac{\left[\rho \frac{d^2\rho}{ds^2} - \left(\frac{d\rho}{ds} \right)^2 \right] \left(1 + \frac{v\rho}{t} \right)}{\frac{d^2\rho}{ds^2} + \frac{v}{t} \left(\frac{d\rho}{ds} \right)^2 + \frac{v}{t} \rho \left(\frac{d^2\rho}{ds^2} \right)}.$$

By (A2'), $\frac{d}{dv} v\rho > 0$, hence $v\rho(s'') > v\rho(s')$. Since s' is an AC-type equilibrium, $v\rho(s')/t \geq 1/2$, thus, $v\rho(s'')/t > 1/2$ and s'' is an AC-type equilibrium.

- Finally, by applying a similar logic to condition (AP6), we can show that holding t fixed, if there is an SC-type equilibrium at some v , there must exist an SC-type equilibrium when v is lower. Q.E.D.