The Manchester School Vol 75 No. 1 January 2007
1463–6786 104–121

THE DISTURBANCE MODEL AND CONGESTION IN EMERGENCY RESPONSE*

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Public security agency response to a call for emergency service is a commons good. As consumers demand more of the commons good there is increased congestion. Police services as a commons good are modeled using the uncertainty about which calls for service are *bona fide*. The results are that optimal alarm systems per officer rise with the officers' wage, fall with the value of avoided losses and rise with the productivity of officers. *Ceteris paribus*, avoided losses are greater in the community with more alarm systems. Homogeneity of the community increases the optimal number of alarms per officer. Fining 'well-behaved' alarm owners more heavily increases police productivity.

1 Introduction

All service providers responsible for emergency response suffer from a high rate of false calls that consume significant amounts of resources.[1] The high incidence of false calls could hinder first response efforts in the event of a terrorist attack and cause a wasteful use of local resources. The question is whether first responders can mitigate the incidence of false calls. We consider the particular case of burglar alarms to illustrate the impact of an appropriate public policy on calls for emergency service. The issue and the solution of the response to burglar alarms can be applied to other emergency services as well.

The false alarm rate for burglar alarm activations is 94–99 per cent[2] in the USA, Canada, Great Britain and New Zealand. The cost of response to

* Manuscript received 8.9.05; final version received 10.8.06.

[1]A false alarm is any request for service that is not a *bona fide* emergency. A false alarm can be a deliberate prank, it can be an honest mistake, or it can be the result of alarm equipment failure. The false alarm rate is the number of false activations divided by the total number of activations per time period.

[2]There are no systematic national statistics on alarm installations, alarm activation rates, false alarm rates and the costs of responding. The data that exist have been assembled by phone surveys. For examples, see Hakim and Buck (1991), Hakim (1995) and Sampson (2001). Milwaukee, Wisconsin, in 2003 reported that 96 per cent of the total 28,346 calls were false (Schwartz, 2004). Raleigh, North Ccrolina, reported that 98 per cent are false (Dorell, 2004). Seattle had a 98 per cent false alarm rate between 2001 and 2004 (Brooner, 2004), or see the Fremont Police Department (2006).

Published by Blackwell Publishing Ltd, 9600 Garsington Road, Oxford OX4 2DQ, UK, and 350 Main Street, Malden, MA 02148, USA.

police departments for false alarms ranges between $50 and $90 in the USA, and is similar in the other countries.[3] Response to false activations consumes 10–20 per cent of patrol officers' time,[4] reduces the ability of police to handle other security services and causes frustration and inattentiveness by officers. The false alarm rate for the fire department is 50 per cent and the cost per response is $500.[5]

There is evidence that the false alarm rate can be actively managed (Sampson, 2001) and thereby police can increase their productivity.[6] This paper examines the problems associated with response to false emergency calls that arise from the random nature of the calls. In Section 2 we review the impact of congestion in the consumption of a 'commons' good[7] as it applies to alarm activation. Section 3 formally models the problem of congestion in police services. Section 4 concludes the paper and suggests possible policy implications.

2 Public Goods, Commons Goods and Congestion in Police Services

To increase safety a household buys an alarm system that consists of some hardware and a contract for ongoing response service when the alarm activates. Most commonly the alarm company's response to alarm system activation is just telephone verification. In the event that the customer does not answer the phone, actual physical response is usually provided by the police at the request of the monitoring company as agent for the alarm owner. Police respond to both real and false activations. However, activators in many jurisdictions do not pay police for the response,[8] or they pay an arbitrary amount set by a local ordinance that is unrelated to the actual or the

[3]The cost of false alarms was calculated by the authors using data supplied by individual police departments. In the mid-1990s the cost ranged from $28 to $73. Adjusted for inflation it is in the range of $50–$90 in 2006. The cities for which we made the calculations are Philadelphia, Pennsylvania, Dade County, Florida, Reno, Nevada, and Phoenix, Arizona (Hakim and Blackstone, 1996).

[4]Our estimate of 10–20 per cent of officers' time devoted to false alarm response is conservative. Sampson (2001) reports 10–25 per cent of police officers' time devoted to false alarm response. See Sampson (2001, p. 1). In fact, 24 per cent of the Palm Beach County Sheriff Department's calls for service arise from false alarms.

[5]The false alarm rate for fire alarms in 2003 was 58 per cent, calculated from data from the National Fire Protection Association (2005). The cost of response to a false fire alarm was calculated to be $615 by the Washington Township Fire Department (*The Romeo Observer*, 2005, Michigan). For 2005 the Battalion Chief of the Salt Lake City Fire Department estimated the cost to be $365.

[6]Demand management is not an especially new idea. It is used by the utility industry to shift consumption from peak to off-peak periods.

[7]The terminology derives from the village commons. A resident cannot be excluded from the consumption of police services. However, if enough residents try to consume the service at the same time then there is said to be rivalry in consumption, or congestion.

[8]Activations by government units such as schools usually are not fined at all.

social cost of response. This policy exists in spite of the fact that economists have long known that unlimited access to a resource leads to the 'tragedy of the commons'.[9]

If an activation is false then police are using scarce resources to respond to an individual's demand for service, the output of which cannot be construed as a public good. Therefore, the financial responsibility for the response should not be borne by the public police.

False alarms are a cause of inefficiency in the public sector, and response to them is a private good not a public good. Citizens are imposing costs on themselves with little or no benefit, in the aggregate. This begs the question of why there are false alarms at all. Apart from carelessness[10] there are four possible explanations. False alarms could be the result of malfunctioning or poorly designed systems, a problem that under the correct incentives would be solved by the vendor and system owner. As long as police respond at a price below that of private response, there is no market incentive for manufacturers to develop technology or methods that reduce false activations.

False alarms could occur because of a high probability of burglary or great loss in the event of burglary.[11] If the loss from burglary is sufficiently skewed then false alarms may be efficient from the standpoint of the property owner. Although about two-thirds of burglaries result in a loss in excess of $500, the mean loss is only about $1700 (Hakim and Buck, 1991). While skewed, losses are not large and apparently not skewed very much, suggesting that again incentives can be used to coerce the system owner to take corrective action.

Third, false alarms could be a mechanism for residents to test the system to determine response times in the event of a *bona fide* emergency. This explanation has little merit since almost all monitoring contracts include some provision for periodic testing.

Finally, false alarms may be an indicator of demand by residents for more local patrol.[12] In fact the vast majority of false alarms are a result of user

[9]Other examples of the tragedy of the commons include the public library and the local municipal swimming pool. The characterization has its antecedents in Samuelson (1954) and Buchanan (1965). There has been much discussion among public economists about congestion. Borcherding and Deacon (1972), Bergstrom and Goodman (1973), Brueckner (1981), Gramlich and Rubinfeld (1982), Craig (1987a, 1987b) and Craig and Heikkila (1989) each estimate an elasticity of congestion. Oates (1988) and McMillan (1989) produced empirical evidence that the degree to which local public goods are subject to congestion was upwardly biased. In any event the congestion effect reduces the 'publicness' of public goods.

[10]Carelessness, leaving the pet loose or a window open, is behavior that can be modified through incentives, as in the four cases we consider at greater length.

[11]For the individual property owner the cost of a hypersensitive system that produces many false alarms may be cheaper than adequately insuring the property. While smart for the property owner, this configuration may impose social costs: the principle of 'smart for one, dumb for all'.

[12]This is another example of the principle of 'smart for one, dumb for all' and results in the loss of economic surplus.

error. Whatever the root cause, the correct fine structure will solve the problem by compelling alarm owners to incorporate social costs in their decision, as enunciated below.

Two characteristics of emergency response can be identified as unique relative to other commons (local public) goods. First, the congestion effect can be measured in probabilistic terms. The frequency and randomness of required response to false calls generates congestion in patrol officer provision of an umbrella of public security to the community. We base our model on a similar probabilistic model developed by Lazear (2001) who considers random disruptions in the classroom as an example of congestion impeding production of the public good of education. Second, there is no *ex ante* knowledge of the nature of the supplied service. Only after the service is provided can it be determined if it is a public or private good.[13]

3 Modeling Emergency Response and Congestion

Only a small fraction of burglar alarm activations are *bona fide*. Scarce resources having both public good and free-access attributes are used to respond to activations (Brueckner, 1981; Benson, 1994; Ekelund and Dorton, 2003).[14] The question is the design of public policy to curtail false activations to achieve an acceptable level of congestion in police services.

There are two circumstances under which the police are working productively. When a burglar triggers an alarm and the police respond, their time is being used productively, denoted by P_{11}. When responding to a *bona fide* activation and apprehending a criminal, the police are acting to restore the property to its owner and, by capturing the intruder, are reducing the likelihood of future victimization in the community.

When there is no alarm activation and there is no burglary, then the property owner suffers no harm and the police remain on routine patrol or are engaged in other activities that benefit the community at large. While on routine patrol services of the police are a public good and all citizens of the jurisdiction enjoy the umbrella of protection and deterrence. The proportion of police time used in this fashion is denoted by P_{22}.[15]

Sometimes there is a break-in, but no alarm activation. In terms of police department resources, this happens for P_{21} proportion of the time. From a

[13]Examples besides response to burglar alarms are fire response, ambulance service, response to gas odors and Coast Guard services. Only after arrival at the scene can it be determined if the call involves a real emergency situation.

[14]All of the cited authors agree that there is congestion in local governmental services. None of them suggest ways to manage the congestion in the context of existing institutional structures, as we do here.

[15]Actual apprehension of a criminal in the act of committing a crime may be a more productive use of police time than is random patrol; plausibly then $P_{11} < P_{22}$. In the former case the criminal is removed from the crime labor market, whereas in the latter case there is only displacement geographically or temporally (Schumacher and Leitner, 1999; Burton *et al.*, 2002). The removal of an individual from the pool of criminals has a greater impact on the

society-wide perspective the system is working ineffectively. Nevertheless, the police department is producing the public good through its routine activities.[16]

The fourth situation occurs when an alarm is activated but there has been no break-in. The police must then visit the property and are called away from their normal, routine duties. Responding to a false alarm redirects the public good endeavor of the police to a private good, imposing a congestion cost on the rest of the community. This unproductive use of police resources accounts for a proportion P_{12} of their time.

In a simplified view there is no difference in the net value of police activity whether the officer is engaged in the public good producing activity of routine patrol (P_{22}), called to a home in response to *bona fide* alarm activation (P_{11}), or investigating a burglary *post hoc* for which there was not a call for emergency response (P_{21}). The union of these three activities represents the proportion of police resources used productively: $P = P_{11} + P_{21} + P_{22}$. Alternatively, P may be interpreted as the proportion of home value for which deterrence and protection is being provided at an instant in time.[17] The proportion of police time/resources being used unproductively is given by $1 - P = P_{12}$. Unproductive use of the police is a result of the rate of false activation of alarm systems.[18]

Suppose that in the neighborhood there are η alarms per police officer. The alarms in the neighborhood activate falsely in a random fashion. Therefore, the proportion of time that the police officers are working productively falls as η increases, and approaches the value P^{η} since activations occur randomly.

Now suppose that police services are produced from one input, a police officer, and that all police officers are homogeneous. A total of m representative police officers work in a neighborhood that has H households, and n of the properties have alarms. The proportion of alarmed properties is $q = n/H$. Thus, there are n/m alarms per police officer in the neighborhood and $h = H/m$ households per police officer. The number of alarms per police officer is given by $\eta = (n/H)(H/m) = qh$.

security of the community than does geographic or temporal displacement of the criminal due to routine patrol (Sherman, 1983). This is a 'bird in the hand is worth more than two in the bush' argument.

[16]In the literature there is an argument about whether police spend their time preventing crime, an unobservable output, or waiting for crime to happen so that they can make an arrest, an observable output. The issue is one of focusing on criminals or focusing on places where crime has occurred, or may occur.

[17]If all police are used productively then there is no loss. This is not the same as saying that there are no criminals; it just means that the criminals have been displaced. Furthermore, by our taxonomy it is clear that the police are not always perfectly productive.

[18]The discussion here suggests that our taxonomy needs only two states, not four. Collapsing to two states would make subsequent discussion less transparent, especially where it is shown that better-behaved alarm owners should pay stiffer fines.

Let V be the value per residence of property that has been secured for protection from loss; in other words, the value of a unit of security. This is property that has not been lost due to crime in the community, and so can be termed avoided losses. There are two types of avoided loss.

Some property loss is avoided because the residence has an alarm. When an intrusion activates the alarm, the police respond and apprehend the criminal. Call the value of this unit of security the avoided loss of alarm-protected property per residence, V_a. A second avoided loss occurs as a result of the efficient use of police resources in routine patrol activities that provide a uniform umbrella of security to an area. The value of these avoided losses per residence is V_p.

The objective function of the community can be expressed in terms of alarms, avoided losses and the proportion of time the police are engaged in productive activity:

$$\Pi = V_a P^{qh} qH + V_p P^{qh}(1-q)H - wm - rqH \tag{1}$$

where Π is net 'profit' accruing to the law abiding segment of society, w is the wage paid to police, of which there are m, and rqH is the police department's administrative costs for a given density of alarm systems. Alternatively, the objective function can be expressed as

$$\Pi = \left[V_a - V_p\left(1-\frac{H}{n}\right)\right] nP^{n/m} - wm - rn \tag{2}$$

Seen in this way the objective function will have a positive value only if the expected value of avoided losses is greater than the sum of the cost of patrol and administrative costs of having alarms in the community. Alarms must not only deter, but they must also result in the recovery of property and the apprehension of the criminal.[19]

The decision variable for the municipality is m, the number of police officers. All of the other variables are exogenous to the public authority, although, by imposing a fine for false activations, the municipal authority can reduce P_{12}, thereby increasing P and improving the productivity of the police. The first-order condition is

$$\Psi = -\left[V_a - V_p\left(1-\frac{H}{n}\right)\right] n^2 \frac{P^{n/m}}{m^2} \ln(P) - w = 0 \tag{3}$$

[19]On the face of it an increase in the number of alarms causes $P^{n/m}$ to decrease, driving down police productivity, with the implication that m should be ∞. As is shown in the comparative statics, this is not correct. From the objective function, it also appears that if $n = 0$ then there should be no police. But $n = 0$ only if alarms serve no purpose and people know it or if there is no crime. Alarms do deter and people do believe that alarms do something, so in practice $n > 0$. Only in the extreme view that $n = 0$ because there is no crime is it obvious and correct to conclude that there will be no police.

This result has a very standard interpretation. The marginal cost of an additional police officer is equal to the productivity-weighted marginal benefit of one more police officer in terms of avoided loss.

Proposition 1: The optimal number of alarms per police officer in the community (a) rises with the wage of the police officers, (b) falls in the value of avoided losses and (c) rises with the productivity of police officers. It is optimal to reduce the number of alarms per police officer when alarms are more frequently falsely activated.

Proof: (a) First, $\partial\Psi/\partial w = -1$. Next, in order for the solution to be an interior one, $\partial\Psi/\partial m = \partial^2\Pi/\partial m^2 < 0$. Applying the implicit function theorem

$$\frac{\partial m}{\partial w} = -\frac{\dfrac{\partial\Psi}{\partial w}}{\dfrac{\partial\Psi}{\partial m}} = \frac{1}{\dfrac{\partial^2\Pi}{\partial m^2}} < 0$$

Since we have $\mathrm{d}\eta/\mathrm{d}m = -n/m^2$, hence $\partial\eta/\partial w = (\partial m/\partial w)(\mathrm{d}\eta/\mathrm{d}m) > 0$.

(b) From the implicit function theorem

$$\frac{\partial m}{\partial V_\mathrm{a}} = -\frac{\dfrac{\partial\Psi}{\partial V_\mathrm{a}}}{\dfrac{\partial\Psi}{\partial m}} = \frac{\left(\dfrac{n}{m}\right)^2 P^{n/m}\ln(P)}{\dfrac{\partial^2\Pi}{\partial m^2}} > 0$$

Hence, $\partial\eta/\partial V_\mathrm{a} = (\partial m/\partial V_\mathrm{a})(\mathrm{d}\eta/\mathrm{d}m) < 0$.

Applying the implicit function theorem again

$$\frac{\partial m}{\partial V_\mathrm{p}} = -\frac{\dfrac{\partial\Psi}{\partial V_\mathrm{p}}}{\dfrac{\partial\Psi}{\partial m}} = \frac{\left(\dfrac{n}{m}\right)^2 P^{n/m}\ln(P)\left(\dfrac{H}{n}-1\right)}{\dfrac{\partial^2\Pi}{\partial m^2}} > 0$$

And, by the reasoning just applied, $\partial\eta/\partial V_\mathrm{p} < 0$.

(c) First,

$$\frac{\partial m}{\partial P} = -\frac{\dfrac{\partial\Psi}{\partial P}}{\dfrac{\partial\Psi}{\partial m}} = \frac{P^{n/m}n[n\ln(P)+m]\dfrac{n(V_\mathrm{a}-V_\mathrm{p})+V_\mathrm{p}H}{m^3P}}{\dfrac{\partial^2\Pi}{\partial m^2}}$$

is negative as long as $P > \mathrm{e}^{-m/n}$. When there are many alarms and few police, then the police must have very high effectiveness. Using the earlier reasoning,

$$\frac{\partial\eta}{\partial P} > 0$$

■

Part (a) of the proposition is an intuitive result; the demand curve for police is downward sloping after all, and police and alarms are substitutes in the production of avoided losses. As the security impact of police becomes more costly due to a rise in their wage there is an incentive to substitute away from the public good towards the private good. A reduction in the wage of private alarm response would have the same effect as an increase in the wage of the police. Empirically, one would expect private guards to be used to a greater extent where the cost of public response is high, which could be for one of two reasons. First, on an expected cost basis there may be high fines for false activations. The second reason is the result of either high police wages or slow response times. A slow response time is equivalent to a high wage paid by the agency when police officers are standardized to effective units of deterrence.

From part (a) of the proposition, alarms per police officer vary directly with the wage rate of police officers. Low wages imply a low alarms per police officer ratio. Reducing an already low ratio further has a larger impact on avoided losses in the low ratio community than in the high ratio community. Therefore, avoided loss effects of alarms are more likely to be observed in communities with low police wages.

Part (b) of the proposition raises the question of the cause of variations in the value of avoided loss, V_j ($j = \mathrm{a, p}$). The proposition may seem counterintuitive, since alarms per police officer fall as either V_a, the value of avoided losses in alarmed houses, or V_p, the value of avoided losses in non-alarmed houses, increases. Thinking of V_j as the instantaneous value of a unit of security clarifies things. In the model police produce the value of security. Therefore, as the value of V_j increases, we want more of the labor input. As with capital and labor, alarms and police are complements in production; but police and alarms also can be substituted for one another, although not perfectly. Fewer alarm systems produce fewer false activations, making the police more effective. Seen in this way, a change in V results in a shift in the demand curve for police.

In part (c), the number of alarms per police officer rises with the productivity of the police. 'Better-behaved' alarm owners, those who generate fewer false alarms and thereby make the police more productive, are found in neighborhoods with fewer police. The local government and the alarm industry can both affect P, the productivity of the police. First, the municipality can make it costly to generate false alarms. Second, technological improvements in alarm systems can reduce the number of false alarms. Third, requiring that the alarm-monitoring company physically verify the activation before notification of the police will result in a more efficient use of police officers' time.

Table 1 provides a numerical illustration of the force of the proposition. In the table V_p has been normalized to 1, the wage of a police officer is five times the value of police security consumed by unalarmed properties ($w = 5V_\mathrm{p}P^{n/m}$), there are 100 households, and 5 per cent of all households have

TABLE 1
OPTIMAL ALARMS PER POLICE OFFICER

V_a/V_p	P	*Police officers*	*Alarms/police officer*	*Output per alarm*
0.5	0.5	8.22	0.61	0.655
0.5	0.58	7.29	0.68	0.690
0.5	0.95	2.24	2.23	0.891
0.5	0.98	1.40	3.57	0.930
2	0.5	8.53	0.58	0.669
2	0.58	7.56	0.66	0.698
2	0.95	2.32	2.15	0.895
2	0.98	1.46	3.42	0.933

alarms. The first column is the ratio of the value of alarm-protected property to non-alarmed property. There are only two values: in the first case the value of alarmed property is half that of non-alarmed property; in the second case twice as much property is protected by alarms as not. The ratio is determined by residents' alarm purchase decisions. The second column, the productivity of police, is determined by the rate of false alarms. The third column is the optimal number of police officers, given the first two columns, as computed from the first-order condition. The last two columns follow directly from the first three, given the definitions of the model.

From the table one can see that, for a given V_a/V_p, as the police become more productive fewer of them are needed. Alternatively, for a given police productivity, increasing the value of alarm-protected property requires that more police be employed. As argued above and shown in the table (see columns 2, 3 and 5), the effect of reducing alarms per police officer is not sufficient to overcome the 'misbehavior' of alarm system owners. This conclusion leads us to the next proposition.

Proposition 2: After adjustment to the optimal alarms per police officer, avoided losses per household are greater in the community with the larger number of alarms per police officer provided that alarms are more effective, i.e. P is greater (there are fewer false activations).

Proof: Restate the objective function as

$$\Pi = R(P, m(P)) - wm(P)$$

in which $R(P, m(P))$ is the value of police output and the optimal number of police, m, is known to depend on their effectiveness. Using subscripts to denote the partial derivative with respect to that variable, the first-order condition states that $R_m(P, m(P)) = w$. Total differentiation with respect to P, police effectiveness, gives $R_{pm}(P, m(P)) + R_{mm}(P, m(P))m'(P) = 0$. The marginal output of the police with respect to the productive use of their time is given by

$$\frac{\partial R(P, m(P))}{\partial P} = R_p(P, m(P)) + R_m(P, m(P))m'(P)$$

Solving the total derivative for $m'(P)$ and substituting the result into the marginal output of police yields $R_p - R_m(R_{pm}/R_{mm})$. Substituting from the derivatives applied to the original objective function gives

$$\left[V_{\mathrm{a}} - V_{\mathrm{p}}\left(1-\frac{H}{n}\right)\right]n^2\frac{P^{n/m-1}}{m} + \left\{\left[V_{\mathrm{a}} - V_{\mathrm{p}}\left(1-\frac{H}{n}\right)\right]n^2\frac{P^{n/m}}{m^2} - w\right\}$$
$$\times\left\{\frac{-\left[V_{\mathrm{a}} - V_{\mathrm{p}}\left(1-\frac{H}{n}\right)\right]\left[\frac{n^3}{m^3}\frac{\ln(P)}{P} - \frac{n^2P^{n/m}}{m^2P}\right]}{\left[V_{\mathrm{a}} - V_{\mathrm{p}}\left(1-\frac{H}{n}\right)\right]\left[\frac{n^3P^{n/m}\ln(P)^2}{m^4} + 2\frac{n^2P^{n/m}\ln(P)}{m^3}\right]}\right\}$$

The first term in braces after the plus sign is nothing more than the first-order condition, so is zero. The remaining term must be positive, so the entire expression is positive. ■

Based on their specific attributes, communities determine their optimal number of alarms per officer, and then avoided losses per household are greater where police productivity is greater, as reflected in the magnitude of P. If the number of alarms per police officer varies because the community is adjusting the size of the police department in response to the better behavior of alarm owners, then communities with more alarms per police officer will be experiencing fewer false activations, making police more efficient, and have greater security output.

In Table 1, avoided losses per household are in the last column. Reading down the column, avoided losses rise with n/m since P is also rising. Alternatively, compare rows 4 and 5: output per alarm has fallen even though the adjustment to optimal n/m still holds. This is because P is lower, presumably due to more false alarms.

Proposition 2 begs the question of whether the community is safer with fewer police. If the community has a higher proportion of *bona fide* alarm activations, then its police are more productive and the output of security, the amount of avoided losses, is greater. Hence, the community can be safer with fewer police; we call this ‘the large community effect’. Thus, when the proportion of false alarms is larger, police become less productive as reflected in lower avoided losses attributable to police.

Since alarms per police officer should vary directly with their wages, the ‘large community effect’ is most likely to be observed where wages are high. Reducing the ratio of alarms per officer (η) has a larger effect on community security in small communities than in large ones.

From the two propositions one can compare the effect of alarms per police officer across communities. Is a change in alarms per police officer greater in a community in which police are more productive than in a community in which they are less productive? The marginal benefit of reducing the number of alarms per police officer is greater in the community in which police are less productive, as is evident in Table 1 when comparing the change in output between rows 4 and 3 with the change between row 2 and row 1. As a corollary, policies aimed at reducing false activations are less effective in communities in which residents already behave responsibly and have few false alarms. This effect can be seen in Table 1 when comparing the change between rows 1 and 5 with the change between rows 4 and 8. Apparently there are diminishing returns to increases in false activation penalties. The same program adopted by two communities for false alarm abatement will be less effective in the community of residents that are already behaving in a responsible manner.

If alarm owners 'behave badly' then there is no surplus accruing to the community. In this instance, the community might like to get out of the security business, but they are not permitted to do so. Instead, a frequent reaction by the community is to not respond to alarm activations in a meaningful way,[20] thereby driving up the productivity of the police. This reaction is understood by again looking at Table 1: compare row 5 with any of rows 2, 3 or 4.

First, the table shows that alarms per police officer are increasing with the productivity of the police: at low levels of P the number of alarms per police officer should be low as well. Reciprocally, for very high productivity there will be many alarms per officer. In the limit, there would be no police and hence no response, regardless of whether or not the activation was *bona fide*. At this stage there are several avenues open to the alarm industry. The first option, doing nothing, would result in less demand for alarms since there would be no one to respond to them. A second option would be to improve alarm technology to the point where there are so few false activations that as a consequence non-response is not an issue.[21] A third option would subsidize the police department's wage bill so that the number of police officers in the community rises, lowering the number of alarms per police officer and increasing the response to false alarms.[22] A final alternative would be for the alarm company to hire private guards to handle the function of response to activations.[23]

[20]For example, alarm activations can be given low priority effectively eliminating response as has been done in Philadelphia, Pennsylvania.

[21]Older alarms are less technologically advanced than newer systems. The bottom line is that the older systems generate more false activations than do newer systems. The consequence is that owners of old systems may be required to participate in a program of physical verification before the police are notified of an activation. Alternatively, the municipality may want to implement incentives for alarm owners to upgrade their systems to the newest technology in order to make the police more productive. This vintage alarm effect also applies to fire alarms. See Finley (2001).

[22]The management of the King of Prussia Mall, the second largest in the USA, pay the wages for an Upper Merion, PA, police officer to be on patrol at the mall at all times.

[23]Choosing this option is equivalent to subsidizing the labor cost of police.

There is a limitation to the final option. Suppose that a community has a high proportion of false alarms. The false activations reduce the productivity of the police, causing a reduction in the demand for alarms. The alarm company could restore the demand for its product by providing private response in lieu of public police. However, for very high false activation rates the requirement that the private company must earn non-negative profits calls into question its viability if it must provide private response.

A reasonable inference based on the model is that every alarm owner is being subsidized since alarm response converts police from a public to a private good. The subsidy is greater as P declines. The subsidy is reduced by not responding to alarm activations, by imposing escalating fines for frequent false activations or by requiring physical, private guard verification. These observations provide an opportunity for the empirical verification of the model. There should be higher fines, less response and/or private guards wherever there are too many alarms per police officer or there are too many false alarms.

For the purpose of public policy design, owners of alarms can be divided into residential security systems, commercial and industrial security systems, and religious and municipal sites. The principles along which membership in the groups is divided are responsibility for alarm system management, pedestrian traffic flow at the site and hours of system operation. In residential systems there are usually a small number of persons with a proprietary interest who are responsible for the system, there is little traffic other than family members, but the system may be operational at irregular intervals. In a commercial or industrial setting where those responsible for the alarm system may not have a proprietary interest in its responsible use, there is likely to be a great deal of pedestrian traffic on the site, but the usage pattern is highly regular. The attributes of the final group are a mix of the first two. In any case, police productivity, P, will vary between groups. Public policy can be changed with respect to each group in order to produce the largest change in output.

There are other distinctions to be made. For example, residential users may be subdivided into single family residences, row houses and apartment buildings. Each group has its own P, say $P_1 > P_2 > \ldots > P_h$; then according to Proposition 1 $\eta_1 > \eta_h$, but we can state another proposition.

Proposition 3: Consider a community of two kinds of residents, A and B. Residents of type A allow the police to work more productively since their proportion of *bona fide* alarm activations is higher than among the type B residents. Community security is greater if the two types of residents can be segregated.

Proof: There are two neighborhoods each with H households. There are two types of households, A and B. Each neighborhood consists of αA + $(1 - \alpha)$B houses. Allocate police officers to the two neighborhoods so that η is the number of alarms per police officer in both places. The neighborhood that segregates the households by type has a level of safety given by $\alpha P_A^\eta + (1-\alpha) P_B^\eta$, whereas the safety level per house in the integrated location is $P_A^{\alpha\eta} P_B^{(1-\alpha)\eta}$. The difference between the values is $\Delta = \alpha P_A^\eta + (1-\alpha) P_B^\eta - P_A^{\alpha\eta} P_B^{(1-\alpha)\eta}$. If $P_A = P_B$, indicating that there are no differences between types of households, then $\Delta = 0$. Hence mixing and matching do not matter. Now suppose that we increase P_A slightly; then

$$\frac{\partial \Delta}{\partial P_A} = \alpha\eta P^{\eta-1}\left(1 - \frac{P_B^{(1-\alpha)\eta}}{P_A^{(1-\alpha)\eta}}\right) > 0$$

Segregation of the neighborhoods results in an increase in safety. ■

The proposition implies that it is better to match than mix alarm owners of different types. Although usually done for different reasons, communities have already adopted such a process through their zoning laws. In a given community it is rare to find heterogeneous types of housing or a mix of, say, single family houses and commercial properties.

Even where zoning cannot be implemented in a useful way there is an equivalent solution. Implicitly, allowing private response serves the function of sorting the types of residents into homogeneous groups. Alarm companies will not find it profitable to provide physical verification to all types of alarm owners. The provider of private response could segment the market within each of the three broad classes of residential, commercial and industrial customers. Commercial property owners may have greater ability to pay and the evidence is that they also generate higher rates of false activation than residential properties. Hence, the alarm company may lump them into a class of consumers to whom they provide private response. Skimming off the cream is not a concern in this scheme. Those alarm owners that generate a small number of false activations may not feel the need to buy private response; *ex ante*, they know that when their alarm is activated there is a very high probability that it is *bona fide*.

Police work more productively when P_{11}, the proportion of time that alarm activations are *bona fide*, is increased. Fining owners for false alarms or requiring verification before dispatch of the police will both increase P_{11}. In the first instance the municipality is imposing a tax on alarm buyers and owners. The twist is that the probability of the imposition of the tax is not one, but is given by the probability of false activation. In any case, alarm owners have an incentive to operate their system more efficiently in order to avoid paying the fine. In the second instance the municipality has imposed a requirement that the product being offered to the consumer be expanded to include not only intrusion detection, but also response. There are two twists in this policy. The first is that the alarm seller is being forced to offer alarm response and bundle it with the sale of the monitoring service. The second twist is that alarm response has both fixed and variable costs. The known fixed cost is the monitoring function. When the alarm company must respond to an activation, it incurs the variable cost, but the fee for services is fixed and has been paid in advance. Hence, the alarm company's net income is reduced in a random fashion. The behavioral impact is equivalent to a random tax on alarm sellers, in which the seller can affect the probability of imposition by reducing the incidence of false alarms.

Since both policies have the same behavioral impact they can be modeled in the same fashion. We can let $P_{12} = P_{12}(d, t)$ where d is the size of the fine for false activation and t is the type of the alarm owner. The owner's type is defined so that a higher t corresponds to a more responsible homeowner. Since $P = 1 - P_{12}$, where P_{12} is the probability of a false activation, and higher fines and better-behaved owners both decrease false activations, we can state that P is increasing in d and t.

The objective function for the community is written in terms of alarms per police officer. The proportion of time that the police are working productively now is a function of the type of household, t, and the size of the disciplinary penalty imposed for a false alarm, d.

$$\Pi = \left[V_{\mathrm{a}} - V_{\mathrm{p}}\left(1 - \frac{H}{n}\right)\right]\eta P(d,t)^{\eta} - w - r\eta\left[1 - P(d,t)^{\eta}\right] \tag{4}$$

The final term is the expected cost to the community resulting from false activations. The variables of choice are now the size of the penalty and η. Letting the subscript on P denote the partial derivative with respect to the variable and suppressing the arguments in P, the first-order conditions are

$$\frac{\partial \Pi}{\partial \eta} = \left[V_{\mathrm{a}} - V_{\mathrm{p}}\left(1 - \frac{H}{n}\right)\right]P^{\eta}[1 + \eta \ln(P)] + r\{P^{\eta}[1 + \eta \ln(P)] - 1\} = 0 \tag{5}$$

$$\frac{\partial \Pi}{\partial d} = P_d P^{\eta - 1}\eta^2 \left\{\left[V_{\mathrm{a}} - V_{\mathrm{p}}\left(1 - \frac{H}{n}\right)\right] + r\right\} = 0 \tag{6}$$

Manipulation of the first-order conditions allows the statement of a proposition regarding the effect of a change in household type on the size of the optimal fine.

Proposition 4: Better-behaved households should pay higher fines for false activations, all other things equal.

Proof: The implicit function theorem allows us to state

$$\frac{\partial d}{\partial t} = -\frac{\dfrac{\partial\left(\dfrac{\partial \Pi}{\partial d}\right)}{\partial t}}{\dfrac{\partial^2 \Pi}{\partial d^2}}$$

$$\frac{\partial d}{\partial t} = -\frac{\left[V_{\mathrm{a}} - V_{\mathrm{p}}\left(1 - \dfrac{H}{n}\right)\right]\eta^2 P^{\eta}\left[(\eta - P)\dfrac{P_t P_d}{P^2} + \dfrac{P_{dt}}{P^2}\right] + r\eta^2\left[(\eta - P\eta)\dfrac{P_t P_d}{P^2} + P^{\eta-1}P_{dt}\right]}{\dfrac{\partial^2 \Pi}{\partial d^2}}$$

The denominator is negative by virtue of the fact that Π must be concave. The numerator is positive; therefore, the entire expression must be positive. ■

Better-behaved alarm owners encounter stiffer fines per infraction because the positive effects of discipline on their behavior are greater. This somewhat counterintuitive result is also found in models of criminal deterrence (Ben-Zion *et al.*, 1993). Responsible, well-behaved alarm owners are able to increase police productivity by a greater amount when they reduce their activations from, say, three to two than can the less responsible owner who decreases her activations from ten to nine.[24]

4 Conclusions

The services provided by the police in a community have attributes that are in the nature of the tragedy of the commons. Calls for emergency response represent the consumption of the commons good aspect of police services. As the number of calls for emergency response increases, there is increasing disruption of the normal work of the police. Eventually, as calls for emergency response increase there is congestion, which reduces the productivity of the police. This paper adapts Lazear's (2001) analysis of student disruption in the classroom to analyze random disruptions in the provision of police services and their effect on avoided losses in the community, the output of the police.

This paper demonstrated how an increase in false alarms yields reduced effectiveness of police and thereby decreases police ability to provide their services. The consequence is that police and alarms are substitutes to the extent permitted by the inefficiencies induced by false activations. It is shown that as police officers' wages rise, police officers are required to be more productive, and hence the optimal number of alarms per officer increases. As police are more productive it is efficient to have them be responsible for more

[24]The elasticity of false alarm reduction with respect to the fine is not at issue. When a monopolist is able to practise price discrimination the fact that the group with the greater elasticity pays the lower price is a result, not the basis for setting the optimal price. In the present situation well-behaved alarm owners have a smaller elasticity of alarm use than do poorly behaved owners, and the small elasticity customer of the police department pays the higher price.

alarms. This conclusion appears on the surface to be an assertion that the demand curve for police services is downward sloping. More importantly, the comparative statics of the paper represent shifts between these downward sloping demand curves.

The model shows that controlling false requests for emergency response is more complex than just setting penalties equal to marginal costs of response. Reducing false alarms in communities where residents are already more responsible is more difficult and less cost-effective than in communities where there are more false activations. The model suggests segregation of alarm owners into groups according to their propensity to falsely activate. Such segregation allows the police to work more productively. This kind of segregation occurs *de facto* as a result of zoning that divides the community into industrial, commercial and residential areas. Research indicates that these three groups have different rates of alarm activation (Hakim, 1995). A further method for segregation is also achieved by the practice of requiring physical verification of an alarm by a private company before the police respond. Most often physical verification is offered in commercial areas and areas where police resources are scarce or highly priced.

The model also suggests that as alarms are more effective, avoided losses in the community are greater for a given optimal ratio of alarms to police. When the rate of false activation is low and police are more productive, it is possible to achieve a given level of avoided losses with fewer police. This is the large community effect. The conclusion also suggests another avenue for public policy response. Namely, the community should provide financial incentives for alarm system owners to upgrade their systems in order to make them more reliable. Education of alarm owners in the use of the system can have the same effect.

Policies aimed at reducing false alarms are less effective in communities in which residents already behave responsibly. This leads to the perhaps counterintuitive result that better-behaved alarm owners should pay higher fines per activation than should less responsible alarm owners. The reason is that the productivity of the police rises faster in the group that can produce the larger reduction in disruptive behavior.

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