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Journal Title: Games in hierarchies and networks : analytical and empirical approaches to the study of governance institutions /

Volume: **Issue:**
Month/Year:

Pages: pp. 351-386

Article Author: George Tsebelis

Article Title: Monitoring in Networks and Hierarchies: Congress and Organizations

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Monitoring in Networks and Hierarchies: Congress and Organizations

George Tsebelis

This chapter uses games among three players to analyze the properties of different monitoring systems. A monitoring system includes at least two players, a monitor and a monitored. The monitoring agent oversees whether some rule or regulation is followed. Because of monitoring costs, the monitoring agent prefers to engage in this oversight activity if there is deviance from the rule; otherwise he does not monitor. The monitored agent would prefer to violate the rule in the absence of the monitoring agent, but complies with the rule in his presence. Either or both of these two players may be individuals, as is the case with ticket inspectors; organizations, as is the case with polluting firms and environmental protection agencies; or collective entities, as is the case with the police and the public. A monitoring system arises as one way of fighting moral hazard, or hidden actions. A hidden action occurs when two interacting players have diverging interests and one of them cannot observe the relevant actions of the other.

It may be the case that in such monitoring interactions other players are also involved. For example, if one considers the monitoring game between the police and the public, it is obvious that both players are affected by the behavior of judges, lawyers, the prison system, the legislature, etc. Similarly, in the monitoring game between the Legislative and the Executive in a Presidential system (usually called Congressional oversight activities), the payoffs of both players are set (assuming a democratic system) by the people through

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This paper was written while I was visiting at the Max-Planck-Institut für Gesellschaftsforschung in the summer of 1991. I would like to thank Joel Aberbach, Miriam Golden, Fritz W. Scharpf, and Tom Schwartz for their comments. I would also like to thank Matthias Reinhardt for research assistance.

elections. All these cases have the common characteristic that third players either set the rules of the monitoring game (as in the case of legislatures writing criminal law, or setting the budget for prisons) or move after the monitoring game itself is over (like judges and lawyers). In game-theoretic terms, these third players move either before or after the monitoring game.[1]

It turns out that when two players are involved in a monitoring game, while other players move before or after this game, under a wide variety of conditions, changes in the payoffs of one player affect the behavior of the other. For example, increases in penalties reduce police monitoring, while increases in the police's payoffs for monitoring reduce crime. These results hold even if the monitor and the monitored players are not unified but are composed of different "types," even if some of the types of the monitor prefer to monitor constantly, and even if some of the types of the monitored prefer to violate or to comply all the time with a rule. The results do not require rationality of the players, but can be derived under less restrictive adaptive behavioral assumptions (Tsebelis 1990a).

I will not examine such cases here. Instead, I will focus on cases where some third player plays simultaneously with the first two. In particular, the third player will assume the role of monitor. In the extreme cases, the third player would be used to monitor one of the other two players exclusively.

If the third player monitors the monitored agent, then the situation may be characterized as one where two independent police forces have the same jurisdiction. An archetypical case would be the legislative oversight of a bicameral legislature in a Presidential system such as the US. This is where the first part of the subtitle comes from.

If the third player monitors the monitoring agent, we face a simple case of a hierarchy, where the superior monitors middle-level agents, who in turn monitor lower-level employees. This archetypical case generates the second part of the subtitle.

Finally, in more realistic settings, the third player may be interested in the behavior of both other players, and the other two players may be affected by his choices. One of the models of this chapter will investigate such general situations.

1 For discussion of such monitoring games see Bianco/ Ordeshook/ Tsebelis (1990) and Tsebelis (1991).

The chapter is organized in three sections. The first discusses different monitoring systems, presents an exhaustive typology, and indicates their common property: absence of dominant strategies for the actors involved. The second presents a series of three-player monitoring games and examines their comparative statics: How do players react to a change in penalties of the monitored agent or agents? What would be the impact of a technological innovation that makes cheating or shirking more difficult for one of the players? etc. The third part will be an attempt to relate the conclusions of these models to existing institutional settings.

1 Styles of Monitoring: Self-Reporting, Fire Alarms, and Police Patrols

Some rules do not need enforcement to be observed. For example, once traffic lights are in place, it is in the interest of all parties to observe them. Similarly, in some cases deviance may be reduced through incentives rather than through monitoring and penalties.[2] However, once we restrict our attention to monitoring as a means to induce compliance to rules, we can distinguish different methods or styles.

McCubbins/ Schwartz (1984) distinguish two ways of detecting violators of a rule. They call the first "fire alarms" and the second "police patrols." In the fire alarm case, the rule-making actor (society, the legislature, or Congress) "establishes a system of rules, procedures, and informal practices that enable individual citizens and organized interest groups to examine administrative decisions (sometimes in prospect), to charge executive agencies with violating congressional goals, and to seek remedies from agencies, courts, and Congress itself" (McCubbins/ Schwartz 1984: 166). Fire alarms are characterized by this third-party intervention and *a posteriori* action of an oversight institution. Aberbach (1990) calls this kind of monitoring reactive oversight. Police patrols are the active case of monitoring. A special agent is

2 The regulation literature (Hawkins/ Thomas 1984) distinguishes between compliance and deterrence. For a discussion of different methods to reduce deviance see Tsebelis (forthcoming).

assigned the role of discovering violations of rules and identifying the violators. This, Aberbach (1990) calls active oversight.

I would like to discuss a third method of monitoring, which I will call self-reporting. This method is not very frequently employed by Congress, so it does not appear in the debate between McCubbins/ Schwartz and Aberbach.[3] Sometimes in order to facilitate its work, a monitoring agency asks players in its jurisdiction to fill out a questionnaire regarding a particular activity. For instance, the Internal Revenue Service asks citizens to make an income tax statement; customs typically requires travelers to fill out a statement about goods purchased abroad; corporate actors may have to respond to agencies about their activities and an agency may follow up upon receipt of statements from a firm. The advantage of self-reports is that they restrict the population of potential violators, thereby easing the monitoring activity. The customs officers, for example, can tax the people who declare that they have brought taxable goods in the country, and randomly check only the subset of people who claim they have nothing to declare.

I will use two different criteria and distinguish three categories of monitoring. The first is whether the monitoring agency takes the initiative to monitor or whether instead it monitors in response to some external catalyst. I will call the first case active monitoring and the second reactive monitoring. The second criterion distinguishes two different kinds of reactive monitoring, according to who took the initiative. If monitoring was triggered by a report from the monitored actor I will speak of self-reporting, while if it is a third agent, I will speak about fire alarms.

McCubbins/ Schwartz analyze congressional oversight of the executive branch and come to the conclusion that fire alarms are cheaper and more profitable than police patrols for Congress, and therefore preferable to them. They conclude that the absence of active monitoring by Congress does not mean that Congress does not exercise its rights (or duties), but that it has found a better way of achieving the same goal: it has assigned to concerned citizens the responsibility of discovering the necessary information concerning violations of laws, so it does not need to monitor on their behalf. The argument seems compelling, persuasive, and general. However, it cannot be but a partial one.

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3 For example, in the 95th Congress "agency reports required by Congress" was the 10th ranking technique for Congressional oversight (Aberbach 1990: 132).

Aberbach's (1990) careful study of Congressional oversight demonstrates that 63% of oversight activities by the Appropriations committee as well as 34% of total activities by all committees can be classified as the active variety of monitoring. Moreover, some 20% can be classified as "intermediate monitoring," leaving less than 50% of oversight activities to fire alarms. Aberbach (1990: 98) concludes that the "police patrol approach is prominent." He explains this prominence by the changing nature of incentives on Capitol Hill and in its environment (especially the increasing importance of zero-sum games between a politically opposed legislature and executive in a period of scarcity of resources, and the exogenous growth of congressional staff).

Since fire alarms are not the best choice regardless of institutional setting, it is interesting to investigate the conditions under which each one of the three forms of monitoring will prevail. I propose the following tentative conditions:

1. Are the violation and the violator obvious?
2. Is it easy to repair damages arising from the change in the status quo?
3. Do outsiders have an interest to report?

If the answers to all of these questions are affirmative, then the likelihood of the use of fire alarms increases. If the answers to the first two questions are affirmative but to the last one negative, self-reporting is likely to prevail. In all other cases, active monitoring will be prevalent.

1. Logically there are two distinct cases of the imposition of sanctions. In the first case, the violation is obvious and the identity of the violator is known. If the rule involves some generally visible or easily identifiable characteristic (such as requiring all soldiers to wear uniforms), the violators can immediately be singled out and punished. Such cases do not require active monitoring and can be delegated to one of the two forms of reactive monitoring.

One particular condition that generates the visibility of violators is related to time. If it takes time for the violator to alter the status quo, then it is likely that the decentralized interests that will be hurt by the change will be able to mobilize and to fight. This is why the public sector announces expected changes ahead of time, inviting all affected parties to participate in public hearings (sunshine measures). Alternatively, legislation provides public announcements of important plans of the private sector, in order to invite other concerned parties to make their opinions (and objections) known. For example, there is mandatory public announcement of plans to undertake new construction, etc.

The second possibility is that the violation may not be visible (waste dumping may be operated at night, in distant places, and have environmental consequences in the distant future), or even if the violation is visible, the identity of the violator may not be obvious (theft). Such cases require the existence of a centralized monitoring agency to prevent violations thanks to its presence, to detect them (waste dumping), or, as a last resort, to clear them once reported (theft).

2. The second condition for reactive monitoring is whether repairing the status quo is easy or not. If repairing the status quo is easy, reactive monitoring will prevail, because the principal can easily ask the violator to correct the mistake or repair the damage. If, however, it is difficult, police patrolling becomes more necessary. This may be one of the reasons why established and credible organizations are less often subject to random checks by police patrols: because if they are found in violation they are likely to repair the damage.

3. The last question distinguishes between self-reporting and fire alarms. If outsiders have an interest to report accurately, fire alarms will prevail. Under what conditions will third parties be willing to report violations? Presumably, if they have something at stake; that is, if their own property rights are violated. But if property rights are assigned collectively, it is possible that no individual actor will bother to collect information about violations, or to complain about them. In order to induce individual actors to be concerned with the violation of a rule, the principal may distribute property rights to individuals. This way, information gathering will be decentralized and collective action problems in reporting violations of rules will be eliminated.[4]

A similar distinction between theoretical and actual violation of individual rights seems to me to be the point of view of Weissing/ Ostrom (1991b: 4.1), who examine the monitoring game between a turntaker and turnwaiters in irrigation systems. They conclude:

> The other N players recruit from the population of turnwaiters. However, only these turnwaiters will be considered as "players" who are directly affected by the turntaker's behavior and who have strategic influence on his decision. In an extremely small irrigation system, the players in our model would include all the farmers. In most systems,

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4 T. Schwartz, personal communication to the author.

> however, the players would include only those farmers who ... feel a direct loss when water is stolen, and who can positively or negatively sanction each other's behavior. In many cases, it will only be the farmer whose turn will come in the next period, who fulfills these requirements. In the latter case, only two farmers would be included among the players even if the irrigation system itself were quite large (Weissing/Ostrom 1991b: 209).

Despite their differences, all monitoring methods share an important common characteristic: Neither the monitoring agent nor the monitored player have a dominant strategy. Indeed, it is preferable for the monitored player to observe the rule in the presence of the monitor and to violate it in his absence. Similarly, it is preferable for the monitoring agent to monitor when there is violation of a rule and not to monitor otherwise. These common characteristic of all monitoring systems generates a strategic equivalence of monitoring games. Assuming that each player has two options, under a wide variety of conditions in self-reports, fire alarms, and police patrols, both players use mixed strategies.[5]

There is one exception to the mixed strategies rule which merits discussion. If fire alarms are *accurate* (the ideal case is that only violators will be reported with probability 1), then the optimal strategy for potential violators is to comply with the rule. The reason is that every violation will be reported, and the violator punished. However, it is most likely that a decentralized system using fire alarms will be inundated with complaints. For example, Robert A. Katzmann (1980: 165) reports a remark by a Federal Trade Commission official as follows: "We simply do not have the resources to fully investigate every possible violation of the law we learn about. Accordingly, we must constantly make hard choices among alternatives in order to maximize the effect of our enforcement activity." Similarly, Suzanne Weaver (1980: 136-137), describing how lawyers in the Antitrust Division find their cases, says that they think of their environment as one of "information scarcity." "Most of the time, the information they got did not have even the remotest possibility of becoming the subject of antitrust prosecution. 'Ninety percent of these things are bummers', one staff attorney summed it up." And Susan Silbey (1984: 160) describes a similar case of fire alarms where the Consumer Protection Department in Massachusetts became the victim of its

5 For an extensive discussion of the strategic equivalence of different methods of monitoring see Tsebelis (forthcoming: Chap. 2).

own success: "the volume became overwhelming and the division became a victim of its own efforts: the more successful it was at resolving consumer complaints, the more complaints arrived and inundated the office." When the accuracy of reports is reduced, both actors (the monitor and the monitored) will use mixed strategies. And if the accuracy of reports is reduced even further, so that a report provides no information about the behavior of the monitored actor, the fire alarms system becomes identical to police patrols (reports are completely discredited).

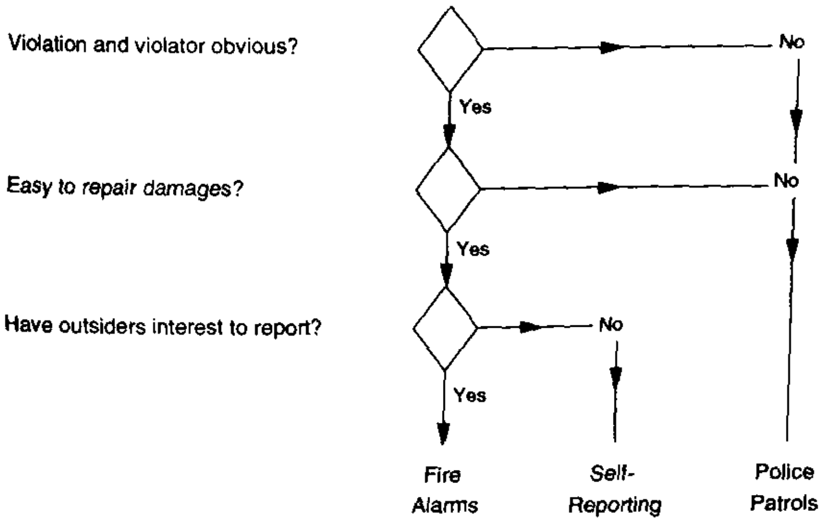
Because of the efficiency of accurate fire alarms, special attention should be given to the question of who has the right to pull the fire alarm. This is an extremely important issue of institutional design and interested parties are aware of it, as the following example from environmental protection indicates. In the United States in the 1970's, a series of Supreme Court decisions established the "standing to sue" of environmental groups (Sierra Club vs. Morton (405 U.S. 727, 1972)), United States vs. Students Challenging Regulatory Agency Procedures (412 U.S. 669, 1973), Duke Power Company vs. Carolina Environmental Study Group (438 U.S. 59, 1978). The Supreme Court stated: "Aesthetic and environmental well-being, like economic well-being, are important ingredients in the quality of life in our society, and the fact that particular environmental interests are shared by the many rather than the few does not make them less deserving of legal protection through the judicial process" (Sierra Club vs. Morton (405 U.S. 727, 1972)).[6] However, the Reagan administration tried to reverse this decision.

> In late 1987, the White House issued a presidential directive to the Department of Justice stating that any staff attorney litigating a case involving the EPA and public interest groups and *not* challenging the group's standing to sue would have to get his or her section chief to prepare a memorandum to the appropriate deputy attorney general explaining why no challenge was filed (Harris/ Milkis 1989: 272, italics in original).

Table 1 summarizes the argument of this section. Monitoring can take three distinct forms, each of which is likely to be adopted under different circumstances. The big advantage of fire alarm mechanisms lies with their low cost. However, the conditions under which they can be adopted are very restrictive. Strictly speaking, their adoption requires the existence of three conditions (affirmative answers to all three questions in Table 1). The self-reporting

6 See also Harris/ Milkis (1989: 242).

Table 1: Conditions for the Adoption of Different Methods of Monitoring

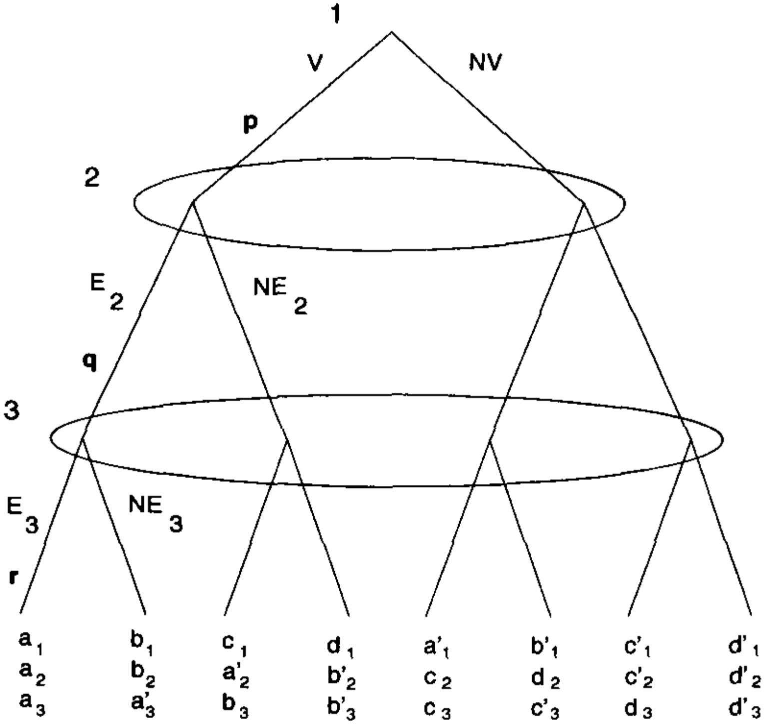


method of monitoring is cheaper than active monitoring, but again, is not generally applicable. Therefore, the adoption of one or the other mechanism of monitoring will depend on trade-offs between the above three conditions and budget constraints.

2 A Three-Person Monitoring Game with Variations

Previous research has studied this monitoring interaction as a two-player game (see Tsebelis 1989, 1990b, 1991; Hirshleifer/ Rasmusen 1992), or as a game with N symmetric monitoring agents (Weissing/ Ostrom 1991a, 1991b). Here I will introduce a third player who will be either a hierarchical superior of the police agent or a new police agent with different payoffs than the previous one (relaxing the symmetry assumption used by Weissing/ Ostrom).

Figure 1: General Form of Monitoring Game with Three Players



Equilibrium conditions

(1) $qr(a_1-a'_1)+q(1-r)(b_1-b'_1)+(1-q)\ r(c_1-c'_1)+(1-q)(1-r)(d_1-d'_1) = 0$

(2) $pr(a_2-a'_2)+p(1-r)(b_2-b'_2)+(1-p)\ r(c_2-c'_2)+(1-p)(1-r)(d_2-d'_2) = 0$

(3) $pq(a_3-a'_3)+p(1-q)(b_3-b'_3)+(1-p)\ q(c_3-c'_3)+(1-p)(1-q)(d_3-d'_3) = 0$

or

(1) $qrA_1+ q(1-r)B_1+ (1-q)\ rC_1+ (1-q)(1-r)D_1 = 0$

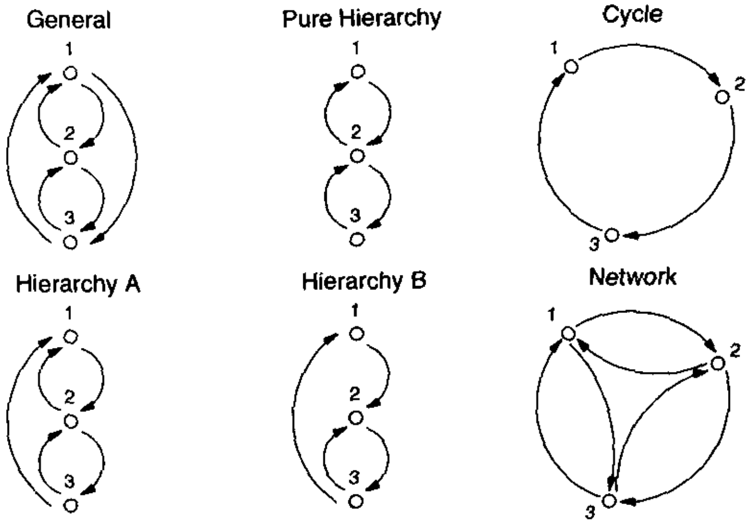
(2) $prA_2+ p(1-r)B_2+ (1-p)\ rC_2+ (1-p)(1-r)D_2 = 0$

(3) $pqA_3+ p(1-q)B_3+ (1-p)\ qC_3+ (1-p)(1-q)D_3 = 0$

The generic interaction is presented in Figure 1. Three actors interact with each other, and have two strategies each: the first can violate or not violate some rule and the other two can monitor or not monitor. The choices take place simultaneously. The payoffs of the players vary according to the model.

In general, the games I examine fall either into the category of hierarchies (if the third player monitors the second) or into the category of networks (if the third player is another police). Figure 2 presents the configurations considered here. The arrows in the figure indicate that the actions of the player at the beginning of the arrow affect the payoffs of the player at the end of the arrow. For example, in the first figure the left arrow that connects the lower player with the higher one indicates that the payoffs of the latter are affected by the choices of the former. Cyclical arrows indicating the impact of one's own actions are omitted throughout.

Figure 2: Networks and Hierarchies of Monitoring Games



The remainder of the chapter will investigate three models:

1. A pure hierarchy, where the public is affected by its own actions and the police's, and the police supervisor is affected only by his own actions and the police's.
2. A more generalized hierarchical model where the supervisor also cares about the choices of the public.
3. A model with two polices with overlapping jurisdictions who monitor the same public. These two polices have different payoffs and may compete with, free ride on, or be completely indifferent to each other.

These three models will be investigated for their comparative statics, that is, the effects of changes in their parameters on the equilibrium strategies of the actors. The mathematical calculations are presented in the appendices. In the main text I will present some of the results, and give the intuitions behind the most important ones.

2.1 Hierarchies

HIERARCHY A. This model is presented for heuristic purposes. It will help us understand and decompose a simple case of interaction between three players. The next section will modify some of the unrealistic assumptions.

Consider three players interacting in the following way. The first has to comply with some rule, although he prefers not to. In the absence of a police agent he would prefer to shirk, while in the presence of the law he would conform to the rule. The second's duty is to monitor, but because of monitoring costs, he prefers not to monitor if there is no violation of the rule. The third's task is to monitor the second. However, he also prefers not to monitor if the second does his job properly (that is, if the second monitors).

We will call the first player the public, the second the police, and the third the police supervisor. Note that in this model the police supervisor is indifferent to the level of crime. He is only concerned with the level of police activity. Similarly, the public is indifferent to the internal affairs of the police (that is, what the supervisor does), and is exclusively concerned with the level of monitoring.[7]

The assumptions are formalized in Appendix 1, where the game is solved. I will present the results verbally. Essentially, the police plays against two different partners: one internal game against the supervisor, and one external game against the public. Each one of these games in isolation would prescribe a mixed strategy for the police; the police would monitor some of the time and not monitor the rest. As I have shown elsewhere (Tsebelis 1989), in each one of these games the frequency of monitoring is determined by the payoffs not of the police but of the opponent (the public or the supervisor). Now the internal and the external game are played simultaneously. In general, each one of these games prescribes different equilibrium behavior for the police.[8]

The police have to choose between the equilibrium strategy q3 in the internal game (the interaction between police and supervisor) and the equilibrium strategy q1 in the external game (the game between police and public). Or, to use the terminology taken from a different research project, the police is involved simultaneously in two different games, and behavior that is optimal in one game is suboptimal in the other. Therefore, suboptimal behavior in one arena should be explained by the prevailing conditions in the other (Tsebelis 1990a). In our particular case, this transition from equilibrium behavior of the internal to the external game and vice versa is an easy one for the police, because of the existence of a mixed strategy equilibrium. In a mixed strategy equilibrium, by definition a player (in this case the police) is indifferent between its two pure strategies (otherwise a rational player would choose the better one), so it can select any combination (any mixed strategy) without penalty.

Depending on the parameters of the game, the police will select one of the two partners, and play either the internal or the external game, while the third player will choose a pure strategy. If the parameter constellation is such

7 This model is an illustration of the argument presented by Weissing/ Ostrom (1991a) of a game where the first player's payoffs do not depend on the third, and vice versa, and accordingly one would expect in mixed strategy equilibria the payoffs of one player to affect the behavior of the other.

8 In the zero-probability event that the two games prescribe the same behavior for the police, the police uses this strategy, while the public and the supervisor have an infinity of combinations.

that the internal game is selected, the public will not violate the law and the police and the supervisor play the internal game. In the opposite case, the police and the public play the external game and the supervisor will not monitor.

The crucial determinant for the selection of the game that is played is, if q_1 (which depends on the public's payoffs) is greater than q_3 (which depends on the supervisor's payoffs) (see Appendix 1). This means that according to this model a change in the payoffs of the public or the supervisor may shift the game from an equilibrium where there is crime but no supervision to an equilibrium where there is no crime *because* internal supervision forces the police to monitor at high levels. This is a surprising result, because it indicates that the selection of a supervisor with appropriate payoffs could drastically reduce deviance (according to this model, to zero).

The reason that the level of crime in this model is zero is that the public is considered a unified actor, and therefore, once the police enforces with probability higher than the equilibrium value of the external game, the best response of the public is to stop violating the law altogether. A more realistic approach would be to consider the public as well as the police as composed of different types (each type with different payoffs), interacting with each other with probability equal to the product of the frequencies with which they are represented in their respective populations. While such a modification does not affect the result of a two-person game (see Tsebelis 1992), it has an important effect on this three-player game. An important proportion of the public (higher than the equilibrium frequency ($1-p^*$) of the two-person game) will choose not to violate the rules. Moreover, an increase in penalties will reduce crime even further.

HIERARCHY B. Now consider a model similar to the previous one, but with the following twist: while the public is indifferent to the actions of the supervisor, the supervisor is concerned both about monitoring (which he likes) and crime (which he dislikes).

Appendix 2 presents the formal assumptions and the solution of the model. In this model only the police will necessarily play a mixed strategy. The other two players may choose pure strategies. Assuming that an equilibrium in completely mixed strategies exists, we come to the following conclusions: an increase in penalties (decrease of A_1) decreases crime, and increases both the monitoring frequencies of the police and the supervisor;[9] an increase in the expected payoff of crime increases the frequency of crime and police monitoring, but decreases the frequency of supervision.

Changes in the payoffs of the police produce ambiguous effects on the supervisor alone, so we will ignore the matter altogether. Changes in the supervisor's payoffs affect both the public and the supervisor. In all cases, the effects go in opposite directions: an increase in A_3 or B_3 (indicating a preference for monitoring when the public violates the law) always decreases crime and increases monitoring by the supervisor, while an increase in C_3 and D_3 (indicating a preference for not monitoring when there is no violation by the public) most likely increases crime and decreases supervision.[10]

Finally, the strategy of the police depends exclusively on the payoffs of the public. This finding is counterintuitive, because one would expect police behavior to depend on the preferences of the police itself. For example, a police force which is concerned about internal enforcement (one that depends very much on the supervisor's strategy) could be expected to behave differently from a police force less responsive to the internal hierarchy. Similarly, a police force concerned about the level of crime could be expected to monitor more frequently than a police force which is oblivious to it. This model indicates that such changes in the payoffs of the police are internalized in the strategy of the supervisor, who in turn increases or decreases his monitoring strategy accordingly. I will compare and discuss the findings of hierarchical models in the next section.

2.2 Networks

Now consider two police forces with the same jurisdiction (both supervising the same public). Their payoffs may be different from each other's and they can have any relationship with each other. In particular, I will consider all three possible relationships: 1) *Competition:* each one of the police forces prefers to arrest the criminals itself rather than see them arrested by the other; 2) *Free riding:* each police prefers to see the criminals arrested by the other

9 See corresponding first derivatives of equilibrium strategies in Appendix 2.

10 When the quantity A_1B_3-C_1A_3 is positive.

rather than to arrest them themselves; 3) *Assignment:* Both police forces agree that arrests by one police are preferable to arrests by the other.

The first case is designed to examine the widespread belief that competition among polices may induce them to monitor more, thereby driving down crime. The second addresses the logically opposite problem. The model I present here is a special case of the Weissing/ Ostrom (1991b) model. They address the question of N polices with identical payoffs who had a free rider problem. I restrict the number of polices to two, but relax the symmetry assumption.[11] Finally, the last case (assignment), is singled out both for logical completion, and to test whether the assigned police would predominantly take charge of monitoring or not.

In all the models, the public is considered indifferent to whether it will be arrested by one, the other, or both polices. The formal assumptions, the equilibria, and comparative statics are presented in Appendix 3.

One important conclusion of this model is that as long as the public is indifferent to the identity of the monitoring agency, the overall frequency of monitoring will be determined exclusively by the payoffs of the public. The division of labor between the two polices may vary, but the overall frequency of monitoring will be exactly the same as it would be if only one police were operating. I will single out this result:

PROPOSITION 1: If the public is indifferent to the identity of monitoring agency (A_1=B_1=C_1), the overall frequency of monitoring is stable and depends exclusively on the payoffs of the public.

The reason for this counterintuitive result is the following: consider two models, one with one police and the second with two police forces. In both models the public receives the same benefits if it violates without being caught or if does not violate while the police (or one of the polices) is around. In a mixed strategy equilibrium the public is indifferent between its two pure strategies. So, it is the same frequency of law enforcement that makes the

11 A particular case of this (free rider) model is indifference instead of preference: each one of the polices does not care what the other does. In this case, according to Weissing/ Ostrom's results (1991a), one would expect the game to be reduced to a two-person game.

public indifferent in both models. This conclusion could end investigation of this model. Regardless whether the polices have competitive or cooperative (assignment) relations or whether they free ride on each other, the overall frequency of monitoring remains the same. This frequency decreases with the size of penalty (as in the model with one police, see Tsebelis 1989).

However, the frequency of monitoring is not the only interesting question to ask of this model. There are two more interesting questions: What happens to the frequency of crime when different parameters vary, and what is the internal division of labor between the two polices?

The effects of variations of different parameters of the model is presented in Table 2. The sign > in the intersection of a column and a line indicates that the first derivative of the strategy (column) with respect to the parameter (line) is positive, and therefore that an increase in the parameter produces an increase in the strategy. It is interesting to note that an increase in penalty decreases all the equilibrium frequencies: the public violates less and both polices monitor less.

Table 2: Effects of Variations of Parameters on Equilibrium Frequencies of Crime and Monitoring

	p	q	r
$(-A_1/(D_1-A_1))$	<0	<0	<0
A_2	<0	<0	>0
B_2	<0	<0	>0
C_2	<0	<0	>0
A_3	<0	>0	<0
B_3	<0	>0	<0
C_3	<0	>0	<0

The sign >0 indicates that the first derivative of the strategy with respect to the parameter is positive and therefore the frequency of the strategy increases with the parameter.

An increase in the competitiveness of one police reduces crime rates, but also (and this is a counterintuitive result) reduces the frequency of monitoring by this police at equilibrium, and increases the frequency of monitoring of the other police. Therefore, the intuition that increasing competition between polices decreases crime is correct. However, the division of labor between the two police forces is exactly the opposite from their motives: the more motivated police monitors less.

This reversal of direction between motives and actions at equilibrium is comparable to the findings of Weissing/ Ostrom (1991a), who observe that when one of their N monitoring agents is in a better position for monitoring, his equilibrium frequency of monitoring goes down compared with the symmetric case, while the equilibrium frequency of the other players goes up. My result reduces the number of players (N=2 in my case), but relaxes the symmetry assumption as the starting point.

Similar comparative statics results are produced with variations in the parameters Bi (the willingness of one police to patrol when the other does not) and Ci (the desire of each police to relax when there is no crime). Variations in these parameters produce a counterintuitive division of labor between polices.

PROPOSITION 2: If all three players use mixed strategies, there is a reversal between motives and behavior of the two polices at equilibrium: the more motivated police monitors less.

Why in a mixed strategy equilibrium does the police which is more motivated for monitoring, monitor less? The reason is the following: In a mixed strategy equilibrium each player is indifferent between his two pure strategies. Consider the equilibrium frequency of crime p* (the frequency that makes the public indifferent between violating and not violating the law). This frequency of crime makes both polices indifferent between monitoring and not monitoring. Now, increase the payoffs from monitoring for one police (player 2) and consider the new equilibrium. There will be a change in all equilibrium strategies, but all players will be indifferent between their two pure strategies. Remember that the overall frequency of monitoring is stable (Proposition 1). When the payoffs of monitoring increase for player 2, player 3 (the other police) has to increase monitoring in order to keep player 2 indifferent between monitoring and not monitoring. A similar argument can be made when incentives for one police to monitor are reduced: this police will increase monitoring and the other will reduce it.

One additional point is necessary: The conclusions reported here regard the equilibrium where all players use mixed strategies. However, there are other equilibria in this game where one police does all the monitoring and the other does not monitor at all. These equilibria have identical properties with the equilibrium in a two-person game (Tsebelis 1989). So, a more intuitive way of understanding Proposition 2 is to say that when the payoffs of monitoring for one police increase, the other has to increase monitoring in order to stay in the game.

3 Discussion

What are the conclusions of this investigation for monitoring in networks and hierarchies?

HIERARCHIES: Hierarchies present comparative advantages over alternative methods of organization (informal networks or the market) in their speed of decision making, as well as for the possibilities for resource allocation. Their disadvantage is the use and processing of decentralized information.[12] My goal here was to investigate one particular aspect of the functioning of organizations: monitoring.

With respect to this particular function, the first model examined in this chapter produced impressive results. The addition of a supervisor in the police–public game drove crime to zero, or to very low levels. Is compliance really so simple to achieve? Is it sufficient to add one supervisor in order to extract a maximum of allegiance from subordinates? The response given by the first model seems to be affirmative. There are some incidents indicating that the change of leadership in a monitoring organization completely transformed its performance. For example, William Ruckelshaus, who succeeded Ann Burford as head of the Environmental Protection Agency (EPA), in speeches to the enforcement staff "referred to them as 'pussycats' and indicated he wanted them instead to be seen as the 'gorilla in the closet' – the bo-

12 See Scharpf (1991) for discussion of these issues.

geyman that state officials could use as a threat in their dealings with recalcitrant polluters" (Russell 1990: 263). Ruckelshaus had a remarkable success: the level of monitoring as measured by referrals to the Department of Justice and independent EPA administrative actions more than doubled after 1983 (Russell 1990: 263, 265).

However, cases of a complete turnaround are rare. Why the discrepancy between predictions and reality? I think that the reason is the particular configuration of payoffs in the pure hierarchy model. There are two peculiar features to these payoffs, the examination of which involves some interesting features of hierarchical systems.

The first peculiarity of the supervisor's payoffs is that he is interested in police monitoring per se. In order to discover whether his agents shirk, he has to engage in a monitoring activity similar to that of his agents. He has to go out and patrol in order to verify whether they patrol. A more astute supervisor may use indirect means to ascertain the activities of his subordinates. For example, in order to facilitate his work, he may ask them to leave a paper trail, so that if anything goes wrong he can investigate and punish (fire alarms). It seems to me that supervisors often select this solution. However, the outcome of such a monitoring scheme and payoff structure is that the police becomes extremely bureaucratic, more interested in producing a paper trail than in monitoring. "The political concerns of regulatory agencies to demonstrate efficiency through aggregate results can result in pressure on enforcement officials to 'close' cases ... Cases with the greatest probability of being closed out quickly take precedence" (Hawkins/ Thomas 1984: 9-10). However, if somehow the police is prevented from separating paper trail and monitoring, this method can become very productive, because it reduces the supervisor's monitoring costs, and therefore increases the monitoring frequency of the police.

Another peculiar feature of the supervisor's payoffs is that he is supposed to care only about the police, and to monitor *their* activities exclusively. His payoffs are not affected by the public, and therefore, he does not relax when crime goes down. It is precisely the break in this feedback loop that produces the extraordinary results in this model.

The next model which reestablishes this feedback loop produces less spectacular results from the point of view of law and order. In this model, changes in the payoffs of the supervisor produce inverse effects on the supervisor's activities and the public's. A change that increases supervision produces a decrease in crime, and a change that decreases supervision produces an increase in crime.

While this second hierarchical model produces behavior that simulates reality better, we should not forget that the steadfastness of the supervisor in the first model produced more desirable results. A historical example may clarify the point.

In 1967 the British Parliament adopted the British Road Safety Act. This permitted the police to perform breath tests in order to see whether alcohol consumption was below a specified limit. The law clearly changed the expected utility of punishment for drunk driving, since it increased the probability of a conviction once caught. Ross (1973) studied the effects of this change in the legal system on drunk driving incidents. He used interrupted time series analysis to control other factors, such as seasonal variation, length of the month, day of the week (there is a higher probability of drunk driving on the weekend), etc. He found that the percentage of fatally injured drivers with alcohol in their blood fell from 32 percent in 1967 (before the adoption of the law) to 20 percent in 1968, but then increased steadily after that. By 1973 it was 33 percent, and by 1978, 38 percent (Ross 1982: 34). A similar picture is presented by the absolute number of fatalities on weekends: the dramatic drop in 1967 had disappeared by the end of 1970 when the time series ended (Ross 1973: 33). Ross also reports the number of breath tests administered. It started at around 3,000 per month after the enactment of the law, and increased more or less steadily to 7,000 or 8,000 in the last months of 1970. The number of tests given was far fewer than had been envisaged by the government, and most of the test kits originally ordered expired before they were ever used. Ross' conclusion is that "from one perspective the Road Safety Act was betrayed by the police. The Act seemed to offer an opportunity to increase the number of arrests of drinking drivers, as well as the opportunity to dispose of the arrested more efficiently. But while the latter opportunity was seized, the former appears not to have been" (Ross 1973: 49). "Also important in the British experience was the decision of the police to use restraint in patrol under the act. It is difficult to locate the level at which this decision was made" (Ross 1973: 76). In terms of the three-player model presented here, as long as the police's decision is determined by the external game, it is the equilibrium value of monitoring that is affected by a change in penalties, and not the level of crime.

In a later study Ross (1977) examines the outcome of a police "breathalyser blitz" that was successful as long as it lasted. A local chief of police vowed to reduce drunk driving, and he achieved his goal. The data stop after a short period of time, so we do not know how durable his success was. However, the three-player hierarchical model can account for the extraordinary level of success of the "blitz." As long as police monitoring was determined by the internal game, the equilibrium level of enforcement was high enough to deter many more drivers than the equilibrium frequency of the external game.

NETWORKS: The investigation here follows the line of argument adopted by Weissing/ Ostrom (1991a). They use irrigation games as an archetypical example. I will use the Congress of the United States as the focus of my investigation. Both cases share the characteristic of decentralized monitoring activities. What can the model with two different monitoring agencies that I introduced here tell us about Congressional oversight?

First of all, a quite robust result is that as long as the monitored player is indifferent between being exposed by either the House or the Senate, overall monitoring activities are independent of the payoffs of the monitoring agencies and depend only on the payoffs of the monitored player (Proposition 1). Consequently, variations in the level of congressional oversight should not be explained by changes in Congress itself, but by changes having to do with the administration. This result may seem dependent on the two-monitoring players assumption. What would happen if one analyzed the different committees, or their different members, or even worse, the different staff members as independent monitoring players? The result holds unchanged as long as the administration is indifferent to the identity of the player that exposes it (whether it is the House or the Senate, or one particular committee, or an individual congressperson).

This argument is different from Aberbach's (1990) analysis of historical trends in the oversight activities of Congress. Aberbach (1990: 46) explains the over-time increase in oversight by the increase in congressional personnel and by the increase of the relative payoffs of oversight compared to other congressional activities. He interrogates top congressional staffers, who attribute the increase in oversight in the last 30 years and particularly in the last 20 years to factors internal to Congress (more and better staff, internal organization) and external to it (increase in the size and complexity of government, the negative reaction to the executive's accrual of power, the increased publicity and value of oversight, an influx of members interested in oversight).

I will divide these factors into two different categories. The first is that because in periods of increasing scarcity of resources and divided government the game between the legislative and the executive becomes more like a zero-sum game. *Consequently, there is a negative correlation between the payoffs* of Congress and the president, and a change in the payoffs of one also affects the payoffs of the other. In this case, any modification of the payoffs of one player will affect the behavior of all three (House, Senate, and Presidency).

The second category of changes are those that affect Congress or the Administration alone. For example, the increase in congressional staff makes detecting violations of laws easier, but does not affect the administration's payoffs. The expectation derived from my model is that the size of congres*sional staff should not affect monitoring*. Aberbach's (1990: 60) tests show that congressional oversight is not affected by staff size: two of the coefficients of staff are positive and two are negative (none of them are statistically significant).

Conversely, an increase in administrative staff does not affect Congress' payoffs. But such changes are exactly the ones that affect congressional oversight. For example, the reason for increased oversight would be the increase of social regulation through enactment of new laws and the creation of new agencies (1966 to 1976).

> These included the National Highway Traffic and Motor Vehicle Safety Act (1966); the first major Clean Air Act amendments (1970); the National Environmental Policy Act (1970); the Occupational Safety and Health Act (1970); the Consumer Product Safety Act (1972); the Federal Water Pollution Control Act (1972); the Safe Drinking Water Act (1974); the Toxic Substances Control Act (1976); and the Resource Conservation and Recovery Act (1976). Along with the new laws came new agencies to implement them: NHTSA, EPA, OSHA, and the CPSC. Older agencies, such as the FDA and the FTC, were given additional responsibilities for protecting the public (Foreman 1988: 29).

Other reasons would be the behavior of the executive (Vietnam, Watergate), indicating to members a change in the executive's payoffs.

More systematic reasons for the increase of congressional oversight according to my model could be:

- Increased centralization of appointments (i.e. decision making on appointments to administrative positions below the cabinet level controlled by the White House).
- Increased centralization in the area of approval of administrative rules. In the US this takes the form of the clearance of rules by the Office of Management and Budget.
- Increased attempts to control contacts between career bureaucrats and others outside the White House orbit.[13]

Empirical tests of these expectations are required, as well as further investigation of comparative statics expectations. For example, a standard expectation in the literature is that split partisan control increases the incentives for Congress to investigate the executive. My model would generate the same expectation for a different reason: because the executive's payoffs are modified.[14]

Another expectation in the congressional literature is that oversight would be negatively correlated with presidential support. Aberbach (1990: 58), testing for this expectation, finds that "the expected negative relation between presidential support and frequency of oversight (higher support, lower level of oversight) was found in seven of the nine years between 1961 and 1977 where data were coded, but the relationships are very weak (the average correlations in these seven years is of −.05)." My model would not expect oversight to be correlated with the payoffs of Congress, but rather with the payoffs of the overseen administrative unit. Thus, it does not predict a systematic relation between presidential support and oversight.

However, another characteristic of legislative oversight requires attention. Aberbach (1990: 61) has found that the behavior of the two houses concerning

13 Joel Aberbach, personal communication to the author. In the final chapter of his book, Aberbach (1990: 192) links similar factors to the development of the "administrative presidency" by Nixon: "Using budget impoundments, creative regulation writing, reorganization, and a personnel policy designed to place individuals wholly loyal to the White House in top agency positions, Nixon's aim was to bypass Congress and seize effective control of the government."

14 Aberbach (1980: 67-68) notes that "if different parties control the presidency and Congress, the majority in Congress has an incentive to harass and embarrass the executive for partisan gain" and Ogul (1976: 18) says: "A congressman of the president's party is less likely to be concerned with oversight than a member of the opposition party." Testing for these expectations, Aberbach (1990: 60) finds an increased congressional oversight activity of the order of 25% in the case of divided government.

monitoring is paradoxical: "The expectation was that the House would be a more active overseer than the Senate, given the fact that committees are more important in the House, House members have fewer committee assignments, and House members, consequently, are more specialized. The actual results appear to be quite different." After controlling for a series of variables such as the total days of committee activity, decentralization, and oversight unit, Aberbach finds that House committees engage in 33 percent less oversight than do Senate committees.

The model presented here could help us interpret the "Aberbach paradox." The reasons that Aberbach provides are correct, and explain why House committees are more effective in monitoring. However, according to the model presented here (Proposition 2), there is a reversal between motives and behavior in a mixed strategy equilibrium. The same factors that produce higher incentives also cause lower activity.

Some further discussion is required here. My argument is that decentralization operates in the expected direction, while fewer committee assignments and the importance of committees operate in the reverse direction. Here are the reasons why: According to Aberbach, decentralization produces a dominant strategy for monitoring. Subcommittee chairmen who cannot claim fame in any other way engage in this kind of activity. If the committee is centralized, the chair has other more important things to do (legislation); if it is decentralized, the subcommittee chairs find hearings politically the most profitable enterprise.[15] However, once one controls for players with dominant strategies, in the mixed strategy equilibrium, motives and actions (performance) get reversed.

Weissing/ Ostrom (1991b: 5.5) discuss this property of the mixed strategy equilibrium:

> In fact, this equilibrium corresponds to the unique symmetric Nash equilibrium point of a symmetric irrigation game without guards. If the asymmetric game results from the symmetric game by a slight disturbance (i.e., if the distinguished turnwaiter differs only slightly from his colleagues), its paradoxical equilibrium is a slightly disturbed version of the symmetric equilibrium of the symmetric game. If small perturbations in a game usually have small effects on the equilibrium behavior, the paradoxical equilibrium should result in the asymmetric game. We are not convinced by this line of argument (Weissing/ Ostrom 1991b: 254).

15 For similar arguments see Kaiser (1977), Bibby (1966) and Ogul (1976).

They compare the totally mixed equilibrium with the one where players use pure strategies, and they favor a path-dependent equilibrium selection.

I want to make two points about how this argument is relevant to monitoring in Congress. The first is that according to this argument, if a totally mixed equilibrium has prevailed in the past, its comparative statics will continue to prevail. So the assumption of no pure strategies in the past would lead to the expectation of a reverse in relations between motives and behavior. The second is that such paradoxical results in combination with the overall fixed rate of monitoring may lead to a completely different dynamic: the independent players may find it to their advantage to overcome collective action problems and form an organization, or to coordinate their activities to avoid overlapping.[16] Indeed, in such a system there are positive incentives for economies of scale since a composite player who can monitor better will in equilibrium have to monitor less. So it may be the case that over time, fewer and fewer independent players will play this monitoring game, unless they have dominant strategies (such as subcommittee chairs) or unless they are institutionally independent (such as the two houses of Congress).

16 For example, in most states of the US, rules review is conducted by a joint committee (31 states) (Bowers 1990).

Appendix 1

PURE HIERARCHY

The game tree is presented in Figure 1. The payoffs, according to the text, are:

$a_1 = b_1,\ c_1 = d_1,\ a'_1 = b'_1,\ c'_1 = d'_1 \Rightarrow A_1 = B_1 < 0,\ C_1 = D_1 > 0$ 1.1

$a_3 = c_3,\ b_3 = d_3,\ a'_3 = c'_3,\ b'_3 = d'_3 \Rightarrow A_3 = C_3 < 0,\ B_3 = D_3 > 0$ 2.1

In view of 1.1 and 2.1, equations (1) and (3) of Figure 1 become:

$$q_1 = \frac{C_1}{(C_1 - A_1)} \qquad 3.1$$

$$q_3 = \frac{B_3}{(B_3 - A_3)} \qquad 4.1$$

Equilibria: There are three possibilities:

1. $q_1 = q_3$. In this case, $q^* = q_1 = q_3$; p^* and r^* are any combination that satisfies equation 2 in Figure 1.
2. $q_1 > q_3$. In this case, $q^* = q_1$; $r^* = 0$ (no *supervision*); $p^* = \frac{D_2}{(D_2 - B_2)}$.
3. $q_1 < q_3$. In this case, $q^* = q_3$; $p^* = 0$ (no violation); $r^* = \frac{D_2}{(D_2 - C_2)}$.

Appendix 2

HIERARCHY

The game tree is presented in Figure 1. The payoffs, according to the text, are:

$a_1 = b_1,\ c_1 = d_1,\ a'_1 = b'_1,\ c'_1 = d'_1 \ \Rightarrow\ A_1 = B_1 < 0,\ C_1 = D_1 > 0$ 1.2

$A_2 > 0,\ D_2 < 0,\ A_2 > B_2 > D_2,\ A_2 > C_2 > D_2$ 2.2

$B_3 > 0,\ C_3 < 0,\ B_3 > A_3 > C_3,\ B_3 > D_3 > C_3$ 2.3

Equilibrium:

$$p^* = \frac{\left(C_1C_3 - A_1D_3\right)}{\left(C_1\left(C_3 - A_3\right) - A_1\left(D_3 - B_3\right)\right)} \qquad 2.4$$

$$q^* = \frac{C_1}{\left(C_1 - A_1\right)} \qquad 2.5$$

$$r^* = \frac{\left(\left(C_1C_3 - A_1D_3\right)B_2 - \left(C_1A_3 - A_1B_3\right)D_2\right)}{\left(\left(C_1C_3 - A_1D_3\right)\left(B_2 - A_2\right) - \left(C_1A_3 - A_1B_3\right)\left(D_2 - C_2\right)\right)} \qquad 2.6$$

This equilibrium prescribes mixed strategy for the police, however one of the other two players may have a pure strategy. Assuming that p* and r* are in the (0, 1) interval gives the additional constraints:

$C_1C_3 < A_1D_3,$

$\left((C_1C_3 - A_1D_3)B_2 - (C_1A_3 - A_1B_3)D_2\right)\left((C_1C_3 - A_1D_3)(-A_1) + (C_1A_3 - A_1B_3)C_2\right) > 0$ 2.7

Comparative Statics:

$$p'(A_1) = \frac{\left(C_1\left(A_3D_3 - B_3C_3\right)\right)}{X^2} > 0$$

where $X = (C_1A_3 - A_1B_3 + A_1D_3 - C_1C_3)$ 2.8

$$p'(C_1) = \frac{\left((-A_1)(A_3D_3 - B_3C_3)\right)}{X^2} > 0 \tag{2.9}$$

$$p'(A_3) = \frac{\left((C_1)(C_1C_3 - A_1D_3)\right)}{X^2} < 0 \tag{2.10}$$

$$p'(B_3) = \frac{\left((-A_1)(C_1C_3 - A_1D_3)\right)}{X^2} < 0 \tag{2.11}$$

$$p'(C_3) = \frac{\left(C_1(A_1B_3 - C_1A_3)\right)}{X^2} > 0 \quad \text{iff } A_1B_3 - C_1A_3 > 0 \tag{2.12}$$

$$p'(C_3) = \frac{\left((-A_1)(A_1B_3 - C_1A_3)\right)}{X^2} > 0 \quad \text{iff } A_1B_3 - C_1A_3 > 0 \tag{2.13}$$

$$q'(A_1) = \frac{(-C_1)}{(C_1 - A_1)^2} < 0 \tag{2.14}$$

$$q'(C_1) = \frac{(-A_1)}{(C_1 - A_1)^2} > 0 \tag{2.15}$$

The derivatives of r* are not reported. r* decreases with A_1 and C_1; it increases with A_3 and B_3; it decreases with C_3 and D_3 if $A_1B_3 - C_1A_3 > 0$; the signs of the derivatives of r* with respect to the police's payoffs are ambiguous. Nonreported derivatives of p and q are 0.

Appendix 3

NETWORK OF MONITORING

The game tree is presented in Figure 1. The payoffs, according to the text are:

$$a_1=b_1=c_1,\ a'_1=b'_1=c'_1,\ \Rightarrow\ A_1=B_1=C_1<0,\ D_1>0 \qquad 3.1$$

$$c_2=d_2,\ c'_2=d'_2,\ \Rightarrow\ C_2=D_2<0,\ B_2>0,\ B_2>A_2>C_2 \qquad 3.2$$

$$c_3=d_3,\ c'_3=d'_3,\ \Rightarrow\ C_3=D_3<0,\ B_3>0,\ B_3>A_3>C \qquad 3.3$$

The system of equations in Figure 1 is reduced to:

$$(1-q)(1-r) = \frac{(-A_1)}{(D_1-A_1)} \qquad 3.4$$

$$prA_2+p(1-r)B_2+(1-p)C_2=0 \qquad 3.5$$

$$pqA_3+p(1-q)B_3+(1-p)C_3=0 \qquad 3.6$$

There are two possible equilibria of this system where one of the polices does not monitor, while the other monitors as if it were a two-person game. Possibly there is also a completely mixed strategy equilibrium of this system. None of these equilibria is guaranteed to exist (although at least one of them will).

For the comparative statics of the completely mixed strategy equilibrium one has to examine the behavior of the roots of the following three quadratics:

$$p^2\left((A_2-C_2)(A_3-C_3)+\frac{A_1}{(D_1-A_1)}(A_2-B_2)(A_3-B_3)\right)+$$

$$p\big((A_2-C_2)C_3+(A_3-C_3)C_2\big)+C_2C_3=0 \qquad 3.7$$

$$q_2C_2(A_3-B_3)+q(2C_2B_3-C_2A_3-C_3A_2)-$$

$$\frac{B_2C_3A_1}{(D_1-A_1)}+\frac{D_1A_2C_3}{(D_1-A_1)}-C_2B_3=0 \qquad 3.8$$

$$r^2C_3\left(A_2-B_2\right)+r\left(2C_3B_2-C_3A_2-C_2A_3\right)-\frac{B_3C_2A_1}{\left(D_1-A_1\right)}+\frac{D_1A_3C_2}{\left(D_1-A_1\right)}-C_3B_2=0 \qquad 3.9$$

Each one of these quadratics has real roots, however, for one root to be positive (and therefore admissible as a solution to the system):

$$X=\left(A_2-C_2\right)\left(A_3-C_3\right)+\frac{A_1}{\left(D_1-A_1\right)}\left(A_2-B_2\right)\left(A_3-B_3\right)<0 \qquad 3.10$$

Comparative statics:

$$p'\ \frac{-A_1}{\left(D_1-A_1\right)}=\frac{\left(A_2-B_2\right)\left(A_3-B_3\right)p^2}{\left(-C_2A_3-A_2C_3+2C_2C_3+2Xp\right)}<0 \qquad 3.11$$

Call Y the denominator of 3.11; Y is negative for the bigger root of 3.7.

$$p'(A_2)=-p\,\frac{\left(C_3-p\left(C_3-A_3\right)-p\frac{A_1}{\left(D_1-A_1\right)}\left(A_3-B_3\right)\right)}{Y}<0 \qquad 3.12$$

$$p'(B_2)=\frac{-\left(B_3-A_3\right)\frac{A_1}{\left(D_1-A_1\right)}p^2}{Y}<0 \qquad 3.13$$

$$p'(C_2)=\frac{-\left(\left(A_3-C_3\right)p+C_3\right)\left(1-p\right)}{Y}<0 \qquad 3.14$$

$$p'(A_3)=-p\,\frac{\left(C_2-p\left(C_2-A_2\right)-p\frac{A_1}{\left(D_1-A_1\right)}\left(A_2-B_2\right)\right)}{Y}<0 \qquad 3.15$$

$$p'(B_3) = \frac{\left(A_2 - B_2\right)\frac{A_1}{\left(D_1 - A_1\right)} p^2}{Y} < 0 \tag{3.16}$$

$$p'(C_3) = \frac{-\left(C_2 + \left(A_2 - C_2\right)p\right)(1 - p)}{Y} < 0 \tag{3.17}$$

$$q' \frac{-A_1}{\left(D_1 - A_1\right)} = \frac{C_3\left(A_2 - B_2\right)}{\left(-C_2A_3 - A_2C_3 + 2C_2B_3 + 2q\left(A_3 - B_3\right)C_2\right)} < 0 \tag{3.18}$$

Call Z the denominator of 3.18; from 3.5 we get that the bigger root of 3.7 corresponds to the smaller root of 3.8. Z is negative for the smaller root of 3.8.

$$q'(A_2) = \frac{-C_3\left(1 + \frac{A_1}{\left(D_1 - A_1\right)} - q\right)}{Z} < 0 \tag{3.19}$$

$$q'(B_2) = \frac{C_3\left(\frac{A_1}{\left(D_1 - A_1\right)}\right)}{Z} < 0 \tag{3.20}$$

$$q'(C_2) = \frac{(1 - q)\left(B_3 + q\left(A_3 - B_3\right)\right)}{Z} < 0 \tag{3.21}$$

$$q'(A_3) = \frac{C_2q(1 - q)}{Z} > 0 \tag{3.22}$$

$$q'(B_3) = \frac{C_2(1 - q)^2}{Z} > 0 \tag{3.23}$$

$$q'(C_3) = \frac{\left(-A_2\left(1-q+\frac{A_1}{\left(D_1-A_1\right)}\right)+\frac{A_1}{\left(D_1-A_1\right)}B^2\right)}{Z} > 0 \qquad 3.24$$

The derivatives of r are symmetric and therefore omitted.

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