

Network Externalities and the Structure of Terror Networks

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Abstract

We analyze the optimal network structure of two types of terrorist organizations. In the centralized network, the leadership selects the level of individual effort and the level of group connectivity so as to maximize the expected net welfare of the organizations membership. Leaders in loosely-connected networks will also seek to balance the trade-off between security and communications. However, with decentralized decision making, the individual nodes may not make optimal decisions from the group's perspective. As a consequence, the decentralized decision making process is suboptimal from the overall perspective of the network. In particular, the leadership in a centralized network is able to coordinate the activities of all network members and to take advantage of important network externalities.

Keywords: Terrorist cells, Network structure, Network externalities, Counterterrorism, Security versus connectivity

It is now clear that terrorist network structures evolve in response to the political and economic circumstances in which they operate. In the past, terrorist organizations involved individuals belonging to a clearly identified organizational structure with a well-defined chain of command. The decision-making structure was typically hierarchical in that the leadership participated in the planning, and oftentimes in the execution, of specific attacks. For example, Andreas Baader and Ulrike Meinhof, founders of the Red Army Faction, were arrested and each given three life sentences for their participation in activities such as bank robbery and arson. Ahmed Sa'dat, Secretary General of the PFLP, was arrested by the Palestinian Authority in 2002 for his suspected involvement in the assassination of Israeli Minister Rehavam Zeevi. In contrast, the so-called "New Terrorism" involves individuals who act in concert through loosely knit organizational structures. The literature provides several reasons for this change in organizational structure of terrorist groups. Arquilla, Ronfeldt, and Zanini (1999) argue that the information revolution has allowed both businesses and terrorist organizations to adopt "flatter" structures such that the chain of command is not completely top-down. Their view is that loosely-knit networks are more flexible and responsive than hierarchies in reacting to new circumstances and in using new information to improve decision making. Enders and Su (2007) emphasize the changes in counterterrorism that have occurred since 9/11. They point out that key provisions of the USA Patriot Act (HR 3162) grant the government new powers to monitor terrorists' communication links and to track the international flow of funds used to finance terrorist activities. Passed only six weeks after 9/11, the act increased the government's ability to (i) seize voice-mail messages; (ii) intercept wire, oral, and electronic communications of

suspected terrorists; and (iii) gather intelligence on suspected terrorists with less congressional oversight. As the leadership seeks to balance overall security against effectiveness, such changes are expected to alter the organization's structure towards being more secretive. Loosely-knit networks are more secure against monitoring and infiltration than are fully-connected networks. In a slightly different vein, Baccara and Bar-Isaac (2009) show that a group will respond to harsh interrogation methods by becoming more secretive and more hierarchical. The basic idea is that the hierarchical structure protects the leadership.

The purpose of this paper is to analyze some of the important differences between the hierarchical and new terrorist network structures. Our focus is on the fact that hierarchical structures have the ability to coordinate the activities of all network members and to take advantage of important network externalities. In contrast, flat networks necessitate decentralized decision making such that the individual nodes may make decisions that do not perfectly align with the overall interests of the terrorist group.¹

Evidence of two-stage decision making within the al Qaeda network is revealed in the July 9, 2005 letter from al-Zawahiri to al-Zarqawi.² The following excerpts reveal how the leadership was trying to exert some control over the behavior of al-Zarqawi. Al-Zawahiri indicates that the organization is fighting a "media war" and that al-Zarqawi's brutality is detrimental to al Qaeda:

"Among the things which the feelings of the Muslim populace who love and support you will never find palatable - also- are the scenes of slaughtering the hostages."

“Therefore, I stress again to you and to all your brothers the need to direct the political action equally with the military action, by the alliance, cooperation and gathering of all leaders of opinion and influence in the Iraqi arena. I can’t define for you a specific means of action. You are more knowledgeable about the field conditions.”

Notice that al-Zawahiri delegates responsibility in that he leaves the “specific means of action” up to al-Zarqawi. Perhaps most interesting is the fact that al-Zarqawi planned the November 9, 2005 bombings of three hotels located in Amman Jordan. As reported by the BBC (2005), the attacks were responsible for 60 deaths and nearly 100 injuries. Most of the carnage occurred at the Radisson SAS hotel which was hosting a wedding party attended by approximately 900 Muslims. The Jordanian response included street demonstrations protesting and chanting “Burn in hell, Abu Musab al-Zarqawi.”

The example shows the obvious point that the outcomes of flat networks can be suboptimal if the separate decision makers have conflicting objectives. However, our aim is to show that the presence of network externalities means that decentralized decisions can be suboptimal even if the individual decision makers have the same preferences. We do this in a model that recognizes three important features of any terrorist organization. Whereas gang members and individuals belonging to organized crime syndicates are primarily motivated by financial interests, terrorists are not generally deemed to be motivated by wage income. Hence, instead of modeling individuals as being pure income maximizers, in our model, members of a terrorist organization have a political and/or religious objective underlying their actions. Specifically, we assume that group members are not altruistic

insofar as each member's utility depends on his/her own level of effort and that of other group members devoted to the group's cause. The second key feature of a terrorist network appearing in our model is that, unlike many social networks, there is an important tradeoff between connectivity and security. Although highly connected networks are best able to conduct logistically sophisticated attacks, they can be quite vulnerable to government infiltration. Thus, as argued in Enders and Su (2007), terrorist groups will become flatter as the costs of connectivity rise. The third important feature of a terrorist organization is the presence of network externalities. The source of these network effects is the additional benefit that the organization derives because individuals are able to interact with each other and coordinate their activities. Although two individuals acting alone can cause great harm, the two acting in concert can inflict even greater damage. The types of logistically complex actions illustrated by the coordinated Kenya-Tanzania embassy bombings, 9/11, the London and Madrid train bombings, and the November 2008 strikes at Mumbai are testimony to the enhanced effects of synchronized behavior. The compound nature of the attacks served notice that the group is well-organized, serious in its resolve and global in reach. Hence, the desire for security can be costly in that there may be unexploited network effects that limit the total output of the organization. The hierarchical network structures are better able to internalize the this externality than are flat structures.

In the next section of the paper, we define some key terms and set out the basic model. The third section analyzes the problem of centrally planned networks. The network planner coordinates the effort levels of the individual members with the optimal level of network connectivity. The fourth section considers decision making in a decentralized

network. One interesting feature of this variant of the model is that the connectivity of the network affects the utility optimizing level of effort chosen by the individual group members. A simple description of the model is developed below. Conclusions and policy recommendations are contained in the final section.

Regular Networks

Definitions

Figure 1 displays five different graphs pertaining to the structure of a potential terrorist network. Each individual terrorist (or terrorist cell) within the organization is represented by a point called a *node*. The lines connecting the nodes (called *links* or *edges*) represent direct communication ties between the individuals. The first graph in the figure is *disconnected* in that some of the individuals have no way to communicate with the others. Since the subgroups must act independently, many would refrain from actually calling such a configuration a network. At the other extreme, the fifth graph represents a *complete* or all-channel network in that every individual is directly linked to every other individual. In the intermediate cases, each individual is linked to some (but not all) of the others in the network. Even if two nodes are not directly linked to each other, the individuals can communicate indirectly through the use of multiple links. For our purposes, the important point is that the information flow through a network is an increasing function of its density.³

Figure 1: Regular Networks (n, r)

More generally, let the set of terrorist nodes be $N = \{1, \dots, n\}$. These nodes form a network $\mathbf{g} = [g_{ij}]$ where $i, j \in N$ and $g_{ij} = g_{ji}$. For $i \neq j$, $g_{ij} = 1$ if there is a link between nodes i and j , and 0 otherwise. Let $g_{ii} = 0$. If $g_{ij} = 1$ for all $i, j \in N$ and $i \neq j$, we say that network \mathbf{g} is complete. The neighborhood of i is the set of all nodes directly linked to node i . As such, it is possible to view the individuals in the neighborhood of i as the cellmates of i . Mathematically, we denote the neighborhood of i as the set N_i and the number of nodes in N_i (often called the *degree* of node i) as η_i . Formally, we let $\eta_i = r$ for all $i \in N$, and define the network \mathbf{g} to be regular of degree r . Notice that all of the graphs shown in Figure 1 are examples of regular networks (n, r) with $n = 6$. In graph theory, it is known that, for integers r and n with $0 \leq r \leq n$, there exists a network that is regular of degree r if and only if at least one of r and n is even.

Terrorists and effort levels

A key aspect of our model is that individuals receive utility from their membership in the terrorist organization. To be specific, we assume that the individual gains utility by working for the organization and that the more node i is capable of producing, the greater is i 's utility. In order to capture the public good aspect of a network, we use the type of production, or payoff, function developed in Bramoullé and Kranton (2007). Let $\mathbf{e} = (e_1, \dots, e_n)$ be an effort profile of all terrorists in the network, where $e_i \in [0, +\infty)$. The utility of node i has the form

$$u_i = q(v_i) - ce_i \tag{1}$$

where e_i is the effort level of i ; c is the constant marginal cost of the individual's effort; and q is the terrorist's production function which depends on total effort of the terrorist and all other terrorists in the neighborhood (v_i).⁴ The nature of the production function is such that $q(0) = 0, q'(0) = \infty, q' > 0, q'' < 0$ and total effort has the form

$$v_i = e_i + \delta \sum_{j \in N_i} e_j. \quad (2)$$

We assume that $\delta \in [0, 1]$ so that a node gains more output from a marginal unit of its own effort than from the effort of others in the same cell.⁵ The magnitude of δ measures the extent of the positive production externality. The greater is δ , the more the effort levels of others contribute to the output of node i . Thus, i directly obtains utility from its own effort and indirectly from the effort levels of others.

Note that (2) follows Ballester, Calvó-Armengol, and Zenou's (2006) model of a network in that each node exerts an effort level that affects its own payoff and the payoffs of other nodes in its neighborhood. We begin by considering a simple case in which all nodes are identical. As such, we consider nonhierarchical networks such that all individuals contain the same number of links.

The nature of the network externality can be seen by re-examining the regular networks shown in Figure 1. The network labeled (6, 1) is not especially interesting for our purposes since it is disjoint. Each node can work only with one other node so that there are few network externalities. Information cannot readily travel across the unlinked segments and cooperative opportunities using three or more network members are impossible. We might expect the total output from each node to be quite limited. In contrast, in the network labeled (6, 2) information can flow to all members, albeit, in a chain-like fashion.

Nevertheless, the six nodes cannot undertake large scale and logistically complex activities since it is not possible to construct teams with more than three members. In the fully connected network (6, 5), all nodes can directly communicate with each other and there is substantial flexibility in the ways that subgroups can cooperate with each other. For example, it is possible to form two teams of three nodes, three teams of two nodes, two teams with two and four nodes each. Thus, even for a fixed number of nodes providing a given level of effort to the organization, total network output should increase as group connectivity is increased. It is straightforward to demonstrate that equation (2) captures the benefits arising from additional connectivity. For simplicity, suppose that each node provides the same level of effort so that $e_i = e$ for all $i \in N$. The output level of each node in network (6, 1) is $q(e + \delta e)$, whereas the output levels in networks (6, r) are $q(e + \delta r e)$.⁶

Although the marginal benefit of connectivity is positive in that $\partial q / \partial r = q' \delta e > 0$, notice that the overall level of group security can be quite tenuous in a highly connected network. For example, in network (6, 5), if the security of any node is breached, the identity of each of the other nodes can easily be compromised. In a loosely connected network, if node i is infiltrated, it can reveal direct information only about the nodes to which it is connected.

Counterterrorism

For simplicity, we assume that the government will infiltrate only one terrorist node and that the destruction of node i may affect other nodes in the neighborhood of i . Specifically, if node i is destroyed, the probability that node $j \in N_i$ will be destroyed as well is $\pi \in [0, 1]$.

If $\pi = 1$, the entire cell is annihilated if any one member is infiltrated and if $\pi = 0$, only the infiltrated node is annihilated. In a sense, π is the vulnerability parameter. Assume that each node has equal probability of being infiltrated ($1/n$). Hence, the probability that i will be infiltrated is $1/n$ and the probability that one of i 's cellmates will be infiltrated through i is π/n . In order to simplify the analysis, we do not allow the infiltration of the neighbors of the neighbors of i to annihilate i .⁷ As such, the probability that terrorist i will be destroyed is $p = (1 + \pi r)/n$. The important point is that for a network of size n , increasing r will increase the probability that the government's counterterrorism effort is successful.

The expected utility of terrorist i is

$$U_i(\mathbf{e}, r) = \left(1 - \frac{1 + \pi r}{n}\right) q(e_i + \delta \sum_{j \in N_i} e_j) - ce_i. \quad (3)$$

Notice that the specification of (3) is such that any destruction of the nodes in the neighborhood of i do not reduce the production, $q(v_i)$, of node i . Once node i has interacted with node j , the subsequent arrest or destruction of j does not reduce the output level of node i . An alternative to (3) is assume that q depends only on the effort levels of cells that have not been annihilated. Such an assumption implies that cooperative efforts prior to the destruction of j have no positive effects on the output of i . Our specification is most appropriate if the network externality is due primarily to activities such as information sharing and cooperation in the planning stages of a terrorist attack. The alternative specification is most appropriate if the externalities arise as a result of cooperative efforts in the execution stage of an attack.

The expected value of total terrorism welfare can be written as

$$W(\mathbf{e}, r) = \left(1 - \frac{1 + \pi r}{n}\right) \sum_{i \in N} q(e_i + \delta \sum_{j \in N_i} e_j) - c \sum_{i \in N} e_i. \quad (4)$$

In our framework, there are three different types of counterterrorism policies that alter the values of c , π , and δ . The marginal cost of effort, c , represents the perceived opportunity cost of devoting effort to terrorist activities. As detailed in Enders and Sandler (2006), the household production function (HPF) approach to terrorism indicates that an increase in the relative price of terrorist activities will induce rational terrorists to substitute into relatively less expensive nonterrorist activities. Certainly, policies that restrict (allow) individuals to address their grievances through legal political channels can be viewed as a decrease (increase) in c . Similarly, policies that raise the overall cost of engaging in terrorist activities represent an increase in c . For example, international cooperation regarding money laundering has enhanced the government's ability to limit the flow of funds intended to finance terrorist activities. Also, INTERPOL maintains a number of databases including a list of stolen motor vehicles, lost and stolen travel documents, DNA profiles, and photographs/fingerprint records of wanted persons. All of the data bases are linked by the MIND/FIND internet technology such that they are instantly available to all participants at border crossings and ports of entry. Sandler, Arce and Enders (2009) report that INTERPOL was involved with 74 and 104 terrorist-related arrests in 2006 and 2007, respectively.

Enhanced intelligence policies can be directed at increasing π , the probability of destroying nodes connected to the infiltrated node. We would expect π to increase in response to those aspects of the Patriot Act directly targeting terrorists' communications

links. Counterterrorism policies that influence the terrorists' benefits from cooperation alter the value of δ . For example, policies making it more difficult to conduct logistically complex actions would reduce the benefits from interconnected tactics. Simple tactics, such as the placement of bombs in railroad stations, do not require as much connectivity as another 9/11-type event or the construction of a WMD.

Centrally planned networks

The network planner's problem

In a centrally planned network, the network planner simultaneously chooses e_i and r . Since nodes are identical and q is concave, all of the individual effort levels will be identical ($e_i = e$ for all i) so that the optimization problem can be written as

$$\max_{r,e} W = \left(1 - \frac{1 + \pi r}{n}\right) nq[(1 + \delta r)e] - nce. \quad (5)$$

The two first-order conditions are

$$W_r = -\pi q[(1 + \delta r)e] + \left(1 - \frac{1 + \pi r}{n}\right) nq'[(1 + \delta r)e]\delta e = 0, \quad (6)$$

$$W_e = \left(1 - \frac{1 + \pi r}{n}\right) nq'[(1 + \delta r)e](1 + \delta r) - nc = 0. \quad (7)$$

Since we cannot find analytic solutions without positing explicit functional forms, we use the implicit function theorem to determine how changes in c , δ and π will affect the optimal levels of e and r , denoted by e^* and r^* , respectively. Totally differentiating (6) and (7), we obtain

$$\begin{bmatrix} W_{rr} & W_{re} \\ W_{er} & W_{ee} \end{bmatrix} \begin{bmatrix} dr \\ de \end{bmatrix} = \begin{bmatrix} W_{rc} & W_{r\pi} & W_{r\delta} \\ W_{ec} & W_{e\pi} & W_{e\delta} \end{bmatrix} \begin{bmatrix} dc \\ d\pi \\ d\delta \end{bmatrix} \quad (8)$$

where W_{ij} denotes the partial derivative of W_i with respect to variable j . The second order conditions for an interior solution require $W_{rr} < 0$, $W_{ee} < 0$, and $\Delta = W_{rr}W_{ee} - W_{re}^2 > 0$.

Notice that the signs of W_{rr} and W_{ee} are both negative and the sign of $W_{re} = W_{er}$ is ambiguous. Specifically,

$$W_{rr} = -2\pi q'[(1 + \delta r)e]\delta e + \left(1 - \frac{1 + \pi r}{n}\right) nq''[(1 + \delta r)e]\delta^2 e^2 < 0, \quad (9)$$

$$W_{ee} = \left(1 - \frac{1 + \pi r}{n}\right) nq''[(1 + \delta r)e](1 + \delta r)^2 < 0, \quad (10)$$

$$W_{re} = -\pi q'[(1 + \delta r)e](1 + \delta r) + \left(1 - \frac{1 + \pi r}{n}\right) n\delta[q''[(1 + \delta r)e](1 + \delta r)e + q'[(1 + \delta r)e]]. \quad (11)$$

Although the sign of W_{re} is ambiguous, there are some special cases in which it is clearly negative. For example, if the production function is such that $q(x) = \ln(x)$, then $W_{re} = -\pi/e < 0$. Similarly, if the network effects can be ignored (so that δ is very close to zero), the sign of W_{re} is also negative. In the limit, for $\delta = 0$, we find that $W_{re} = -\pi q'((1 + r)e) < 0$. However, it is also possible that W_{re} is positive. An interesting special case occurs if the production function has the form $q(x) = x^\alpha$ where $0 < \alpha < 1$. In this circumstance we find $W_{re} = 0$. In general, the condition for $W_{re} > 0$ is

$$-\frac{q''[(1 + \delta r)e]}{q'[(1 + \delta r)e]} < \frac{1}{(1 + \delta r)e} - \frac{\pi}{(n - 1 - \pi r)\delta e} \quad (12)$$

which is true when the concavity of q , i.e., $-q''/q'$, is not too large. In the analysis below, we assume that $W_{re} \geq 0$. This is equivalent to assuming that increased effort levels increase the marginal product of connectivity. Nevertheless, this condition is overly strong to contain most of our comparative statics results. The necessary condition for us to sign most of our comparative statics results is for $\Delta = W_{rr}W_{ee} - W_{re}^2 > 0$.

Comparative statics

The effects of c : To find the effects on a change in c on the levels of effort and connectivity, first differentiate W_r and W_e with respect to c in order to obtain

$$W_{rc} = 0, \quad (13)$$

$$W_{ec} = -n < 0. \quad (14)$$

Now, if we solve (8) for the changes in r^* and e^* resulting from a change in c , we find

$$\frac{\partial r^*}{\partial c} = -\frac{W_{rc}W_{ee} - W_{ec}W_{re}}{W_{rr}W_{ee} - W_{re}^2} \leq 0, \quad (15)$$

$$\frac{\partial e^*}{\partial c} = -\frac{W_{rr}W_{ec} - W_{rc}W_{re}}{W_{rr}W_{ee} - W_{re}^2} \leq 0. \quad (16)$$

Hence, any counterterrorism policy that increases the marginal cost of effort, c , will lead to a reduction in the optimal level of effort and a reduction in the connectivity of the network. Clearly, as the marginal cost of effort rises, it will be optimal to devote less effort to the network. Moreover, assuming that (12) holds (so that $W_{re} > 0$), the decline in effort means a complementary decline in r as well. Thus, policies that increase c will lead to a reduction in total terrorism welfare because individuals devote less effort to the

organization *and* because the lower level of effort leads to a reduction in the level of connectivity.

The effects of π : The effects of a change in the vulnerability parameter (π) can be obtained by partially differentiating (6) and (7) with respect to π . Specifically,

$$W_{r\pi} = -q[(1 + \delta r)e] - rq'[(1 + \delta r)e]\delta e < 0, \quad (17)$$

$$W_{e\pi} = -rq'[(1 + \delta r)e](1 + \delta r) < 0. \quad (18)$$

Solving (8) for the changes in r^* and e^* resulting from a change in π , we find

$$\frac{\partial r^*}{\partial \pi} = -\frac{W_{r\pi}W_{ee} - W_{e\pi}W_{re}}{W_{rr}W_{ee} - W_{re}^2} \leq 0, \quad (19)$$

$$\frac{\partial e^*}{\partial \pi} = -\frac{W_{rr}W_{e\pi} - W_{r\pi}W_{re}}{W_{rr}W_{ee} - W_{re}^2} \leq 0. \quad (20)$$

As the network becomes less secure, the optimal strategy for the network planner entails reducing the level of connectivity. This is the point made by Enders and Su (2007). Moreover, as connectivity declines, the optimal level of effort declines as well.

The effects of δ : There is no simple relationship between changes in δ and changes in the levels of network connectivity and effort. Partially differentiating (6) with respect to δ , we obtain

$$W_{r\delta} = -\pi q'[(1 + \delta r)e]re + \left(1 - \frac{1 + \pi r}{n}\right) n[q''[(1 + \delta r)e]r\delta e^2 + q'[(1 + \delta r)e]e]. \quad (21)$$

The value of (21) is positive when

$$-\frac{q''[(1 + \delta r)e]}{q'[(1 + \delta r)e]} < \frac{1}{\delta e} \left[\frac{n - 1 - 2\pi r}{r(n - 1 - \pi r)} \right]. \quad (22)$$

Partially differentiating (7) with respect to δ , also yields an ambiguous expression.

Consider

$$W_{e\delta} = \left(1 - \frac{1 + \pi r}{n}\right) nr[q''[(1 + \delta r)e](1 + \delta r)e + q'[(1 + \delta r)e]]. \quad (23)$$

Note that (23) is equal to zero when $q(x) = \ln(x)$, and (23) is positive when

$$-\frac{q''[(1 + \delta r)e]}{q'[(1 + \delta r)e]} < \frac{1}{(1 + \delta r)e}. \quad (24)$$

Therefore, if (22) and (24) hold so that $W_{r\delta}, W_{e\delta} > 0$, we have

$$\frac{\partial r^*}{\partial \delta} = -\frac{W_{r\delta}W_{ee} - W_{e\delta}W_{re}}{W_{rr}W_{ee} - W_{re}^2} \geq 0, \quad (25)$$

$$\frac{\partial e^*}{\partial \delta} = -\frac{W_{rr}W_{e\delta} - W_{r\delta}W_{re}}{W_{rr}W_{ee} - W_{re}^2} \geq 0. \quad (26)$$

Thus, the greater the importance of network externality, the greater the levels of connectivity and effort. All of these work together to make for a high-effort, tightly connected network. Clearly, policies that reduce the spillover effect will reduce the damage level from this type of organization.

An example

In order to get a sense of the change in the optimal network structure due to the three counterterrorism policies, we consider the specific case wherein the production function has the specific form $q(x) = x^\alpha$ for $0 < \alpha < 1$. The use of this functional form allows us to obtain analytic solutions for the optimal levels of effort and connectivity. As such, it becomes straightforward to provide a simulation exercise showing how the optimal solutions of the network planner respond to counterterrorism policies. Specifically, we assume that the network planner chooses r and e to solve the following optimization problem

$$\max_{r,e} W = \left(1 - \frac{1 + \pi r}{n}\right) n e^\alpha (1 + \delta r)^\alpha - n c e. \quad (27)$$

Let $r^*(\pi, \delta, c)$ and $e^*(\pi, \delta, c)$ denote the optimal solutions for r^* and e^* as functions of the parameters π, δ , and c . Also let $W(r^*, e^*)$ denote the value of the total expected welfare of the network. The solid lines in Figure 2-4 show how these three functions respond to changes in the policy parameters. In constructing these figures, we assumed that $\alpha = 0.5$ and $n = 25$.⁸ As a practical matter, the level of connectivity must be such that r^* takes on an integer such that $0 < r^* < n$. In our simulation, if the solution for r^* turned out to be greater than $n - 1$, we set $r^* = n - 1$ and reoptimized over e . Similarly, if the solution for r^* turned out to be negative, we set $r^* = 0$ and reoptimized over e .

Figure 2: The Effects of Changes in c

Figure 3: The Effects of Changes in π

Figure 4: The Effects of Changes in δ

In Figure 2, we set the values of $\pi = 0.5$ and $\delta = 0.5$ to show how e^* , r^* , and $W(r^*, e^*)$ respond to changes in c . Clearly, as indicated by (16), the optimal level of effort steadily declines as c increases from one to three as shown in Panel 1. Since $W_{rc} = 0$ and, in this special case, $W_{ec} = 0$, the overall effect of a change of c on r^* , indicated by (15), is zero as shown in Panel 2. Nevertheless, as shown in Panel 3, network welfare declines as a result of the decreased level of effort.

In constructing Figure 3, we set the values of $c = 2$ and $\delta = 0.5$. As indicated by equation (20), the optimal level of effort shown in Panel 1 steadily declines as π increases

from zero to unity. Panel 2, the graphical representation of (19), indicates the effect of π on connectivity. Notice that connectivity takes on its maximal possible value of 24 ($= n - 1$) for small values of π . However, as π continues to increase, the level of connectivity monotonically declines. Panel 3 shows how the decreases in e^* and r^* resulting from an increase in π act to reduce the level of total network welfare.

Panels 1 through 3 in Figure 4 trace out the effects of changes in δ on e^* , r^* , and $W(r^*, e^*)$, respectively. In constructing the graphs, we set the values of $c = 2$ and $\pi = 0.5$. As indicated by equations (26) and (25), the levels of effort and connectivity are positively related to δ . Since e^* and r^* both increase as δ increases, as shown in the Panel 3, the overall effect on network welfare is positive.

Two-stage decision making

The results in the preceding section were predicated on the assumption that the network planner can simultaneously set the levels of e and r . In this section, we consider the effects of a loosely structured network. In such a network, the network planner selects the level of connectivity before individual agents select their own effort levels (treating the network structure, r , as fixed). In choosing the value of r , the network planner takes account of the fact that the effort levels of the nodes will depend on the chosen r .⁹ Before proceeding, it is important to note that there need not be an actual network planner in a flat network. A form of ‘natural selection’ may be at work such that suboptimal networks do not thrive and sustain themselves. Groups that are not especially secure will be readily infiltrated and groups that are too flat will not be able to produce enough output to satisfy its

membership and to attract new members.

The optimal level of effort

Given r chosen by the network planner, terrorist i 's optimization problem is

$$\max_{e_i} U_i = \left(1 - \frac{1 + \pi r}{n}\right) q(e_i + \delta \sum_{j \in N_i} e_j) - ce_i. \quad (28)$$

The first order condition can be written as¹⁰

$$\left(1 - \frac{1 + \pi r}{n}\right) q'(e_i + \delta \sum_{j \in N_i} e_j) - c = 0. \quad (29)$$

We focus our analysis on an equilibrium in which each node makes the Cournot conjecture.

Since each node is identical and faces the same optimization problem, we can let \hat{e} denote the common effort level of each node. As such, (29) becomes

$$\left(1 - \frac{1 + \pi r}{n}\right) q'[(1 + \delta r)\hat{e}] = c. \quad (30)$$

An analytic solution to (30) is not possible without a specific production function.

Nevertheless, it is possible to compare \hat{e} to e^* , the level that a network planner would choose. For the time being, suppose that r is given. At e^* , (7) can be written as

$$\left(1 - \frac{1 + \pi r}{n}\right) q'[(1 + \delta r)e^*] = \frac{c}{1 + \delta r}. \quad (31)$$

Now compare (31) to (30). Of course, if $\delta = 0$, the two equations are identical.

However, if $\delta > 0$, the concavity of q necessitates that $e^* > \hat{e}$. As such, for any r , a network planner would choose a higher level of effort than the level selected by the individual nodes.

At first, the result that the effort level selected by the individual nodes is below the network optimum seems surprising given that the terrorists receive utility from belonging

to the organization. However, since each receives utility from the others' efforts, high effort levels from the others in the cell allow the individual to curtail his/her own effort level.

Suppose, for the time being, that the value of r and the overall size of the network, n , are fixed. It should be clear that the envelope theorem guarantees that any policy that acts to increase c , increase π , or decrease δ will decrease the terrorist's expected utility. Also, from (30), for a given value of r , an increase in c , π , and/or δ will lead to a decrease \hat{e} since the function q is concave. Any reduction in \hat{e} reduces the overall level of benefit, q , of the organization.

The optimal level of connectivity

The results in the preceding section were predicated on the assumption that the level of r is invariant to counterterrorism policies. However, rational terrorists will alter the level of connectivity in response to counterterrorism policies. Moreover, as can be seen from (30), changes in r will have consequences for the level of effort of the individual nodes. The function $\hat{e}(r; c, \pi, \delta)$ shows how this value responds to the chosen r , given c , π , and δ . As such, the network planner's maximization problem is

$$\max_r \widehat{W} = \left(1 - \frac{1 + \pi r}{n}\right) nq[(1 + \delta r)\hat{e}] - nc\hat{e}. \quad (32)$$

Notice that the planner's objective is perfectly aligned with those of individuals. Hence, we rule out the type of behavior exhibited by al-Zarqawi. After all, it is straightforward to show that the network will be inefficient if the different decisionmakers have different objective functions. In our model, any differences in the effort and connectivity levels for the two types of networks is due solely to the nature of the decision making process.

The first-order condition in the first stage can be written as

$$\widehat{W}_r = -\pi q[(1 + \delta r)\hat{e}] + \left(1 - \frac{1 + \pi r}{n}\right) nq'[(1 + \delta r)\hat{e}][\delta\hat{e} + (1 + \delta r)\hat{e}_r] - nc\hat{e}_r = 0. \quad (33)$$

Substituting (30) in (33) yields

$$\widehat{W}_r = -\pi q[(1 + \delta r)\hat{e}] + nc\delta(\hat{e} + r\hat{e}_r) = 0. \quad (34)$$

Let \hat{r} denote the solution to the network planner's problem. Signing the responses of \hat{r} to changes in π , δ , and c is much more difficult than that for the centrally planned network. Since the point of the paper is to illustrate the differences between the two types of networks, we return to the example used in the previous section (i.e., so that $\alpha = 0.5$ and $n = 25$). The dashed lines in Figures 2-4 denote the responses of \hat{r} , \hat{e} , and \widehat{W} to counterterrorism efforts. The dashed lines in Panels 1 and 2 of Figure 3 indicate that effort turns out to be increasing in π whereas connectivity is decreasing in π . The network planner sees the increase in π as a threat to security and acts to decrease connectivity. Individuals are also threatened by the increase in π , and as indicated in Section 2, for a given value of r reduce effort (recall that for a given value of r , effort is decreasing in π). However, given that the planner decreases r , the individual nodes are induced to devote more overall effort to the organization. As shown in Panel 3, the net effect of the changes in r and e must be to reduce overall network welfare.

Before proceeding, be aware that the welfare of the network with two-stage decision making cannot exceed that of the centrally planned network. Obviously, the planner capable of selecting both e and r can always mimic the solution of the two-stage decision maker. Since, the reverse is not true, the maximized value of \widehat{W} will never exceed expected

welfare in the centrally planned network, $W(e^*, r^*)$.

Conclusions

We analyzed the optimal network structure of two different types of terrorist organizations. In the centralized network, the leadership selects the level of individual effort and the level of group connectivity so as to maximize the expected net welfare of the organization's membership. In highly connected networks, information can readily flow from one member to another and the group can perform logistically complex actions. However, connectivity acts to compromise security so that the optimal level of connectivity will depend on the behavior of the counterterrorism authority. Leaders in loosely-connected networks will also seek to balance the trade-off between security and communication. However, with decentralized decision making, the individual nodes may not make optimal decisions from the group's perspective. In particular, the leadership in a centralized network is able to coordinate the activities of all network members and to take advantage of important network externalities. In comparing the two forms, the centralized network is likely to:

- *produce more overall output.* The level of individual effort and the level of group connectivity will be higher in the centralized network than in the decentralized network.
- *respond more strongly to counterterrorism efforts.* As illustrated in the simulation shown in Figures 2-4, the overall responses of the decentralized network to counterterrorism efforts are small. The centralized leader alters effort levels *and* network structure in response to changes in c , π and δ . However, in loosely structured

networks, the two decision makers do not coordinate their actions in that there is less overall responsiveness of the group to changes in the economic and political environment.

- *act in a more conventional way to changing circumstances.* We find more sign ambiguity in our comparative statics for the decentralized network than for the centralized network. This is a result of the nature of the two-stage decision making process in decentralized networks. Notice that in Panel 1 of Figure 3, an increase in π actually increases the effort levels of individuals in the loosely structured network. As infiltration becomes more successful (i.e., as π increases), the connectivity in the decentralized network declines. However, individuals take this as an incentive to increase their effort. In the centralized network, both effort and connectivity decline as π increases.

In an earlier version of this paper we showed that these results are not specific to the assumption that the network is regular or to the assumption that all individuals are alike. There are some important implications of these findings. Obviously, it is important for the counterterrorism authorities to know the type of network they are dealing with. The optimal counterterrorism policies depend on the structure of the terrorist organization. Policies that may be effective in hierarchical networks may be relatively ineffective in flat networks. In our numerical example, terrorism output in flat networks is quite responsive to changes in c but is almost invariant to changes in π . In contrast, both policies are effective in hierarchical networks. Nevertheless, policy makers need to be aware that their counterterrorism efforts will induce substitutions across attack modes. Efforts that reduce

the connectivity of al Qaeda will also induce a substitution from sophisticated attack modes into simple, yet deadly, bombings, armed attacks, and hostage takings.

Although it is tempting to treat the comparative static exercises in Sections 3 and 4 as being descriptive of the nature of counterterrorism policies, in our view this may not be entirely appropriate. As al Qaeda has become more loosely connected, we believe that there has been a switch from a relatively centralized decision making process toward a more decentralized process. As such, the appropriate comparative static results of counterterrorism policies are not likely to be those shown by either the solid or the dashed lines in Figures 2-4. The implication is that increases in π , for example, have caused a reduction of effort and connectivity because (i) connectivity and effort are negatively related to π for a given planner and (ii) the planning process has become less centralized.

In addition to using measures that decrease δ and increase π and c , it is important to recognize that loosely-structured networks are composed of multiple decision makers. As illustrated by al-Zawahiri's letter to al-Zarqawi, treating al Qaeda as a unified whole can be a mistake. Cronin (2006) makes the point:

“It is possible that bin Laden and his lieutenants have attempted to cobble together such disparate entities (or those entities have opportunistically attached themselves to al-Qaida) that they have stretched beyond the point at which their interests can be represented in this movement. ... The key is to emphasize the differences with al-Qaida's agenda and to drive a wedge between the movement and its recent adherents.”

Cronin's point is relevant in circumstances in which the multiplicity of decision makers do not share the same objective function. Yet, even if they have identical preferences, our model shows that different decision makers may not be able to internalize important network externalities. As such, it makes sense for the counterterrorism authorities to enhance the devolution of al Qaeda's network structure. Given the group's size, exploiting fissures between the different decision makers will only make it more difficult for it to engage in logistically complex actions and to capture network externalities.

Notes

1. Siqueira and Sandler (forthcoming) consider the optimal delegation problem for the leadership when there are several groups. Feinstein and Kaplan (2010 [this issue]) consider a model of a strategic terror organization that plans attacks over multiple periods to maximize its growth.
2. The Arabic letter and an English translation were released on October 11, 2005 by the Director of National Intelligence. The text uses the English translation available at http://www.dni.gov/press_releases/20051011_release.htm
3. The *density* of a network can be defined as the number of actual links divided by the maximum number of all possible links.
4. In our model, terrorist nodes do not choose their own levels of connectivity. Instead, there exists a network planner who makes this decision.
5. Note that individuals are not altruistic in the sense that they derive utility from others' consumption or output levels. Instead, our model is designed to capture a positive externality from others' efforts that spill over into the individual's production level. The spill-over effect, measured by δ , is assumed to be less than unity.
6. Of course, there is a potential inefficiency in a highly connected network because of congestion effects. We assume $\frac{\partial q}{\partial r} > 0$ so that the connectivity benefits exceed the congestion costs. No planner would choose a level of connectivity such that $\frac{\partial q}{\partial r} < 0$.
7. Such an assumption is most plausible if it takes time to annihilate cells. An

alternative assumption is to allow a successful infiltration of node j to compromise j , all nodes connected to j , and with some probability less than unity, the cells connected to this latter set of cells. In this scenario, the infiltration of j could annihilate i even though i and j are not connected. However, nothing of substance would be changed as long as $\pi < 1$.

8. The general shapes of the functions shown in the figure are not altered by variations in α and n . A RATS program that can calculate values of $e^*(\pi, \delta, c)$, $r^*(\pi, \delta, c)$, and $W(r^*, e^*)$ for alternative values of α and n is available from the authors.
9. Of course, it would be possible to allow effort levels to be set prior to the level of connectivity. However, it hardly seems likely that individuals join the network and then the network planner chooses the level of connectivity.
10. We assume that node i treats the values of e_j as being fixed.

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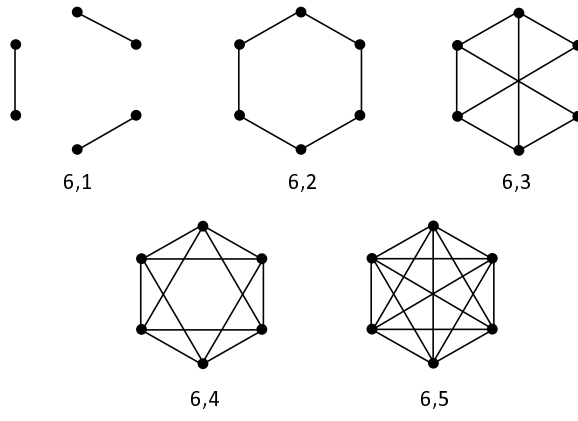


Figure 1: Regular Networks (n, r)

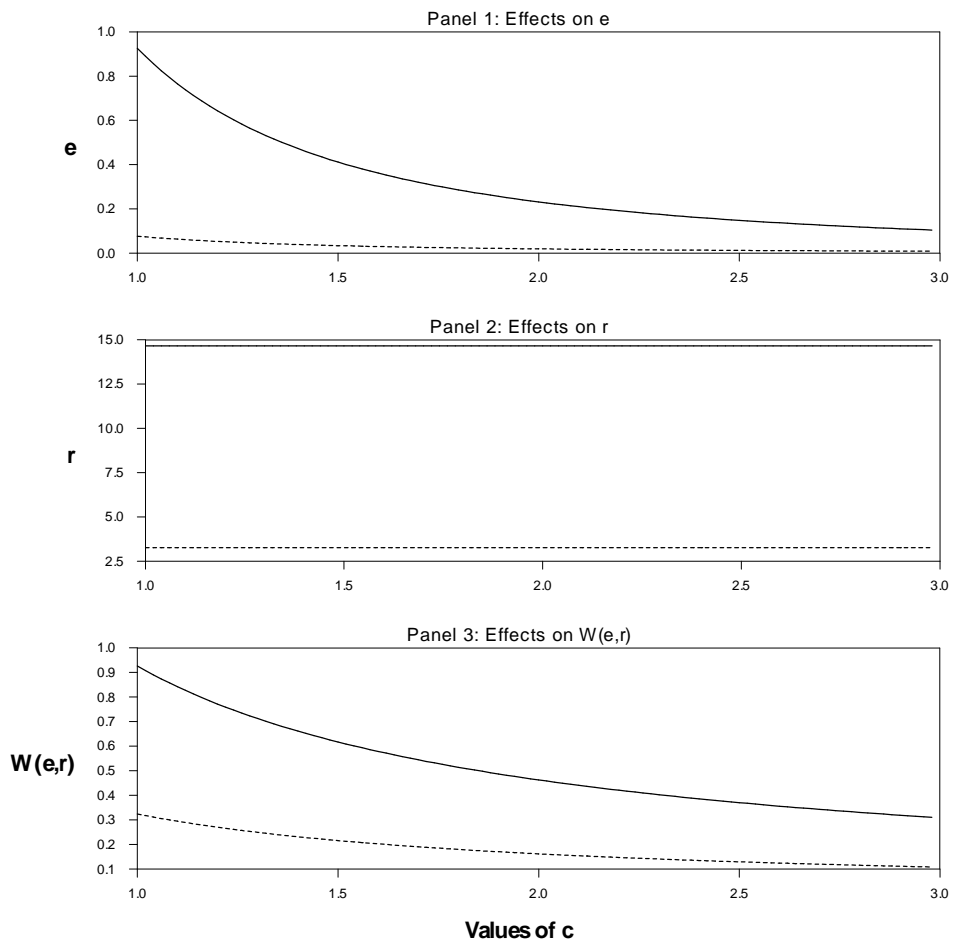


Figure 2: The Effects of Changes in c

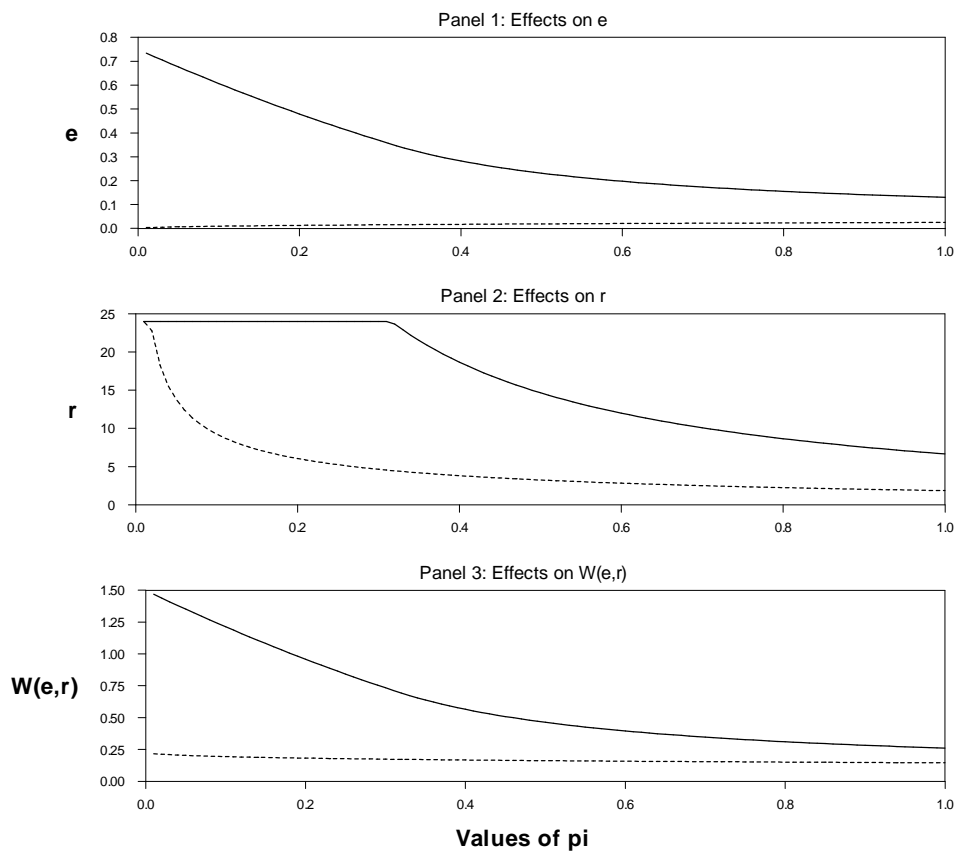


Figure 3: The Effects of Changes in π

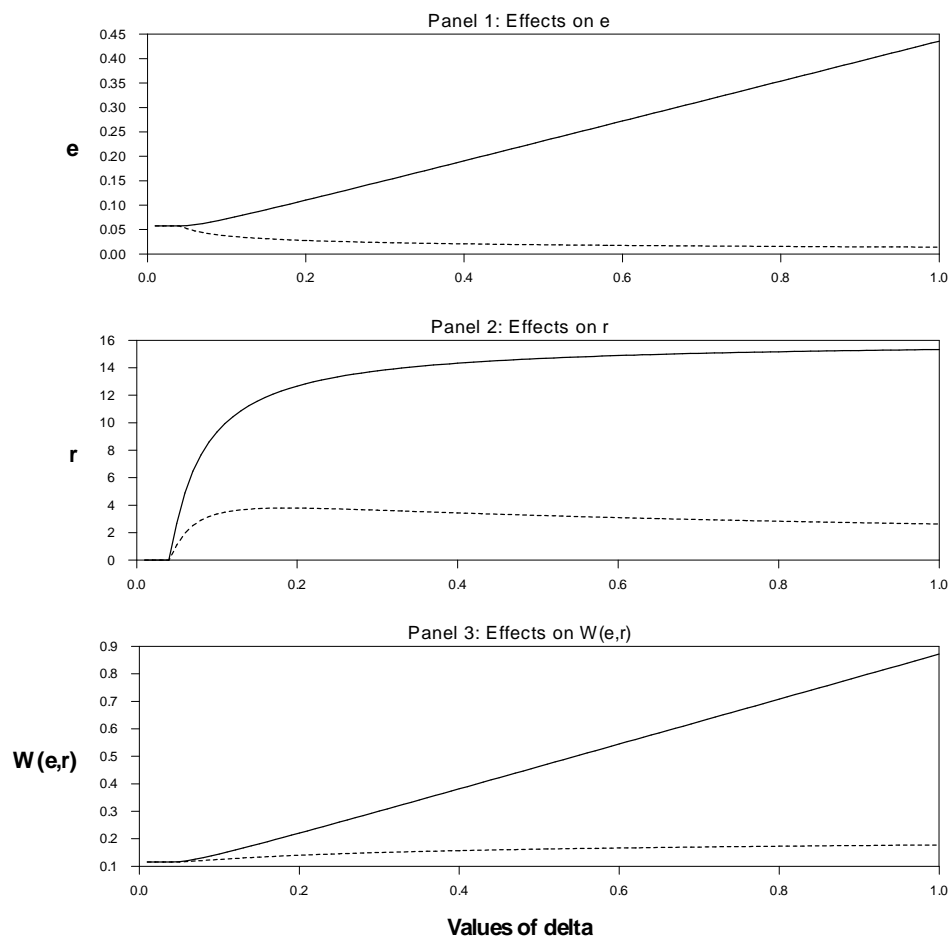


Figure 4: The Effects of Changes in δ