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Chaos from order: a network analysis of in-fighting before and after El Chapo's arrest

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Abstract

The effect of leadership decapitation—the capture or killing of the leader of an armed group—on future violence has been studied with competing conclusions. In Mexico, leadership decapitation has been found to increase violence and in-fighting among drug cartels. However, the causal pathways between leadership decapitation and in-fighting are unclear. In this article, it is hypothesized that leadership decapitation will weaken alliances between armed actors, lead to greater preferential attachment in networks of cartels and militias, and result in greater transitive closure as cartels seek to expand their power. These hypotheses are tested with a stochastic actor oriented model on a network dataset of episodes of infighting among cartels and the militias formed to oppose them between the five years before and after Joaquín, “El Chapo” Guzmán Loera, the former leader of the Sinaloa Cartel, was arrested in 2016. The results show that alliances have virtually no effect on the decision of cartels and militias to fight each other; weaker organizations faced a higher reputational cost after El Chapo’s detention; and post-arrest cartel in-fighting did not increase as a result of uncertainty about the relative balance of power among cartels.

Keywords

Cartels, El Chapo, In-fighting, Leadership decapitation, Network analysis.

This article examines how leadership decapitation affects the decisions of drug cartels and militias to fight each other. Previous work investigates how the arrest or killing of a criminal or insurgent leader affects the viability of the group being targeted and changes in the level of violence (Atuesta and Ponce, 2017; Cronin, 2009; Johnston, 2012; Phillips, 2015; Price, 2012). However, the effect of such operations on the infighting network of criminal and vigilante organizations has not received much attention. Addressing this gap, I model the changes in the decision of drug cartels and militias in Mexico to attack each other between the 5 years before and after Joaquín, “El Chapo” Guzmán Loera, the former leader of the Sinaloa Cartel, was arrested in 2016. To do so, I create a new network dataset and employ a stochastic actor oriented model. I find that the effect of alliances on cartels’ and militias’ decisions

to attack rivals changed little after El Chapo was arrested; El Chapo’s arrest increased the reputational cost to cartels and militias for appearing weak; and El Chapo’s detention did not change uncertainty about the balance of power among cartels. The rest of the paper is organized around four sections. First, I review the literature on leadership decapitation and derive testable hypotheses. In the second section I outline the research design. The third section presents the results, and the final section is a discussion of and conclusions from the results.

Leadership decapitation

Leadership decapitation is the capture or killing of the leader or leaders of a criminal, terrorist, or insurgent organization. The logic of pursuing a leadership

decapitation strategy is that violent organizations will not be able to function without their leader and violence will decrease. While many studies have attempted to estimate its effect on subsequent violence, the evidence is mixed. Pape (1996) argues that the unpredictability of leader succession in war makes it difficult to pinpoint leadership decapitation as the cause of a movements' decline. Despite Pape's skepticism, some studies have found leadership decapitation to be effective against terrorist organizations. Johnston (2012) finds that counterinsurgents are more likely to be successful if they capture or kill insurgent leaders and Price (2012) reached a similar conclusion.

Other work does not claim that leadership decapitation is either always or never effective at reducing violence but investigates under what conditions it may work. A pioneering study by Jordan (2009) found the success of a leadership decapitation strategy against terrorist groups to be dependent on the groups' age, size, and type. Similarly, Cronin (2009) argues that leadership decapitation's effectiveness against a terrorist group is conditional upon the group's structure, whether it revolves around a charismatic leader, the availability of a successor, the group's ideology, the political system in it exists, and whether the leader is captured or killed. Likewise, Colby (2021) argues that the effectiveness of leadership decapitation is dependent upon how participatory the political system is in which an insurgency exists, the credibility of security forces, and whether or not the armed group alienates civilians. Looking to Mexican cartels, Phillips (2015) finds that leadership decapitation may be effective in the short term, but violence increases in the long term as cartels fragment and fight for territory. Finally, Atuesta and Ponce (2017) find that major security operations against Mexican cartels and their resulting fragmentation led to more violence.

Following El Chapo's arrest, Mexico experienced an increase in cartel-related violence and the formation of new cartels and militias (Ahmed, 2019; Ward, 2019); however, there is little information on how the network of these actors has changed between the periods before and after El Chapo was arrested. With the Sinaloa Cartel in decline, at least temporarily, one likely outcome is that alliances between cartels break down as former allies compete to fill the resulting power vacuum.

Hypothesis 1: Following El Chapo's arrest, the importance of alliances on cartels and militias' decisions to attack each other will decrease.

If alliances break down, smaller cartels that were part of alliances should be less protected from violent confrontation with rivals, eliciting a preferential attachment for future violence in general, but especially

from more aggressive cartels looking to consolidate their power by attacking cartels already under attack.

Hypothesis 2: After El Chapo's arrest, the probability that a cartel or militia decides to attack another organization will be greater for organizations with higher levels of preferential attachment.

Hypothesis 2.1: After El Chapo's arrest, the probability that one cartel or militia attacks another will be greater if the attacker is more aggressive and the victim has already been under attack.

Furthermore, when El Chapo was in control of the Sinaloa Cartel, there was certainty around its strength, the territory it controlled, and who its allies were. But El Chapo's arrest might signify a weakening of the cartel, leading to uncertainty around which areas it controls and its power relative to other cartels. This uncertainty could then spark more competition among cartels to control a greater share of the drug trade, resulting in greater transitive closure. For example, one cartel might attack a second cartel, the second cartel might attack a third cartel, and the third cartel might attack the first cartel to establish who will control a particular area.

Hypothesis 3: In the post-arrest period, higher transitive closure will increase the probability of one cartel deciding to attack another actor.

Before describing how I will examine changes to in-fighting among Mexico's cartels and militias, it is worth mentioning that leadership decapitation is not the only strategy a state may use to disrupt an illegal network. According to Roberts and Everton (2011) states can pursue a kinetic approach that targets individuals and organizations directly or by increasing allies' capacity or a non-kinetic strategy to undermine an organization's influence and control. Unlike leadership decapitation, kinetic strategies might seek to neutralize the most central nodes, which may not be leaders of a covert organization. States can also target financial, social, or political networks rather than members of the group (Carley, 2006). While states may pursue any of these strategies in isolation or alongside leadership decapitation, examining their effect on in-fighting after El Chapo's arrest is beyond the scope of this article.

Methods

Stochastic actor oriented model

To model changes in the decisions of cartels and militias of whether to engage in infighting between the five years before and after El Chapo's capture I employ a before-and-after design. Effects are estimated via a stochastic actor oriented model (SAOM), although it would also be

possible to utilize relational event modeling (REM) or a temporal exponential random graph model (TERGM). However, while REM models may be interpreted in an actor-oriented framework (Butts, 2017), they are fundamentally tie-oriented (Stadtfeld et al., 2017). Similarly, TERGMs treat ties as a function of previous ties rather than actor choices (Block et al., 2017; Snijders and Pickup, 2017). On the other hand, SAOMs explicitly model actors' choices with a rate function and an objective function. The rate function determines the probability that an actor can change a tie. In this analysis, the rate function gives each actor an equal probability of being able to change its tie at a given time step. The optimization function is a linear combination of covariates that nodes try to maximize given by

$$f_i(x^{(0)}, x; \beta) = \sum_{k=1}^K \beta_k s_{ki}(x^{(0)}, x) \quad (1)$$

where $s_{ki}(x^{(0)}, x)$ are network effects. SAOMs proceed in mini steps where nodes are randomly selected by the rate function to change a tie according to their objective function (Snijders and Pickup, 2017).

To understand how El Chapo's arrest changed the way cartels and militias decide whether to attack each other, I employ SAOMs to estimate the differences in the mean relative importance in the five years before and after El Chapo was captured. The relative importance for a single network effect k on an actor i derived from an estimated coefficient $\hat{\theta}$, as proposed in (Indlekofer and Brandes, 2013), is given by

$$I_k(X, i) := \frac{\|\pi_i - \pi_i^{-k}\|}{\sum_{l=i}^K \|\pi_l - \pi_l^{-k}\|} \quad (2)$$

where π_i is the probability that actor i forms a tie with the actor it was observed forming a tie with. Stated differently, the relative importance of an effect k on an actor i represents the change in i 's probability of forming a tie with another actor j if effect k was excluded from the model. The mean relative importance of an effect k is the summation of the relative importance of k on all actors divided by the number of actors. In this analysis, the difference in the mean relative importance of an effect represents the change in how much it contributed to cartels' and militias' decisions to attack other organizations after El Chapo was arrested compared to before his arrest. It is important to note that this is not the same as the regression coefficients of a SOAM.

Data

To create the network data, I collated event data from the Social Conflict Analysis Database (SCAD) (Salehyan

et al., 2012), the Uppsala Conflict Data Program Georeferenced Events Dataset (Pettersson et al., 2021; Sundberg and Melander, 2013), and the Armed Conflict Location and Events Database (Raleigh et al., 2010) that occurred between 2012 and 2021. Each data source relies on news articles from a different set of media outlets, so combining them ensures a greater number of events are included in the final dataset and at least partially eliminates the reporting bias that might be present in any one dataset. Additionally, some events in each dataset were coded as having unknown actors but employing multiple datasets ensures that at least some of the gaps in each dataset will be filled in by the others. All datasets include events from around the world and events where the state was the perpetrator. In addition to lethal attacks, SCAD includes riots strikes, and protests.

To isolate violent interactions between Mexican cartels and militias, I excluded events that occurred outside of Mexico; included a government actor; were coded as a protest, riot, or strike; or occurred before 2012 or after 2021. The final dataset includes militias because they were formed to protect communities from cartel violence and may influence tie formation between cartels. One might make the case that transnational actors should also be included in my analysis because they operate in Mexico and are involved in the Mexican conflict. However, unlike Mexican cartels, these groups are not heavily involved in Mexican politics and do not attempt to gain material support and sympathy from Mexican citizens, so their role in Mexico's drug war is tangential to the role of Mexican actors. Finally, I merged events that had the same attacker and victim and occurred on the same day in the same municipality.

Ties between actors are directed and represent at least one violent interaction from the sender to the receiver. I created one network for interactions that occurred between 2012 and 2016 and another for 2017 to 2021. To ensure an equal comparison, the network in the pre-arrest period only contains ties that were observed before El Chapo's arrest and the post-arrest network only contains ties that were observed in the post-arrest period. Many militias and sub-factions of larger cartels were not observed in the pre-arrest network, so I code them as "joiners" as per Ripley et al. (2021). The network in the pre-arrest period only contains 29 nodes and 19 edges while the post-arrest network contains 132 nodes and 124 edges, due to the formation of new sub-factions and militias after El Chapo's arrest. This does not mean that edges only observed in one period were not present in the other, but that they were not observed in the other period. Figure 1 shows

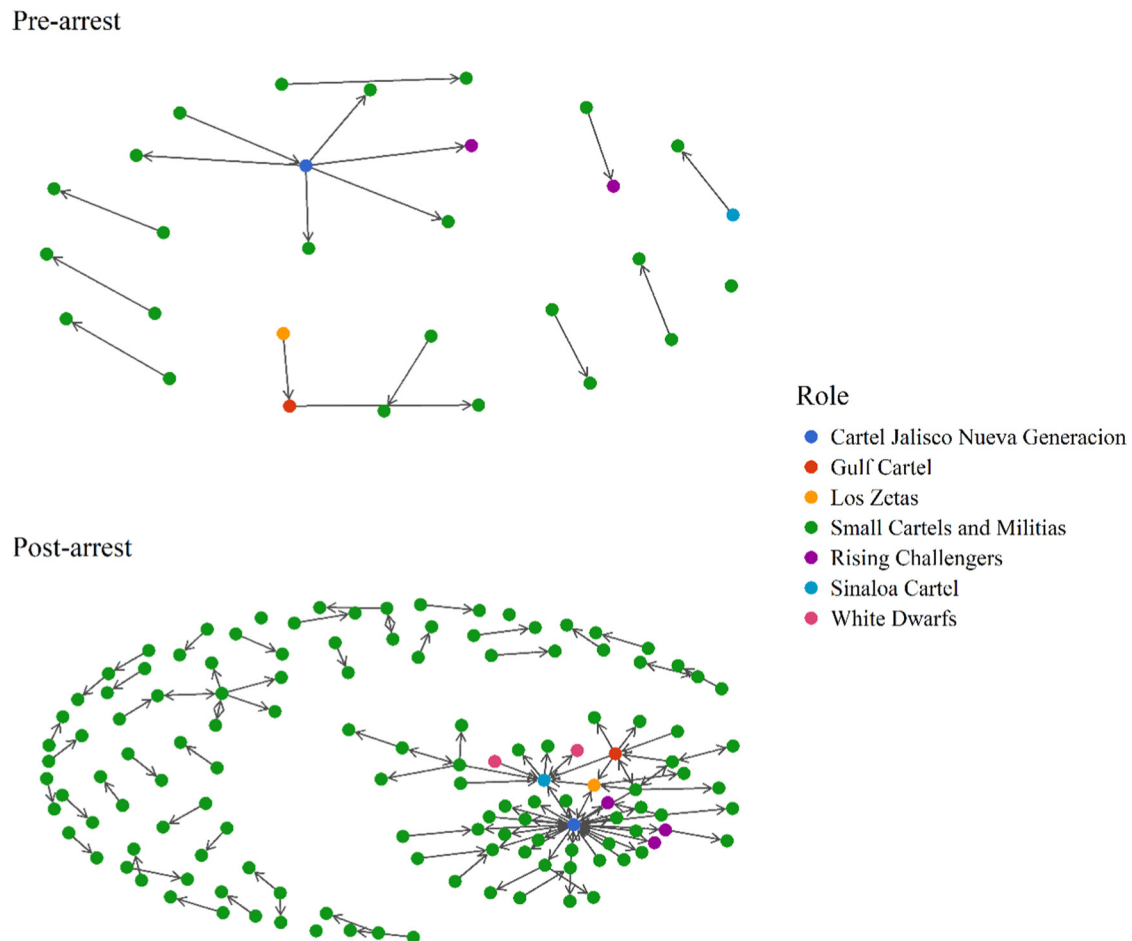


Figure 1: The network of in-fighting among cartels and militias in Mexico. The top panel is the network of interactions among groups in the five years leading up to El Chapo's arrest and the right side shows interactions in the five years after El Chapo's arrest. Nodes are colored according to their structurally defined role and it is assumed that interactions that occurred during before El Chapo's detention persisted after he was arrested.

the two networks and Figure 2 displays their degree distributions. Nodes in Figure 1 are colored according to their structurally defined role. The majority of nodes are small cartels and militias that control small swaths of territory. The cartels in this role tend to specialize in a small number of subtasks of drug trafficking and align themselves with larger cartels. Unsurprisingly, the most powerful cartels—the Gulf, Jalisco Nueva Generacion, Los Zetas, and Sinaloa cartels—occupy a unique role. Rising Challengers—Nueva Plaza, Santa Rosa de Lima, Los Caballeros Templarios, and La Nueva Familia cartels—are relatively new cartels that are rapidly growing while the White Dwarfs—Juarez and Beltran Leyva cartels—represent cartels that are on the decline.

I include four independent variables that allow for the testing of the hypotheses above. *Out-degree*

Jaccard similarity is the Jaccard similarity of out-degree ties between a node and every other node in the network. A high Jaccard similarity between the out-degree of two actors means that they both fight similar other actors, which would indicate an alliance. To account for preferential attachment, I include the *in-degree popularity* metric. If preferential attachment exists, this metric will be higher, indicating that attacks against a cartel or militia beget future attacks against the same cartel or militia. The *out-in-degree assortativity* effect is similar, but it quantifies the propensity for actors with high in-degrees to attract ties from actors with high out-degrees. Put differently, it indicates stronger cartels and militias preying on weaker groups. The final effect, *transitive closure*, is an approximate measure of clustering, which suggests increased competition among cartels

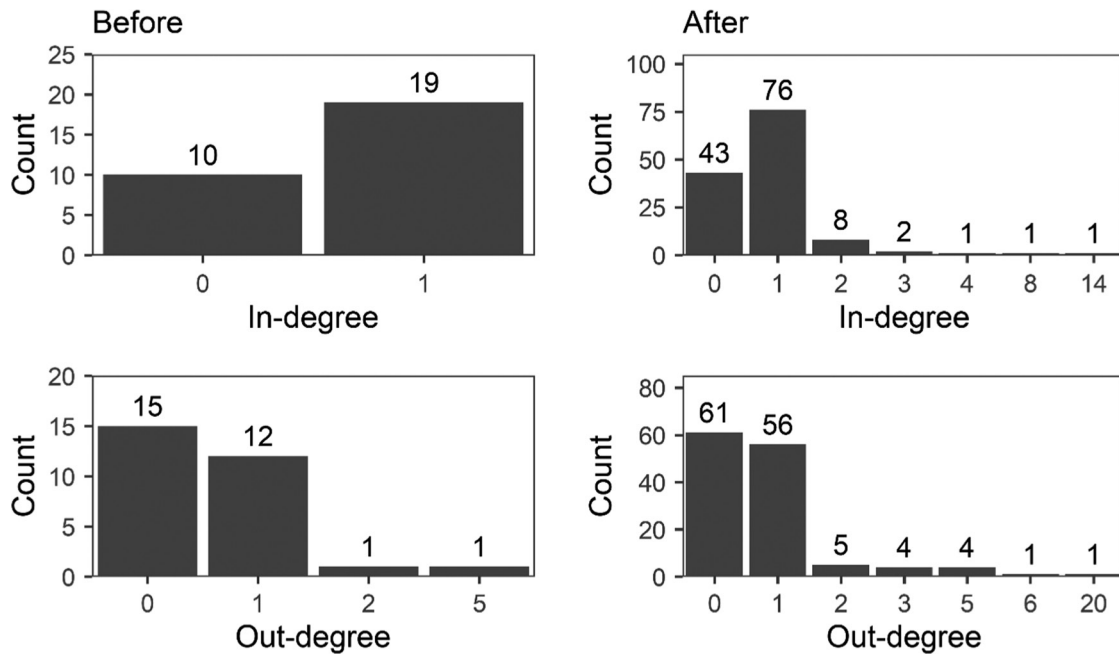


Figure 2: Degree distribution of in-fighting networks before and after El Chapo's arrest. The plots on the left show degree distribution of the in-fighting network before El Chapo was arrested and the right side is after. The top portion displays in-degree distribution while the bottom shows out-degree. Ties from the pre-arrest period are assumed to persist in the post-arrest period.

due to uncertainty about the balance of power after El Chapo's arrest.

In addition to these variables, I include five control variables. *Reciprocity* accounts for the proportion of a group's outgoing ties that correspond to incoming ties from the same node that the outgoing ties are sent to. I also control for homophily related to four node-level attributes. *Aggression* is the log of the number of attacks conducted by each actor during both periods. The *subfaction* attribute codes whether an organization is a subfaction of a larger group or independent. *Militia* is a dummy variable that takes the value 1 if an organization is a militia and 0 if an organization is a cartel. The *role* variable assigns each organization to one of seven previously described roles as determined by each group's structural equivalence with other organizations. More details on how structural equivalence groups were created is available in Appendix A.

Results

I estimate four SAOMs that correspond to the three main hypotheses. In the first model I estimate the impact of alliance formation and maintenance on the decisions of actors to attack one another by including a term for out-degree Jaccard similarity, or

the proportion of common out-degree ties versus all out-degree ties of node pairs. In the second model, I include a term for indegree popularity, or the sum of the in-degree ties of all of a node's neighbors, which is an indicator of preferential attachment. The third model includes a term for assortativity of outdegree ties to nodes with higher in-degrees, which indicates more aggressive organizations preferentially attack cartels and militias that are already under attack. The final model incorporates a term for transitive closure that corresponds to clustering, in line with Feld's (1981) theory, indicates tie formation around a shared focus, which in this case is drug trafficking. All the models include controls for reciprocity and homophily among the four node-level attributes. Table 1 above shows the raw coefficients for these results before they are transformed to changes in mean relative importance.

Alliance degradation

Figure 3 shows the results of the first model. *Out-degree Jaccard similarity* is marginally positive (estimates are rounded to two decimal places) but does not achieve statistical significance. This somewhat contradicts Hypothesis 1, which predicts that actors would be less likely to refrain from attacking their allies after El Chapo's

Table 1. Results of four stochastic actor oriented models

	Alliances	Reputation	Strong-vs-weak	Clustering
Jaccard Similarity	0.13 (3.29)			
In-degree Popularity		0.18 (0.10)		
Out-in-degree Assortativity			-0.90*** (0.23)	
Transitive Closure				0.34 (0.63)
Aggression Homophily	-0.20 (0.47)	-0.19 (0.44)	-0.30 (0.43)	-0.20 (0.47)
Subfaction Homophily	2.06*** (0.58)	2.04*** (0.56)	1.87*** (0.54)	2.05*** (0.55)
Militia Homophily	1.23*** (0.34)	1.20*** (0.35)	1.32*** (0.32)	1.24*** (0.33)
Role Homophily	-1.91*** (0.39)	-1.55*** (0.45)	-2.65*** (0.48)	-1.89*** (0.37)
Reciprocity	4.72*** (0.76)	4.73*** (0.96)	4.83*** (0.69)	4.72*** (0.84)
Iterations	19176	19176	19176	19176

*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$

Each model corresponds to one of the hypotheses. Standard errors are in parentheses.

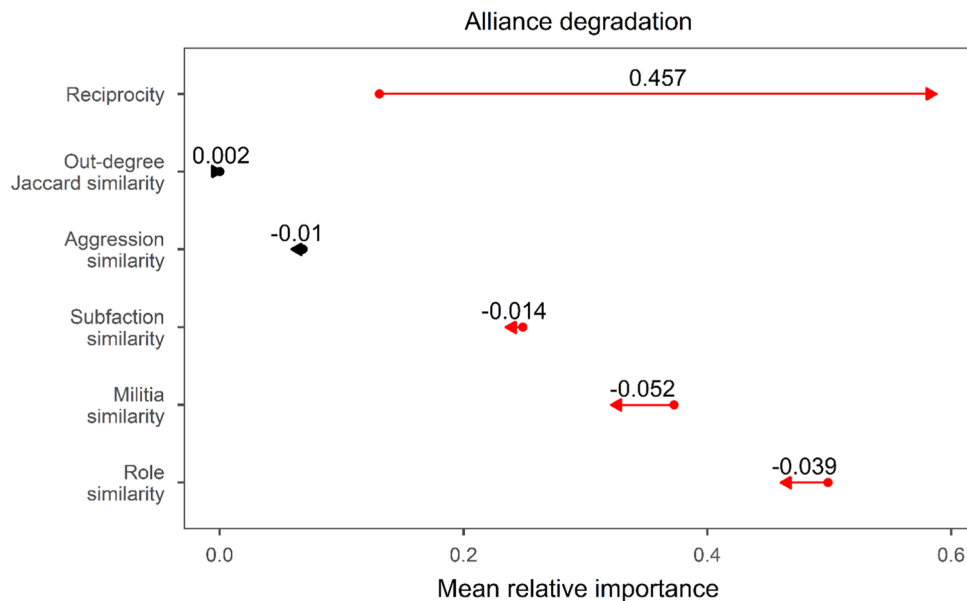


Figure 3: Change in the mean relative importance for network effects between the pre-arrest and post-arrest periods. Out-degree Jaccard similarity is an indicator for alliances. Arrowheads indicate the direction of change and numbers show quantities of change. Statistically significant effects, per a Wald test with $p < 0.05$, are red.

arrest. If that were the case, we would see a statistically significant change in the positive direction for the effect of *Jaccard similarity* on tie formation. To the contrary, one might argue that cartels and militias have strong incentives to form alliances. With the power vacuum left by El Chapo's arrest, cartels have more to gain from forming alliances because doing so increases their ability to wrestle control of drug smuggling routes from rivals. Militias also have an incentive to form alliances because they can pool personnel, resources, and intelligence to combat increasing cartel violence. In this case, we would see a statistically significant negative change in the effect of *Jaccard similarity* on tie formation probability. However, the lack of a positive or negative statistically significant effect implies that the decision-making of cartels does not adhere to either of these logics. Instead, they may have neither greatly expanded or backed out of their alliances because, as Christia (2012) has shown to be the case with insurgent groups, organizations aim to create alliances large enough to achieve their objectives while maximizing individual payoffs. Another possible explanation is that alliances between cartels formed more informally around the sharing of knowledge and resources among lower-level

leaders. If this is the case, it would also explain why changes to upper echelon leadership seemed to have little effect on alliance formation or maintenance.

Reputational mechanisms

Figure 4 presents the results for general preferential attachment and the preferential attachment of aggressive organizations to form conflict ties with those already under attack. In the first of these models, *in-degree popularity* has a large effect but is not statistically significant. In the second model, the effect of *out-in-degree assortativity* is large and statistically significant. This means more aggressive cartels preferentially attack cartels and militias that have already been under attack, probably to consolidate their power. With a power vacuum left after El Chapo's arrest, more aggressive cartels probably view cartels that are frequently attacked as easy competition to eliminate. Yet some of the increase in the mean relative importance of *out-in-degree assortativity* might also be attributable to the growing number of militias after El Chapo's detention, which more aggressive cartels might direct violence

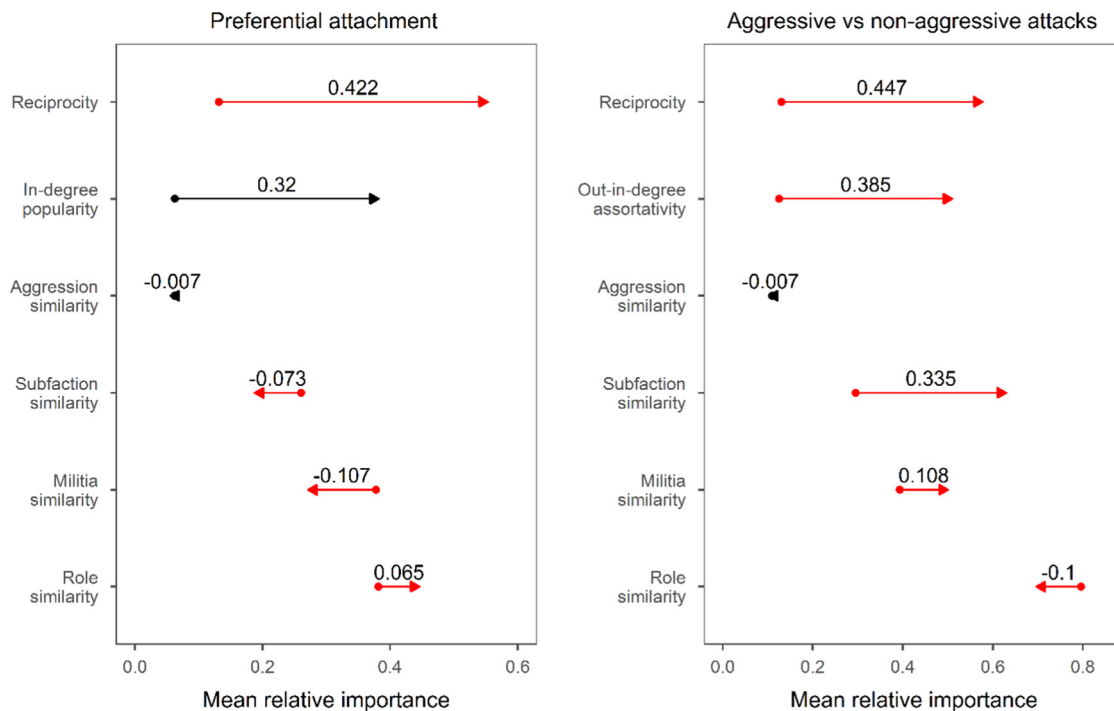


Figure 4: Change in the mean relative importance of network effects between the pre and post-arrest periods. In-degree popularity reflects preferential attachment while *out-in-degree assortativity* is indicative of aggressive organizations preying on less aggressive rivals. Arrowheads show the direction and numbers show quantities of change. Statistically significant effects are red.

against. Conversely, cartels and militias with lower in-degree centralities were less likely to be attacked after El Chapo's arrest than before, suggesting those organizations are more bellicose and would not be perceived as easy targets.

Another interpretation is that very aggressive organizations are more involved in in-fighting as both initiators and victims of attacks. Put differently, cartels that are heavily involved in in-fighting and initiate many attacks against their rivals are probably on the receiving end of more attacks due to their involvement in in-fighting. Then, they probably reciprocate violence against the initiators so they are not viewed as easy targets. Accordingly, the large and statistically significant effect of *reciprocity* implies that retaliation against organizations highly involved as both initiators and victims of attacks is more likely to be carried out by the victims of those organizations than by a different cartel or militia. As in the previous interpretation, this suggests that cartels and militias on the receiving end of attacks are quick to reciprocate violence to prove that they are not easy targets.

Transitive closure

Figure 5 shows the results for *transitive closure*. A negative change in the mean relative importance of this effect would indicate an avoidance of cartels to engage in in-fighting. For example, if a cartel attacked

a second cartel and the second cartel attacked a third cartel, the third cartel would not attack the first. On the other hand, increased transitive closure would suggest that in-fighting ties are more likely to form around common social foci, as predicted by Feld (1981). Though Feld's theory predicts that ties in a friendship or similar context will form around a social focus such as club membership, increased transitive closure in Mexico's drug trade would imply that conflict ties are more likely to form around the shared focus of drug trafficking in contested areas. If that were the case, it would indicate that cartels are uncertain about the balance of power in a given area, which fighting would reveal. However, the effect of *transitive closure* is not statistically significant and only marginally contributes to the decisions of cartels and militias. This indicates that El Chapo's arrest did not lead to uncertainty, or at least not enough to significantly increase transitive closure, around contested territories. Moreover, the lack of a statistically significant increase for *transitive closure* means the Sinaloa Cartel's rivals did not greatly change the perceived balance of power. Finally, it is worth mentioning that the lack of uncertainty about the balance of power is likely due in part to the reputational mechanism described above. Cartels with higher in-degrees would be perceived as weak and those with low in-degrees would be perceived as strong, so there would be no need for them to form transitive closure around contested areas to reveal the balance of power.

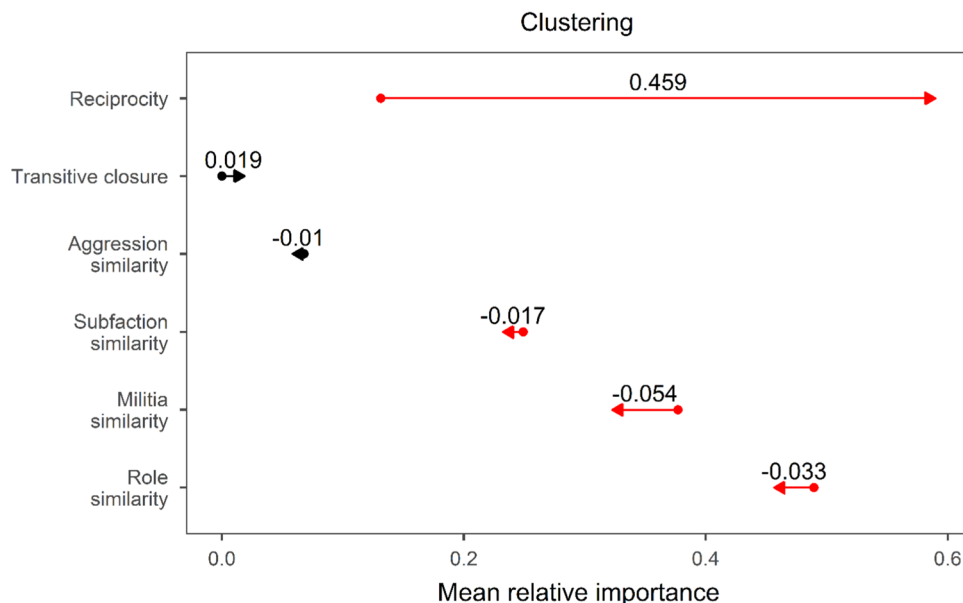


Figure 5: Change in the mean relative importance for network effects before and after El Chapo's arrest. Transitive closure approximates clustering. Direction of changes is represented by arrowheads and effect size is given by numbers above each line segment. Statistically significant effects are shown in red.

Discussion and conclusions

In this article I investigated the change in cartels' and militias' decisions to engage in infighting before and after the arrest of Joaquín "El Chapo" Guzmán Loera, the leader of Mexico's most powerful drug cartel, in 2016. The three main insights from this analysis are (1) alliances had virtually no effect on cartels' and militias' decisions to fight one another; (2) after El Chapo's arrest, cartels and militias faced greater reputational costs for appearing weak, and; (3) El Chapo's arrest did not greatly affect certainty about territorial control and relative power of other cartels. These findings are important because they illuminate the dynamics of inter-group violence that can occur when governments pursue leadership decapitation to reduce violence. Still, governments may have reason to be optimistic because greater infighting might lead powerful armed actors to neutralize weak rivals thereby decreasing the number of actors governments must neutralize. Though the results of this study show that to not be the case after El Chapo's detention, it might be the case with other types of armed actors and in different political and economic contexts. Accordingly, a fruitful direction for future studies would be to use cross-national data on leadership decapitation to examine the potential for leadership decapitation to facilitate the elimination of weak armed actors by stronger rivals.

One potential concern with these findings is the lack of a variable for territorial control. Of the four independent variables of interest, only *out-in-degree assortativity*, achieved statistical significance. If the effect for *out-in-degree assortativity* is biased, we would expect to see a statistically significant change in *transitive closure*, because territorial control is a focus around which cartels and militia would cluster (Feld, 1981). Furthermore, coding territorial control would be highly subjective because different cartels control different territories at different times (Dulin and Patiño, 2020).

Critics may also be skeptical because, despite having achieved acceptable levels of convergence, the simulated networks in the SAOM might not closely align with the observed networks. Under normal circumstances the goodness of fit of the models could be tested using the Mahalanobis distance test recommended in (Lospinoso and Snijders, 2019), but this test is not appropriate when the number of actors changes between periods (Ripley et al., 2021). Therefore, some skepticism is warranted, but it should also be noted that these findings are generally congruent with the literature on leadership decapitation.

Some might also question the external validity of these findings. One could make the case that these

findings do not apply to terrorist or insurgent groups, which the majority of research in the literature review focus on. However, the distinction between criminal and terrorist organizations is not black and white. Some insurgent organizations (e.g., the Taliban, Abu Sayyaf, the Shining Path) are heavily invested in drug trafficking and other criminal activities. Conversely, Mexican cartels behave similarly to many of the insurgent organizations cited in the literature. They recruit civilians to fight against the state and their rivals, provision social services, exercise judicial functions, and they are present in all levels of politics, leading to the term narcoterrorism. Still, every illegal armed organization exists in a different context and I cannot rule out other actions of the Mexican government other than El Chapo's arrest as having effected in-fighting. Therefore, I make no claim that these findings will apply to any other specific case and leave it to the reader to determine the applicability of these results to other contexts.

This analysis extends previous work on the effect of leadership decapitation by linking it with temporal network dynamics. In addition, it adds to a burgeoning body of literature that bridges the divide between political science and sociology by applying network analytic methods to questions related to intrastate violence (Gade et al., 2019; Larson and Lewis, 2018; Moore, 2019). Without network analytic methods, many questions treated in the literature on substate conflict would be impossible to answer. Likewise, without consulting the political science literature on alliances and rivalries, any network analysis of the dependence of armed actors would probably be ill-conceived because modeling assumptions and coding decisions would not be realistic. Thus, given the impact of government strategies against non-state armed actors, applying social network analysis to this class of problems should be of great interest to both political scientists and network analysts.

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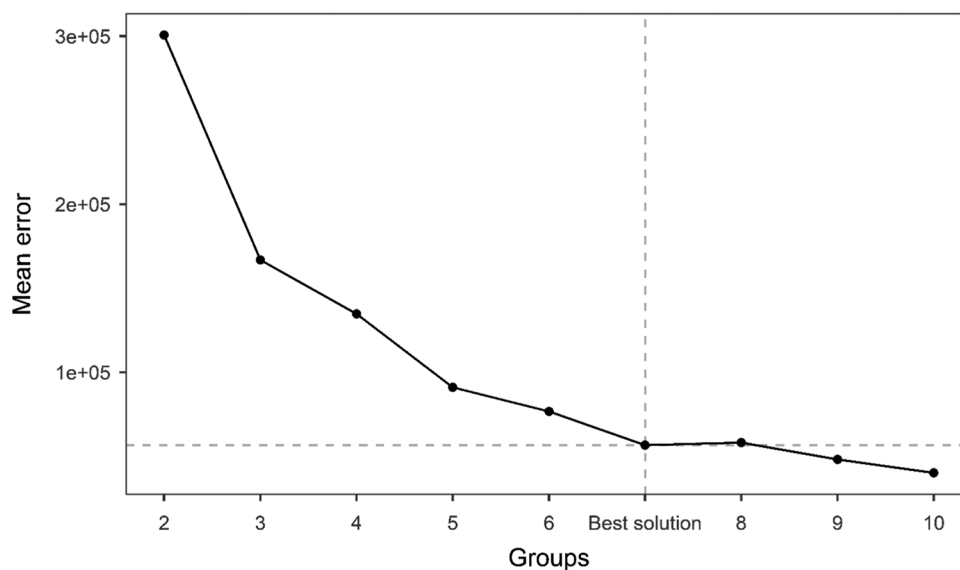
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Appendix A

Here I briefly describe the method I used to derive the roles associated with cartels and militias. As Borgatti and Grosser (2015) have explained, structurally equivalent nodes, or those that have similar connection profiles, have similar beliefs, attitudes, and behaviors. Stated differently, structurally equivalent nodes have similar roles. To assign cartels and militias in the network to roles, I use a generalized blockmodel proposed by Žiberna (2007). The model attempts to partition nodes into a given number of blocks in which the value of each nodes' ties with the rest of the block exceeds a value m optimized by the algorithm. To determine the difference between the partitions created by the model and what an ideal partition should be, I use the sum of squared errors between each block and a block of the same size in which all values are greater than

or equal to the parameter m . Then, I take the mean of the error over all of the 10 iterations I conducted for each blockmodel with k equivalence groups. To determine the ideal number of equivalence groups, I estimate blockmodels with values of k ranging from two to ten. Using only this range of values for k may only converge to a local minimum, but as the number of equivalence groups increase towards the number of nodes in the network, the mean error would be biased by the decreasing size of each equivalence group. To find the optimal number of groups within this domain, I create a plot where the x-axis represents the number of equivalence groups and the y-axis is the mean of the errors for all of the runs of the blockmodel with k equivalence groups. From this plot, shown below, I identify the number of equivalence groups at which the rate of the decrease in the mean error levels off. That point represents seven structural equivalence groups.



Note: 10 iterations were used for each number of partitions

Figure A1: Structural equivalence group solutions. Numbers on the x-axis are the number of structural equivalence groups and the y-axis represents the mean of the error between fitted structural equivalence groups and the ideal structural equivalence groups across ten simulations.