Network Influence Effects in Agent-Based Modelling of Civil Violence

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Abstract. In this paper we describe an Agent-Based model of civil violence with network influence effects. We considered two different networks, 'family' and 'news', as a simplified representation of multiple-context influences, to study their individual and joint impact on the size and timing of violence bursts, the perceived legitimacy, and the system's long term behaviour. It was found that network influences do not change either the system's long term behaviour or the periodicity of the rebellion peaks, but increase the size of violence bursts, particularly for the case of strong 'news impact'. For certain combinations of network influences, initial legitimacy, and legitimacy feedback formulation, the solutions showed a very complicated behaviour with unpredictable alternations between long periods of calm and turmoil.

Keywords: Agent-Based model, civil violence, network influences

1 Introduction

The study of social conflict phenomena, and civil violence in particular, is an important topic in political science, sociology, social psychology and social simulation studies. Social context factors can increase the potential for violence [9], whereas widespread access to information and communication technologies (ICT) and Social Networks (SN) can trigger gradual (e.g. escalation) or sudden (e.g. revolution) uprisings [11], which in turn change the social context.

Epstein et al. [3] (see also Epstein [2]) introduced a very successful Agent-Based model (ABM) of rebellion against a central authority (Model I) and ethnic violence between two rival groups mediated by a central authority (Model II), in an artificial society with two types of agents ('agents' and 'cops' for representing citizens and policemen, respectively). The success of Epstein's ABM derives from the simplicity and soundness of the action rule for 'agents', the relevance of the dependent variables used and the capability for representing mechanisms of collective violence. Epstein's ABM has been extended and refined by several authors for studying different conflict phenomena [10], [4] and mechanisms of violence uprisings [12].

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In this paper we present an ABM of civil violence with network influence effects by considering two forms of network influence, *i*) 'family' represented by a union of small undirected cliques (individual families), and *ii*) 'news' represented by a union of directed star networks with agents of a new type (called 'media') as hubs. These networks provide an abstract representation of two important influence modes in a society, one associated with highly cohesive small scale communities connected by strong undirected links (two-way influence) with local information and high internal homogeneity [7], and another associated with (weaker, one-way) directed links through which influential agents shape global perceptions [7], [15]. The purpose of the present work is to seek answers to the following questions:

- How can network influences due to 'family' and 'news' networks be included in an ABM of civil violence while preserving its simplicity?
- What is the impact of network influences on the nature of the solutions (equilibrium or complex)?
- What is the relative importance of network influences with respect to other mechanisms such as imprisonment delay and legitimacy feedback?

The remainder of this paper is organized as follows. In section two we present the theoretical background, with emphasis on Epstein's ABM of civil violence and an extension of that model which includes small scale memory effects (imprisonment delay), media influence and legitimacy feedback. Section three contains a description of the present ABM. In section four, we present the results of the model and their discussion for different combinations of 'family' and 'news' network influences as well as for homogeneous or heterogeneous legitimacy perception. Section five contains a summary of the conclusions.

2 Theoretical Background

2.1 Epstein's ABM of Civil Violence

Epstein's ABM of civil violence [3], [2] simulates rebellion against a central authority in an artificial society with two types of agents, 'agents' and 'cops' for representing citizens and policemen respectively, moving in a homogeneous 2D torus space. Both types of agents have one movement Rule M: 'move to a random empty site within the agent's vision radius'; and one action rule, called Rule A for 'agents' and Rule C for 'cops', as described below. 'Agents' can be in one of three possible states, 'quiet', 'active' (rebellious) or 'jailed'. 'Agents' that are not 'jailed' switch between 'quiet' and 'active' according to the following action rule

Rule A: if $G - N > T$ be 'active'; otherwise be 'quiet'

where $G = H \cdot (1 - L)$ is the grievance, $H \sim U(0, 1)$ is the perceived hardship, L is the perceived legitimacy of the central authority assumed equal for all agents, $N = R \cdot P$ is the net risk perception, where $R \sim U(0, 1)$ is the risk aversion, P

is the estimated arrest probability, and T is a threshold (assumed constant for all 'agents'). The form of the arrest probability presented in Epstein's model is

$$P = 1 - \exp(-k \cdot (C/A)_v) \quad (1)$$

where C and A are the number of 'cops' and 'active' agents within the agent's vision radius v and $k = 2.3$ is the arrest constant [3], [2]. Implementations of Epstein's ABM often replace $(C/A)_v$ by $\lfloor C_v/(A_v + 1) \rfloor$ in equation (1) which leads to a drop of P from 0.9 to zero when $C = A$, avoids divide-by-zero errors (the 'agent' counts itself as 'active' when estimating the arrest probability) and produces complex solutions with intermittent bursts of rebellion [17], [4], [12]. 'Cop' agents have one action Rule C: Inspect all sites within v' and arrest a random 'active' citizen, where v' is the 'cop' vision radius (which may be different from v). Arrested citizens are removed from the simulation space ('jailed') for $J \sim U(0, J_{max})$ cycles (jail term), where J_{max} is set as an input variable.

The strength of Epstein's model lies in its simplicity (just two types of agents with two simple rules for each type), the relevance of the variables chosen for representing the social context (legitimacy) and individual attributes (grievance, hardship and risk aversion), and its explanatory power (intermittent bursts of rebellion, effects of sudden or gradual variation of legitimacy or deterring capability of the central authority, etc.).

2.2 The Effects of Imprisonment Delay, 'News Impact' and Legitimacy Feedback

The model used in the present work is based on an extension of Epstein's ABM of civil violence (Model I) that includes *i*) a time delay for imprisonment, *ii*) a third type of agent called 'media' for representing the 'news impact effect' of the system, and *iii*) and endogenous legitimacy variation [12]. In the ABM developed herein, we combined the imprisonment delay and improved legitimacy feedback with a formulation of network influence effects, in which 'family' influence is modelled via a network of undirected and unconnected cliques (families) and 'news impact' is modelled using a third type of agents, called 'media', working as hubs of a directed star network. This allows a better representation of information propagation and collective behaviour processes related to civil violence in real societies.

3 Model Description

3.1 Synopsis

The ABM used in this work was implemented in NetLogo [16], using the "Rebellion" NetLogo Library Model example [17]. Table 1 shows a summary of the model characteristics, using a subset of the "Overview, Design Concepts and Details" (ODD) protocol [8]. The details of the implementation are described below.

Table 1. Simplified ODD description of the ABM of civil violence with network influence effects

ODD item	Description
Purpose	Introduce network influence effects in an extended version of Epstein's ABM of civil violence with imprisonment delay and legitimacy feedback
Entities, state variables and scales	Agents: 3 types of agents, 'citizen', 'cop' and 'media' with one 'move' and one 'behave' rule Networks: 2 networks, one consisting of a union of directed star networks with 'media' agents as central hubs ('news coverage') and another consisting of a union of unconnected cliques ('family')
Scenario	Homogeneous 2D torus space
Scales	Whole artificial society, undefined time step and patch size Spatial scales in units of patch size: vision radius Time scales in units of time step size: 'fight duration', 'jail term'
Process overview and scheduling	All agents activated once per cycle in random order
Submodels	Legitimacy feedback Aggregation of network influences

3.2 Model Entities

The model entities are the agents, the scenario (spatial domain) and the networks. The scenario is a 2D homogeneous torus space, which is appropriate for an "abstract" ABM [5]. Figure 1 shows the class diagram for all agents in the NetLogo implementation. The 'observer' (i.e. model user) box shows the global parameters and the model's main procedures (`setup` and `go`). The initial densities for 'citizen' and 'cop' agents, number of 'media' agents, simulation duration, vision radius, initial (reference) government legitimacy, maximum jail term, 'fight duration', 'media audience', 'family size', and the influence weights for 'family' and 'news' networks are numeric parameters. The 'legitimacy-feedback' variable F_L is a list with three strings, `''none''`, `''global''` and `''agents''`, used to define the legitimacy feedback mechanism (see figure 1).

'Citizen' agent specification 'Citizen' agents have one move rule and one action rule, and can be in one of the following states: 'quiet', 'active' (rebellious), 'fighting' or 'jailed'. Agents that are not 'fighting' or 'jailed' change state between 'quiet' and 'active' according to their action rule. The move rule is the same as Rule M in the original model.

To formulate the action rule, we need to specify how the agent's own perception is to be aggregated with the information conveyed by the 'family' and 'news' networks, which agent attributes are affected by the network influences, and how the agent's final decision is made. Our proposed solution is based on two conjectures. The first is that an individual decides by aggregating basic (raw) elements instead of information processed by others. This implies, for example, that the

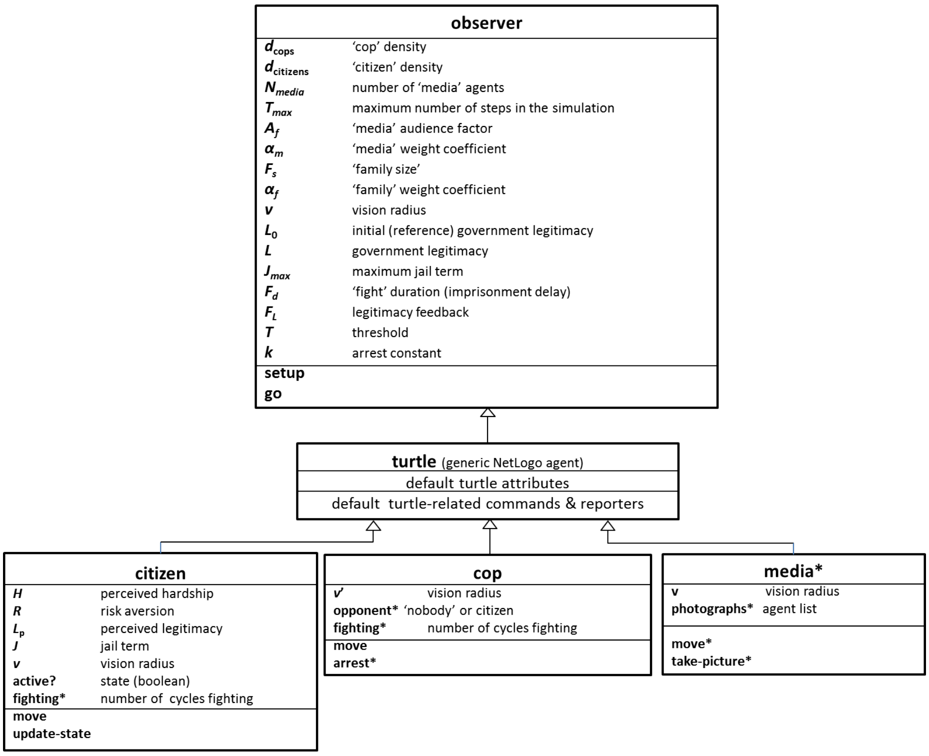

Fig. 1. Class diagram for all agent types in the NetLogo implementation. In NetLogo, agent types are implemented as subclasses of a generic 'turtle' class via the `breed` primitive. Agent types, attributes and methods that are extensions of Epstein's model are marked by an asterisk.

number of rebellious agents seen by 'family members' and 'media' is more relevant in forming the legitimacy perception than the legitimacy perceptions of these individuals. The second conjecture is that *i*) the legitimacy percept (a "latent concept" [6]) is affected by the own perception and network influences, *ii*) the state ('quiet' or 'active') is affected by the own perception and 'family' influence, and *iii*) the estimated arrest probability is affected only by the individual's own perception. This is consistent with the idea that in dangerous situations individuals rely on themselves and their family and when survival is at stake they act on their own. This leads to the formulation of the following two-step action rule (somewhat similar to the two-step rule of the Standing Ovation model of Miller and Page [14]):

Rule A1: if $G - N > T$ be 'active'; otherwise be 'quiet'

Rule A2: if more than 50% of the 'family members' are 'active', be 'active'

where $G = H \cdot (1 - L_p)$ is the level of grievance, $N = R \cdot P$ is the net risk perception, T (constant exogenous variable) is a threshold, $H \sim U(0, 1)$ is the (endogenous) perceived hardship, $L_p \in [0, 1]$ is the "perceived government legitimacy", $R \sim U(0, 1)$ is the (endogenous) risk aversion, and P is the estimated arrest probability computed using the expression

$$P = 1 - \exp(-k \cdot \lfloor C_v/(A_v + 1) \rfloor) \tag{2}$$

where $k = 2.3$ and C_v and A_v are the numbers of 'cops' and 'active' citizens within the agent's vision radius, respectively. 'Active' agents engaged by one 'cop' agent change state to 'fighting' if $F_d > 0$, or 'jailed' if $F_d = 0$. 'Fighting' agents are immobilized for F_d cycles before they are 'jailed'. 'Jailed' agents are removed from the simulation space for J cycles, after which they are reinserted in a random empty site within the simulation space with their state set to 'quiet'.

'Cop' agent specification 'Cop' agents can be in two states, 'non-fighting' and 'fighting'. 'Non-fighting' cops have the same move and action rules as in Epstein's model. In the simulations reported herein, we used that same vision radius for 'citizens' and 'cops' ($v = v'$). If $F_d = 0$ 'cop' agents immediately arrest one 'active' citizen; if $F_d > 0$ they seek one 'suspect', mark it as 'opponent' and start 'fighting' with it for F_d cycles. During the 'fight' both enforcing 'cop' and its opponent are immobilized and at the end of the 'fight' the 'active' citizen is 'jailed' for $J \sim U(0, J_{max})$ cycles.

'Media' agent specification 'Media' agents have the following two rules:

Rule M': If there are any 'fighting' agents within the vision radius v, move to the empty site that is closest to the nearest 'fighter'; otherwise follow Rule M
Rule P: Take one 'picture' of a 'fighter' within the vision radius

Rule M' is a departure from the use of random movement and torus geometry in "abstract" ABM (interaction probabilities independent of position, no clustering emergent patterns), and was used to represent in a very simplistic way the 'agenda setting bias' towards showing violence. In the present version of the model Rule P does not influence the dynamics since neither the legitimacy update nor the 'news influence' depend on the number of 'pictures' recorded by 'media' agents, but this rule is still useful to get information about how efficient the 'news coverage' is.

Networks' specification The 'family' network is set by forming cliques of undirected links between citizens using the `undirected-link-breed` primitive. The clique size is defined by the `family-size` parameter. The 'news' network is set by connecting each 'media' agent to a proportion of 'citizens' defined by the `audience-factor` parameter, via directed links created using the `directed-link-breed` NetLogo primitive. One 'citizen' can be connected to more than one 'media' agent. Both networks remain fixed during the whole simulation.

3.3 Process Overview and Scheduling

The model is implemented in two main procedures, `setup` and `go`, which initialize the simulation and run the main cycle, respectively. The `setup` procedure clears all variables from the previous simulation, initializes the global variables, creates the agents list, builds the 'news' and 'family' networks (if there are any 'media' agents and the family size is greater then one, respectively), displays the simulation space and opens the output file used for post-processing. The `go` procedure implements the main cycle, which consists of the following operations: *i*) test for termination and closing of the output file; *ii*) initialization of global variables that are reset at each time cycle (number of arrests and 'pictures' taken by 'media' agents); *iii*) update the legitimacy; *iv*) run the move and action rules for all 'non-fighting' agents; *v*) decrement F_d for all 'fighting' agents; and *vi*) print the cycle information to the output file.

3.4 Legitimacy feedback

Legitimacy feedback is formulated by expressing the legitimacy as a function of three variables, "legality" (L_{leg}), "justification"(L_{just}) and "acts of consent" (L_{cons}) [6]. The form of the legitimacy function is a key but unsolved question in political science [1], [6]. In the present ABM we considered the following expression

$$L = L_0 \cdot \left(\frac{1}{4} \cdot (L_{leg} + L_{cons}) + \frac{1}{2} L_{just} \right) \tag{3}$$

in which

$$L_{leg} = \frac{n_{quiet}}{N} \tag{4}$$

$$\begin{aligned} L_{just} =& \frac{1}{2} \cdot \left(1 - \frac{n_{active} + n_{fighting}}{N} \right) + \\ &+ \frac{1}{2} \cdot \left(1 - \exp\left[-\frac{\ln(2)}{2} \cdot \left\lfloor \frac{N}{n_{active} + n_{fighting} + n_{jailed} + 1} \right\rfloor \right] \right) \end{aligned} \tag{5}$$

$$L_{cons} = L_{leg} \tag{6}$$

where N is the population size and n_{quiet}, n_{active}, $n_{fighting}$ and n_{jailed} are the total number of 'citizens' in each state. For the theoretical foundations and formulation of these functions, see [6] and [13] respectively.

If F_L is set to `''none''` or `''global''`, the value of L_p is set equal to the value of the global variable L. If F_L is set to `''agents''`, L_p is computed for each 'citizen' agent using equations (3)-(6) with n_{quiet}, n_{active}, $n_{fighting}$ and n_{jailed} replaced by aggregate values obtained using

$$n^*_{active} = \alpha \cdot A_v + \alpha_f \cdot \overline{A_f} + \alpha_m \cdot \overline{A_m} \tag{7}$$

and analogous expressions for n^*_{quiet}, $n^*_{fighting}$ and n^*_{jailed}. In equation (7), A_v, A_f and A_m denote the numbers of 'active' citizens that are 'visible', 'visible by family members' and 'visible in news', respectively; α_f and α_m are the influence weights for the 'family' and 'news' networks; and $\alpha = 1 - \alpha_f - \alpha_m$.

4 Results and discussion

We performed three sets of simulations and compared the results with a reference case run using Epstein's original ABM (Run 2 in Appendix A of [3]). In the first set we investigated the effect of varying the network influences without introducing imprisonment delay and legitimacy feedback. In the second set we combined network influence effects with imprisonment delay and legitimacy feedback, for the same value of initial legitimacy of the reference case ($L_0 = 0.82$). In the third set, we studied the effect of increasing the initial legitimacy ($L_0 = 0.89$). We considered family sizes 3, 4, and 6 and three combinations of 'media' audience and influence factor, to simulate two types of society: 'rural' with numerous families and low 'media' impact, and 'technological' with opposite characteristics. In all cases, we analysed the impact of the newly introduced effects on the system's long term behaviour, and in the cases with punctuated equilibrium or large oscillating peaks of rebellion we studied the waiting time and size of the rebellion peaks. We used a 40×40 torus space, 1120 'citizens' (70% density), 64 'cops' (4% density) and maximum jail term $J_{max} = 30$. Tables 2-4 show the parameters for the three sets of simulations. Legitimacy feedback was computed using equations (3)-(6). We performed ten simulations for each case, with a duration of 2000 cycles in the first and second sets and 5000 cycles in the third set (due to the difficulty in determining the long-term behaviour).

Table 2. Parameters and system's long term behaviour for the first set of simulations. E1 is the reference case. Case E1F includes only a 'family' network and case E1N only a 'news' network. Cases E1-LF-WM and E1-SF-LM simulate societies with large family size and influence and poor 'media' coverage and small family size and influence and large exposure to 'media', respectively.

	E1	E1F	E1N	E1-LF-WM	E1-SF-LM
L_0	0.82	0.82	0.82	0.82	0.82
num. Media	2	2	2	1	2
m. audience	0	0	20%	10%	20%
α_m	0.0	0.0	0.1	0.1	0.2
family size	0	4	4	6	3
α_f	0.0	0.4	0	0.4	0.1
Behaviour	punctuated equilibrium	punctuated equilibrium	punctuated equilibrium	punctuated equilibrium	punctuated equilibrium

Figure 2 shows plots of the simulation space for two runs of different cases. These plots allow a suggestive visual interpretation of the spatial distribution of the 'news' network coverage (weak in the first case, strong in the second) and imprisonment delay ('cops' and 'agents' involved in temporary fights, one 'media' agent near 'fighting' agents, plotted in a larger size).

Table 3. Parameters and system's long term behaviour for the second set of simulations. Cases F2 and F3 include only 'family' networks, cases N1 and N2 only 'news' networks, and cases NF1 and NF2 include both types of influences, considering homogeneous (global) and heterogeneous (agents) legitimacy feedback.

	F2	F3	N1	N2	NF1	NF2
L_0	0.82	0.82	0.82	0.82	0.82	0.82
F_d	0	0	0	1	0	0
feed. mech.	global	agents	agents	global	agents	global
num.media	0	0	2	2	2	2
m. audience	0%	0%	20%	20%	20%	20%
α_m	0.0	0.0	0.1	0.1	0.1	0.1
family size	4	4	0	4	4	4
α_f	0.4	0.4	0.0	0.4	0.4	0.4
Behaviour	violence peaks no calm periods	violence peaks no calm periods	violence peaks no calm periods	permanent rebellion	permanent rebellion	permanent rebellion

Table 4. Parameters and system's long term behaviour for the third set of simulations. Cases F2L089 and F3L089 include family influence only, whereas cases NF1L089 and NF2L089 include both types of influence ('family' and 'news').

	F2L089	F3L089	NF1L089	NF2L089
L_0	0.89	0.89	0.89	0.89
feed. mech.	global	agents	agents	global
num.media	2	2	2	2
m. audience	0%	0%	20%	20%
α_m	0.0	0.0	0.1	0.1
family size	4	4	4	4
α_f	0.4	0.4	0.4	0.4
Behaviour	tipping point indefinite	violence peaks no calm periods	violence peaks no calm periods	tipping point indefinite

Table 5 shows the mean value and standard deviation of the waiting times and peak sizes of the rebellion peaks (maximum number of 'active' agents in large bursts of violence) for the simulations of the first set.

It can be concluded that in Epstein's ABM the periodicity of the rebellion peaks is determined by the jail term parameter. Introduction of network influences does not change either the system's long term behaviour (see table 2) or the waiting times between rebellion peaks, but significantly increases the peak sizes. This is particularly notorious for the case of small 'family' and large 'news' influence, such as in modern technological societies where people tend to stick to TV and SN in detriment of family contact.

Imprisonment delay and legitimacy feedback had a larger impact and changed the system's long term behaviour in several ways (table 3). Increasing the initial legitimacy (table 4) lead to complex solutions. Figure 3 shows that in case F2L089, the system was near a tipping point, with indefinite long term behaviour, alternating between long periods of calm and turmoil. Such alternations

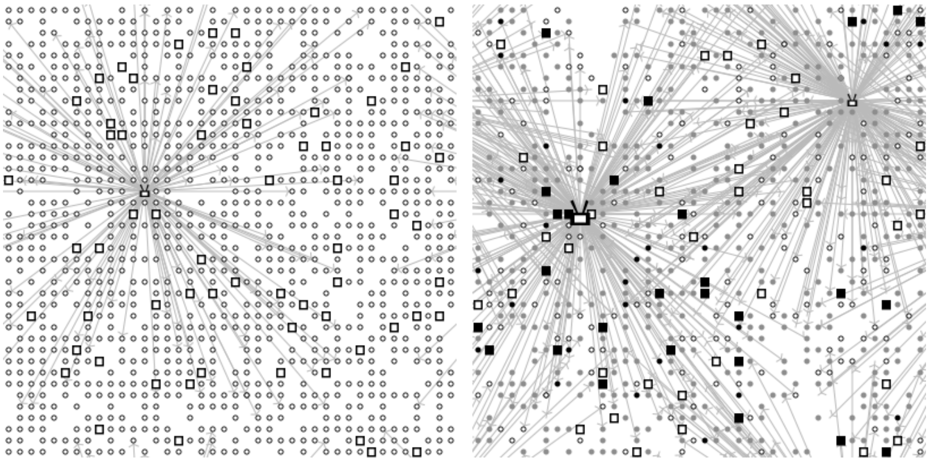

Fig. 2. Plots of the simulation space for runs of cases E1-LF-WM (left) and N2 (right). 'Quiet', 'active' and 'fighting' agents are represented by white (hollow), grey and black circles, respectively. 'Jailed' agents are hidden from view. 'Fighting' and 'non-fighting' cops are represented by white (hollow) and black squares, respectively. 'Media' agents are represented by small TV icons, which are larger when they are 'taking pictures'. 'News' links are represented in light grey and 'family' links are hidden from view.

Table 5. Mean value and standard deviation of the waiting time and peak size, for the first set of simulations

	wait. Time μ	wait. Time σ	peak size μ	peak size σ
E1	29.2	8.7	252	85
E1F	30.2	7.7	348	117
E1N	31.6	8.0	360	109
E1-LF-WM	31.0	8.7	311	110
E1-SF-LM	32.1	7.48	504	153

occurred after hundreds of cycles in an unpredictable way. In real societies, apparently stable authoritarian regimes may suddenly face large rebellions and in democratic regimes we often observe alternating periods of calm and protests.

5 Conclusions

We presented an extension of Epstein's ABM of civil violence with network influence effects associated with two different networks, 'family' and 'news', including two other effects, imprisonment delay and endogenous legitimacy variations. We performed three sets of simulations to study the effects of *i*) network influence for different network sizes and influence factor, *ii*) legitimacy feedback and imprisonment delay, and *iii*) variation of the initial legitimacy, combined with network

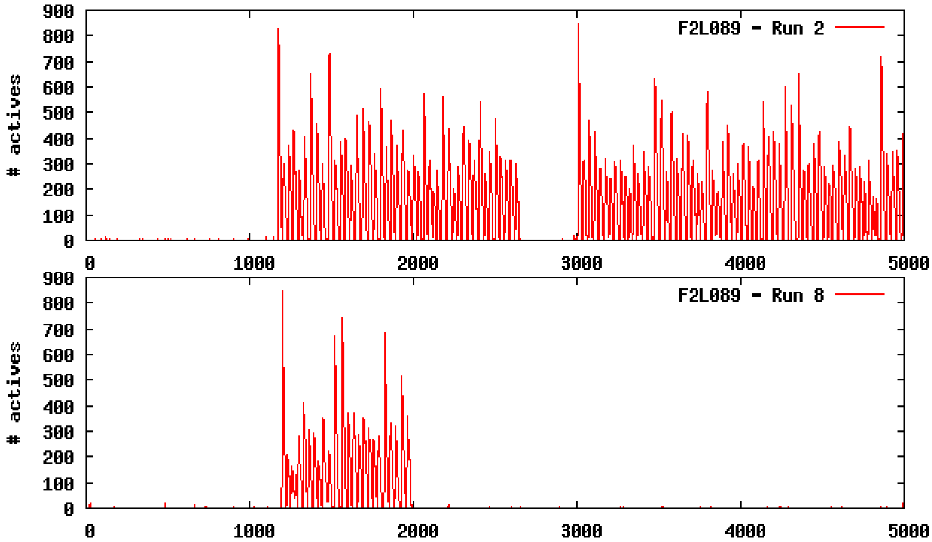

Fig. 3. Time history of number of 'active' citizens, case F2L089, run 2 and run 8.

influences and legitimacy feedback, and compared the results with a reference case run using Epstein's model.

The results from the first set showed that network influences did not change either the system's long term behaviour or the periodicity of violence bursts, but increased their size, particularly for small 'family' and large 'news' influence. The simulations of the second set showed that the introduction of legitimacy feedback changed the system's long term behaviour from punctuated equilibrium to bursts of violence with no calm periods or permanent rebellion. For the third set of simulations the solutions showed a very complicated behaviour with unpredictable alternations between long periods of calm and turmoil occurring after several hundreds of cycles. These results reinforce the conjecture that network influences by themselves do not trigger revolutions, but amplify their size (first set of simulations). Legitimacy variations and their relationship with the model's parameters and dependent variables (i.e. the social context in real situations) are more important, for they determine the system's behaviour in very complicated and sensitive ways. Thus, networks are important for triggering uprisings only if their existence contributes for changing the perceived legitimacy (second and third sets of simulations), which in real situations depends on their size, structure, influence, and information content.

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