Annex 1: Supplementary material

Technical Implementation and Interface

The agent-based model was coded in the open-source, multi-agent modeling environment Netlogo 6.4. We extended and adapted a pre-existing implementation of Epstein's civil violence model that was included in the model library (all original parameters were adopted), then iterated through multiple prototypes. The user interface can be seen in Figures 1 and 2 and will be explained below.

According to the explanations in the article, in Fig. 1 and 2 we see the representation of elements integrating the simulation environment and agents:

- Quiet agents are green,
- Agitated agents are red,
- Violent agents are **black**,
- Jailed agents are represented by brown dots,
- Cop agents are blue police cars,
- Visible cameras are represented by large targets with an adjustable light blue range of vision,
- Hidden cameras are identifiable by small targets with an adjustable yellow range of vision.

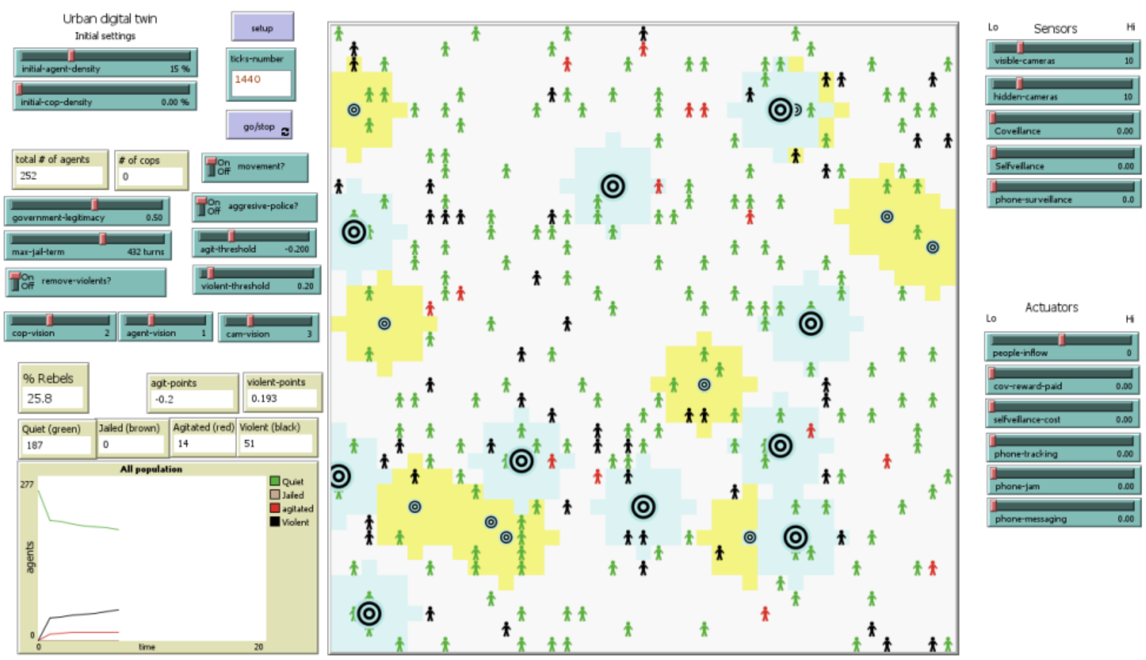

Figure 1: GUI of the agent-based model with "initial-cop-density" = 0. Features both types of surveillance cameras as well as quiet, agitated and violent agents.

The square in the middle of the GUI (Fig. 1-2) is the grid on which the simulation takes place. On the left side, general starting conditions can be determined by the user. On the right side, one may adjust the influence of sensors and actuators. All sliders except "initial-agent-density" and "initial-cop-density", which can be adjusted only before setup, may be changed either before the start of the simulation or during runtime. Note that the plot and the gauges in the lower left corner-were added to monitor certain values while the simulation was running and have no influence on the way the model functions.

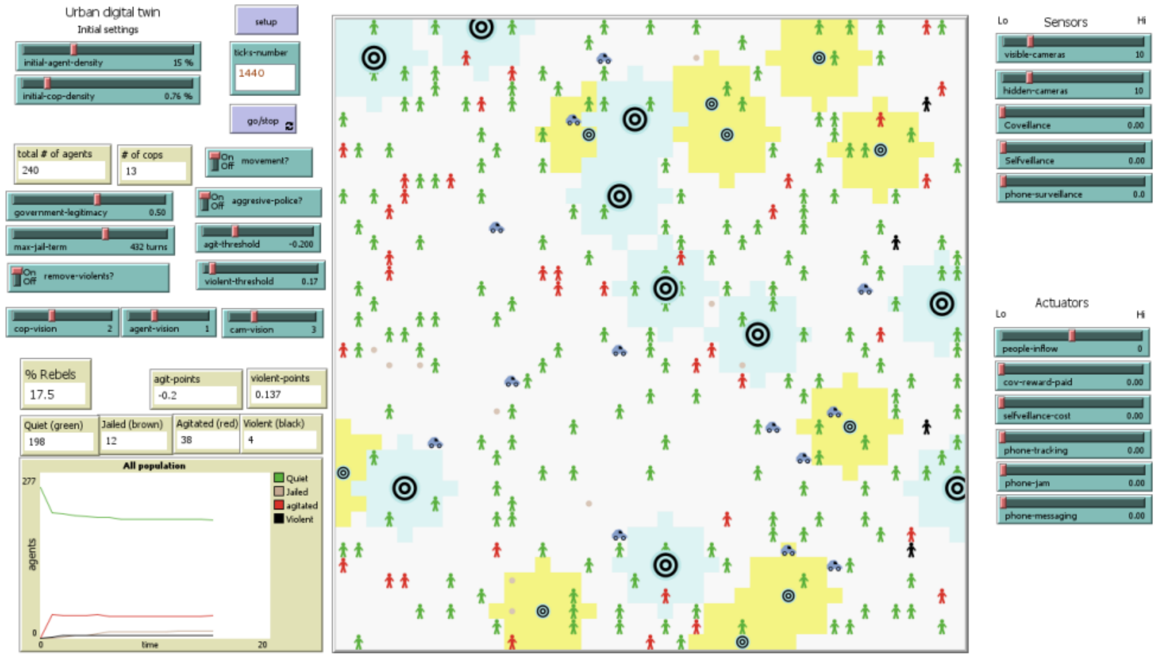

Figure 2: GUI of the agent-based model with a non-zero initial cop density. Features both types of surveillance cameras as well as quiet, agitated, jailed and cop agents.

Time cycle

We now move on to explain which commands the simulation executes at each time step. The model makes no use of empirical data or external files. As with most agent-based models, we are more interested in qualitative relationships than quantitative measurements. Hence, the ranges and default values are largely arbitrary, determined by trial and error, though we ensured that variables of a similar category (e.g. the camera or surveillance types) had a similar range to render them comparable. In accordance with model fitting literature, we tested the upper and lower bounds for plausibility, as exceeding them might lead our submodels to produce incoherent results (Railsback, 2019). We also performed basic plausibility checks to ensure realism (e.g. no instantaneous violence outbreaks). In the table below, we see the default values of the global variables prior to each run.

Variable Name	Description	Default Value	Range
visible-cameras	C_v: number of visible cameras	10	[0,50]
hidden-cameras	C_h: number of hidden cameras	10	[0,50]
coveillance	Cov: Coveillance	0.0	[0.0, 10.0]
selfveillance	S: Selfveillance	0.0	[0.0, 10.0]
phone-surveillance	p_s: data mining through phones	0.0	[0.0, 10.0]
people-inflow	i	0	[-10,10]
cov-reward-paid	Cov_{paid}: Paid coveillance reward	0.0	[0.0,0.3]
selfveillance-cost	S_{cost}: Selfveillance cost	0.0	[0.0,0.3]
phone-tracking	p_t: targetted phone espionage	0.0	[0.0,0.5]
phone-jam	p_j: blocking phone communication	0.0	[0.0,0.5]
phone-messaging	p_m: sending phone messages	0.0	[0.0,1.0]
initial-agent-density	d_p: % of population agents	15	[0,50]
initial-cop-density	d_c: % of cops	0.0	[0.0, 5.0]
ticks-number	T: duration of simulation	1440	–
movement?	Do cops move?	on	on, off
government-legitimacy	L	0.5	[-0.1,0.99]
max-jail-term	T_j	432	[0,720]
remove-violents?	Can cameras trigger violent agent removals?	on	on, off
aggressive-police?	Do cops arrest agitated agents?	on	on, off
agit-threshold	t_{agit}: threshold to turn agitated	-0.2	[-0.5,0.5]
violent-threshold	t_{vio}: threshold to turn violent	0.2	[0.0,2.0]
cop-vision	V_{cop}: cop vision radius	2	[0,5]
agent-vision	V_{pop}: population vision radius	1	[0,3]
cam-vision	V_{cam}: cam vision radius	3	[0,10]

Table 1: Description of global variables with initial values and ranges.

At each tick, two procedures (i.e. methods) are called in succession.

1. setup

Resets all variables from the previous simulation to either default or user-defined values. The new perceived government legitimacy L is calculated as follows, with L_{user} being determined by the user through the interface: Then, new population and cop agents with default values are created. The number of created cameras is fixed

$$L = L_{user} + S_{cost} - Cov_{paid}$$

by the user-defined variables "hidden-cameras" and "visible-cameras" respectively. Cop (and population numbers) are calculated by multiplying initial cop (or agent) densities with the number of total patches, i.e. 1600. The procedure subsequently calls a function that displays the agents on the user interface. Furthermore, an error message will be generated if the sum of the initial cop density and the initial population density exceeds 100%. This was implemented to accommodate the user, in case they make a mistake when manually adjusting these values in the GUI.

2. go

This procedure executes the main cycle of the simulation, advances the time and updates any plots in the GUI. Additionally, it is capable of informing the user of e.g. overpopulation when a maximum number of agents is exceeded, in this case set to 1400. Each agent on the grid then displays different behavior, depending on its status.

- Population agent (not jailed): Every population agent that isn't jailed will call the "move" procedure. If they are violent, an additional method, "move-violent", is called afterwards which determines further behavior. Then, their new state is identified and changed according to the procedure "determine-behavior", followed by an update of their visual representation.

- Population agent (jailed): If a citizen is jailed and "jail-term" > 0, said variable is reduced by 1, i.e. it reduces the number of ticks the agent must still remain inactive for. Otherwise, it is set to 0, i.e. the agent is freed.

- Cops move to a random, unoccupied patch within their range of vision. Afterwards, the "enforce" procedure is called and their visual representation is updated.

If the current number of cops is lower than 20% of the initial cop numbers, reinforcements are called (i.e. a random number of cops between 0 and the initial cop density is created), which are then distributed randomly across the grid. Cop numbers may drop due to attacks by violent agents. Furthermore, every 60 ticks (i.e. every ten minutes) "add-agents" is called. Every 30 ticks, the procedure checks: if people-inflow > 0, then new agents are added. If people-inflow <0 and there are more than 50 agents in total, "reduce-agents" is called.

Submodels

The term "submodels" describes the remaining Netlogo procedures that are called by "setup", "go", etc. They can be grouped into four categories. Firstly, procedures concerning the creation and removal of agents:

- add-agents: Creates new, randomly distributed population agents and assigns them default values. Risk aversion and perceived hardship are set to a random float value between 0.0 and 1.0. Furthermore, all agents are by default quiet with a jail term of 0. The number of new agents is determined by "people-inflow".

- reduce-agents: Randomly selects a number of population agents according to "people-inflow" and permanently removes them from the grid.

Secondly, procedures concerning agent movement and related behavior.

- move
  Moves an agent (either a regular citizen or a cop) to a random patch within their range of vision, as long as it isn't occupied by an active agent. Note that jailed agents and cameras are considered inactive. Therefore, it is possible to share a patch with them. If there are at least six violent agents in the neighborhood of a cop, the latter gets incapacitated and removed from the grid.

- move-violent
  Dictates further behavior of a violent agent after moving. If there are less than 30 other violent agents on the grid, it will try to stay out of sight of visible cameras. Else, the agent will be bold enough to enter the camera's range of vision. Additionally, if over 120 ticks have elapsed, it will have gained the confidence to destroy the camera. Note that if a hidden camera was located within the destroyed camera's range of vision it will cease its function as well. Lastly, this is also the procedure which ensures that violent agents will be removed by cameras, if they are located within the range of vision and 60 ticks have elapsed.

  - Enforce

  Determines cop behavior. Like in Epstein's simulation, at each tick a cop scans its radius of vision. If "aggressive-police?" is toggled on, its will search for both violent and agitated agents. If it spots one, it moves to the same patch and jails them. Violent agents are punished with the maximum jail term (set by the user). The jail term of agitated agents is a random number within the range of [0, $\frac{maximum\,jailterm}{2}$]. If "aggressive-police?" is toggled off, cops will only seek out violent agents and proceed as just described.

Thirdly, procedures that determine agent status.

Determine-behavior calculates "agitation-points", which in turn decide whether an agent will cross t_{agit} and change its state from "quiet" to "agitated" or vice versa. It also determines "violent-points" which, analogously to "agitation-points", decides whether an agent will turn violent. "violent-points" is the sum of "rebel-points" (explained in the description of the corresponding procedure) and "agitation-points". If it is larger than t_{vio}, the agent turns violent, else it retains its old state.

It must be emphasized that the calculation of agitation points and rebel points utilize different sets of parameters and weights. Sometimes variables they have in common can have opposing effects. Note that in order to turn violent, an agent must therefore fulfill one of three conditions: very high rebel points, very high agitation points or a medium mix of both. The decision to include two sets of points with a single respective threshold, instead of one set of points with two thresholds, was made to increase realism. After all, not every agitated, i.e. displeased, citizen is bound to turn violent, while not every violent citizen requires high levels of dissatisfaction to act on their destructive desires. Thus, e.g. a quiet agent with strong violent tendencies might "skip" the agitation state and turn violent immediately when certain conditions are fulfilled, though that happens rarely.

For our purpose, we tried to keep the formulations that calculate agitation and rebel points as simple as possible by giving them the form of weighted sums. They were developed with the following methodology: 1) identification of relevant parameters; 2) determining the qualitative effect of each parameter (positive or negative sign); 3) determining the weight of each parameter. This is accomplished through calibration, i.e. running the simulation numerous times while varying only a single parameter and observing subsequent changes in the simulation.

In this research, we are working with ambiguous parameters that might have non-linear forms, meaning that they are inherently difficult to measure and evaluate by hard metrics. Furthermore, agent-based models can not be simply fit to empirical data due to their relative complexity (e.g. inclusion of numerous entities and sub-processes). They do not require precise calibration to yield interesting results. Therefore, choosing specific parameter values is more comparable to “fine-tuning” the model than fundamentally altering its behavior (Railsback, 2019).

This process does not yield a single, objectively correct equation and is somewhat reliant on the calibrator’s worldview as well as the information they have access to. Certainly, one could easily choose different parameters and values. We would therefore like to restate that, based on prior literature and educated guesswork, we deem our formulations to merely be a “first step” that can and should be supplemented by further research (e.g. by adapting the equations or re-calibrating the model based on data from real civil violence outbreaks).

Having discussed our methodology, we can now resume the explanation of our procedures. Agitation points are calculated as follows:

$$\frac{1}{12}[2(G-PR)+r_a-\frac{(C_v+C_h)}{2}-\frac{Cov}{5}-Cov_{paid} \\ -\frac{S}{2}+S_{cost}-\frac{p_s}{10}-1.5p_t+3.5p_j-3p_m-\frac{T_j}{200}]$$

With r_a being the value procedure "reds-around" returns. The variable G and PR stem from Epstein’s model, representing grievance and net risk term (N = PR) respectively. Note that originally, $G-PR$ was the value that determined whether an agent would switch from quiet to active. Said term, being in close proximity to other agitated agents and blocked phone communications increase agitation. However, video surveillance, coveillance, coveillance reward, selfveillance, high jail terms, phone surveillance/tracking/messaging all act as deterrents. Though citizens are not aware of the exact number or locations of hidden cameras, there may still be a general consciousness of their existence through media or the citizens' social environment. Therefore, we decided to take the existence and number of hidden cameras into consideration in our formulations. This admittedly simplistic modeling could be refined in future research, e.g. by considering the gap between perceived and actual hidden surveillance or the perceived reliability of a citizen's source of information.

Rebel-points is a procedure that calculates a weighted sum. As previously explained, these l points are then added to agitation points in the function "determine-behavior" to calculate "violent-points", which in turn decide an agent's state.

The rebel points are calculated as follows:

$$\frac{1}{10}[1.3(1-L)+2(G-PR)+j_a+\frac{C_v+C_h}{10}+\frac{Cov}{5}-\frac{S}{2}+3vio+p_a]$$

With the following relationships:

- Jail rate: $j_a = \frac{\#JailedAgents}{\#Agents_{total}}$
- Phone actuation: $p_a = p_t - p_j + p_m$ defines the cumulative effect of phone-based actuators. Note that phone jamming is negative, i.e. it reduces rebel points.
- Violent Tendency: vio expresses an innate or acquired proclivity for violence. It is a random value assigned to each agent upon creation and was added to make the model more realistic. It is calculated by generating a random float value between 0 and 1, from which 0.2*agent vision is subtracted to take the deterring effect of cameras into account.
- L: Identical to Epstein's model, representing perceived government legitimacy.

The equation was developed through the same method as before. High jail rate, coveillance, being monitored (either by video or through your phone) and a violent streak are all factors that would contribute to civil violence outbreaks. The term 1.3(1 – L) does not correspond directly to Epstein's "grievance" metric (which is taken into consideration in the next term in the form of variable G) but emphasizes the importance of government legitimacy by weighting it more strongly. This decision is explain in the main article section 2.3. As previously mentioned, $G - PR$ is another expression that determines whether an agent turns agitated, i.e. the addition of 1.3(1 – L) merely strengthens Epstein's original formulation. Conversely, selfveillance would discourage an agent from becoming violent.

Lastly, we discuss auxilliary procedures employed.

- Rebel-percent – civil violence rate: Divides the sum of agitated and violent agents by the total number of agents. Ignores all jailed agents. Used for plotting.

- Various display methods: The procedures display-agent, display-agent-2d, display-cop, display-camera and display-camera-hidden all assign a color and shape to the respective agents. The vision range of the cameras is colored to provide better visualizations.

- Reds-around: Reports whether more than three agitated or violent agents are in the neighborhood of a given population agent (if so return 0.1, else return 0).

- Grievance: Calculates grievance in the same way as Epstein's model.

- Estimated-arrest-probability: Calculates the estimated arrest probability for a limited vision radius like in Epstein's model. Note that "C", originally the cop number, is now calculated as the sum of active cops and cameras on the grid. "A" now describes the sum of agitated and violent agents. The arrest constant k is identical to Epstein's and defined at the beginning of the simulation.