Model Overview
In the model, there are two types of agents placed on a grid: citizens and police. Citizen agents have a “criminal” flag, such that if their “grievance” is above some threshold, the flag is set to “active”. Citizens and police move around the grid, and if a police agent sees a criminally-active citizen, the police agent “arrests” the citizen, removing it from the model for a random period of time up to the maximum jail term.

Funding will be shifted between police spending and social spending. Shifting funds to the police and away from social spending increases a “hardship” parameter, which is a factor in determining grievance, but also increases the number of police agents in the grid. Shifting funds in the other direction has the opposite effect.

The model will be run many times with different settings for the funding slider, and the average number of active citizens per day for that run will be recorded (this is a metric used in Fonoberova et al., 2012).

The model parameters are calibrated on real-world data to address one of the concerns about agent-based models raised by Groff et al. (2019).

Model Design and Parameters
The citizen agents’ grievance is taken exactly as in Epstein’s (2002) model, that is:

$G = H(1-L)$, where,

G = Grievance
H = Hardship
L = Legitimacy.

Citizen agents are also averse to the risk of being arrested. Each citizen agent has a base risk aversion parameter (K) drawn between 0 and 1. A value of 1 indicates that the agent is very risk-averse while a value of 0 indicates that the agent has zero risk aversion. Perceived arrest risk is also impacted by the number of criminals and the number of police in the agent’s vision radius. Seeing more criminals means a lower arrest risk while seeing more police means a higher arrest risk.

The perceived risk function, as seen in both Epstein (2002) and Fonoberova et al. (2012) is given by:

$P = 1-\exp(-kC/A)$ where:

k = -9 (empirically-tuned parameter from Fonoberova et al. rounded to one digit.)
C = Police agents in a citizen’s vision radius
A = Criminally active citizens in a citizen’s vision radius

The net risk parameter (N) is a combination of the risk aversion constant and the above risk function, such that:

N = KP

A citizen becomes criminally active when G - N > T, where T is a criminality threshold, drawn for each agent between 0 and 1. An active citizen ceases to be active when G - N < T

So far, all of these parameters have followed Fonoberova et al. (2012) and Epstein (2002). The main difference is that L is a global parameter in those models and a dynamic individual one here. We introduce a few additional parameters. The full list is shown in table 1.

Table 1: List of parameters used in the model

Parameter	**Description**	**Value/Range**	**Source**
Hardship (H')	Baseline hardship. Contributing factor to criminality, affected by social spending	0 to 1	Epstein (2002)
Legitimacy (L')	Initial legitimacy. Contributing factor to criminality, affected by police presence	0 to 1	Epstein (2002)
Risk aversion (K)	Willingness to become an active criminal when chance of arrest is high	0 to 1	Fonoberova et al. (2012)
Criminality threshold (T)	Threshold to determine when a citizen becomes an "active" criminal	0 to 1	Epstein (2002)
Initial social budget	Initial social budget	$2250 per citizen	Urban Institute (2020), Tax Policy Center (2021)
Fraction citizens	What fraction of the grid is populated by citizen agents	70%	Initial condition similar to Epstein (2002) and Fonoberova et al. (2012)
Fraction police	What fraction of the grid is populated by police officers	Determined by police budget, baseline value is 0.36%	Federal Bureau of Investigation (2019) Full-time law enforcement employees
Legitimacy impact multiplier (X)	Percent that legitimacy is decreased when police are active in an area	0-20%	Sensitivity analysis test parameter
Hardship multiplier (M)	Percent reduction in Hardship as a function of Social spending	0-100%	Sensitivity analysis test parameter
Cost per officer	Annual cost of a police officer	$150000	See discussion
Police vision	Radius of cells that police agents can see	16	Initial condition

Citizen vision	Radius of cells that citizen agents can see	14, 16, 18	Lower, same, and higher than police vision as in Fonoberova et al. (2012)
Police Budget Multiplier	Multiplies the initial police budget	0-3	Main test parameter
Maximum Jail Term	Maximum jail term for arrested citizens	30	Epstein (2002)

The initial social budget is set at $2250 per citizen agent. This approximates the value we see in the real world, which is roughly $2264 spent per citizen on average on public welfare expenditures (Urban Institute 2000, Tax Policy Center 2021). In principle, we could also have included education and health expenses in this number, since the social budget is what determines “hardship” in our model, and health and education can impact hardship. However, not every dollar spent on public welfare goes to reducing hardship, nor does every dollar spent on education. We assume these effects roughly cancel out and perform sensitivity analysis on this parameter to see how much of an impact this decision has.

The other budgetary parameter we use is the cost per police officer. This also varies by location, but several sources point to a similar range of values. Chicago’s ward 43 alderman put out a detailed breakdown of the annual cost of a police officer (Chicago ward 43, 2015), including equipment and supervision, and came up with a value of $149,362. The Boston Police Department has an annual budget of roughly $400 million (City of Boston 2021) and has roughly 2139 uniformed officers (Federal Bureau of Investigation 2019), leading to an annual cost per officer of around $187,000. Some of these costs will be fixed and some unrelated to actual policing, so it makes sense that the number is a bit high. Our estimate of $150,000 per officer is in line with what we’d expect in an urban police department. Small deviations from this number didn’t substantially change the behavior of the model.

The spending per officer and per citizen need to be multiplied by the number of officers and number of citizens respectively. We use a grid size of 100 x 100 for 10,000 total cells. 70% are occupied by citizens, for 7000 total. The initial number of police agents is 25, which is 0.36% of the citizen agents. That number lines up closely to the number of police officers per capita in the FBI’s Uniform Crime Reporting data (2019). This leads to a baseline budget of $19,500,000, where $15,750,000 is for social welfare and $3,750,000 is for police. The ratio between the two, 4.2, lines up well with real-world data, as seen in Figure 2.

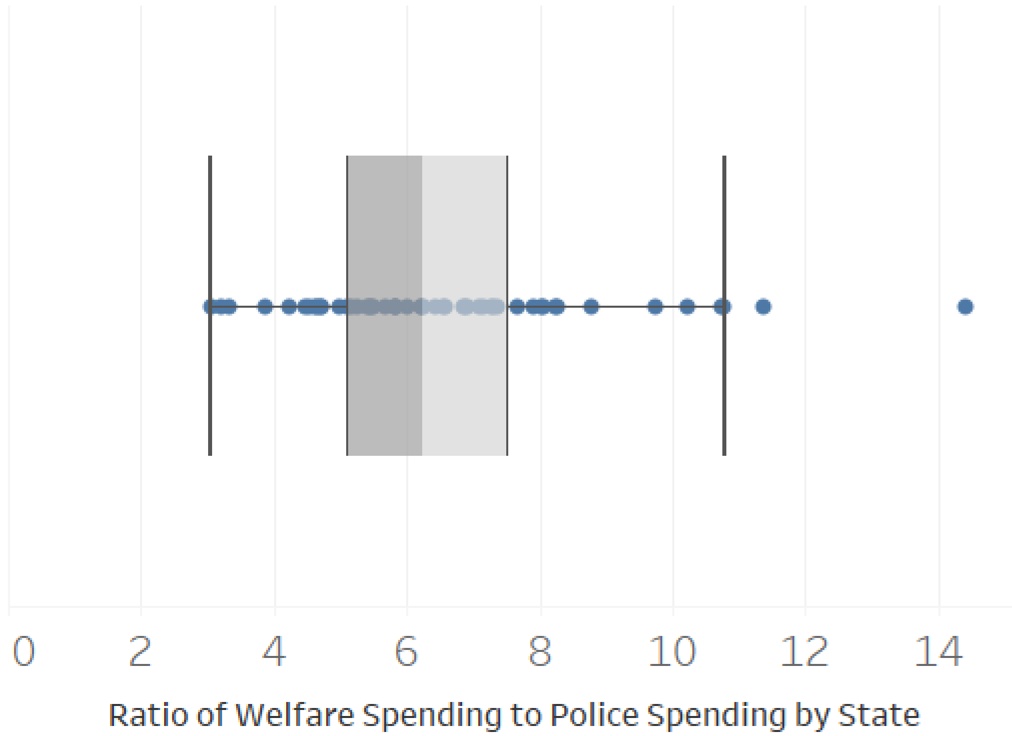

Figure 1: *Ratio of public welfare spending to police spending by US state. Spending data is from Tax Policy Center (2021). The baseline spending ratio in our model is 4.2*

A key part of the model is dynamic legitimacy. When police make an arrest, citizens nearby (determined by their vision) will have their view of legitimacy reduced by the legitimacy impact multiplier. In other words, L = L' * (1-X).

This isn't necessarily realistic. Weisburd & Telep (2014) show in their summary article that in some cases police activity increases the view of police legitimacy of the citizens, especially among those with a high view of legitimacy to begin with and among affluent citizens (low hardship). In our model, those with a high view of legitimacy and low hardship are unlikely to become active even if L decreases by a small percent. Thus, it doesn't matter whether L increases or decreases for them if they don't become criminally active either way. However, those with a high H, low L, or both (as is often the case in disadvantaged communities), are more likely to become an active criminal when L is lowered further, and this lines up well with previous research (as outlined in section 2.2). We perform sensitivity analysis on X, not only to test the robustness of the model but also as a policy lever. As noted earlier, different police tactics can affect the view of police legitimacy, and this parameter gives us a way to model that.

At the end of each tick of the model, half of the missing legitimacy is recovered, meaning:

L = L + (L'-L)/2

This means that occasional encounters with police won't have a lasting impact, but repeated interactions (like in hot spot policing) will add up over time.

Police vision is set to 16, which means at each step they look in a 16 cell radius to see whether there are any active criminals to arrest. Citizen vision determines net perceived risk and the legitimacy impact of seeing police arrests. Citizen vision was tested at a little lower than, the same as, and a little higher than police vision. This was previously tested in Fonoberova et al. (2012) and found to be significant with regards to the level of crime. With the addition of dynamic legitimacy tied to citizen vision, we expect this to be an important parameter.

The main funding lever is the police budget multiplier. The police budget is determined by the initial police budget ($3,750,000) multiplied by the police budget multiplier. The number of police agents on the grid is equal to the total police budget divided by the cost per officer, rounded down. Increasing the police budget decreases social funding.

As social funding changes, so does hardship. Each agent is assigned a baseline hardship value from 0 to 1, which is then modified by the level of social funding, such that:

$H = H' * \exp(M * (1-(SB/2250)^2))$,

where SB is the social budget per citizen. This is calculated by taking the initial budget of $19,500,000, subtracting the total police budget, and dividing it by 7,000 (the number of citizens). M, the hardship multiplier, is used to test the sensitivity of our model to the assumption that hardship actually changes as the budget changes.

This functional form was chosen so that hardship was bounded as the social budget went to 0. The functional form of $H = H' * (2250/SB)$ was also tested, but that leads to infinite hardship as SB goes to zero.