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GLODERS-S: a simulator for agent-based models of criminal organisations

Luis Gustavo Nardin[1,2] · **Áron Székely**[1] · **Giulia Andrighetto**[1,3]

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Abstract Computer simulation has recently been recognised by criminologists as a useful tool for bridging the gap between theoretical and empirical analyses of organised crime and for supplementing their weaknesses. GLODERS-S is an innovative and configurable agent-based simulator specialised in reproducing the dynamics of a specific type of criminal organisations: protection racketeering groups. The simulator adopts an event-based approach that provides a more realistic operation of the agents, which integrated with its configurability provides policy-makers with a highly flexible platform for analysing multiple scenarios and assessing policies to counter organised crime. In this paper, we describe the principles of the simulator design, its features and limitations, and possible applications.

Keywords GLODERS-S · Protection racketeering · Criminal organisations · Agent-based simulation

✉ Luis Gustavo Nardin
gnardin@uidaho.edu

Áron Székely
aron.szekely@istc.cnr.it

Giulia Andrighetto
giulia.andrighetto@istc.cnr.it

[1] Italian National Research Council, Institute of Cognitive Science and Technology, Rome, Italy

[2] Center for Modeling Complex Interactions, University of Idaho, Moscow, ID, USA

[3] Department of Political and Social Sciences, European University Institute, Fiesole, Italy

Introduction

Criminal organisations are difficult and risky phenomena to investigate. The secretive nature of their activities makes it hard to uncover reliable empirical data about their operations and dynamics. While indispensable, data extracted from police and judicial documents may be biased and they represent an incomplete picture of the organisation. Similarly, fieldwork-collected data can also suffer various biases (Siegel 2008). Verbal and analytic theoretical models have limitations too: the former are not deductively secure, while it is difficult to represent and analyse complex interactions with heterogeneous agents with the latter.

To complement these traditional empirical and theoretical approaches in the study of criminal organisations, criminologists have recently started using computer simulations (a comprehensive description of models of crime can be found in Liu and Eck (2008), and Groff and Mazerolle (2008)). Computer simulations help to bridge the current gaps of both analytic theoretical models and empirically-based approaches (Eck and Liu 2008; Gerritsen 2015; Malleson and Evans 2013). Simulation models allow us to formally represent and analyse each entity involved in the dynamics of criminal organisations as well as the mechanisms driving their behaviour. This formal representation deepens our understanding of such organisations' dynamics and the major factors determining them. Additionally, computer simulations can function as key tools that provide a data source with which to compare or enrich empirical data, bolstering or conflicting with what has already been found. Thus, they can be used as checks for what has been found providing further reassurance in case there is congruence, or as warning flags when incongruence occurs.

Agent-Based Modelling (ABM) is a computational technique that enables researchers to create models composed of agents interacting within an artificial environment, experiment with the system and agents, and analyse the resulting outcomes (Conte et al. 1997; Gilbert 2007; Gilbert and Conte 1995). Agents are usually defined as entities that behave on the basis of mechanisms and representations incorporated into them. ABM may be used to evaluate how different initial conditions and behavioural mechanisms affect the resulting outcomes. Thereby they enable (i) users to gain a deeper understand of the system's causal relationships and (ii) policy-makers to analyse the effects of different policies in silico before intervening on the real system. ABM has a number of important strengths that make it a useful tool for simulating criminal organisations and their dynamics (Malleson 2012).

First, ABM is a powerful modelling tool that has been successfully used since the end of the 1970s to study diverse social phenomena and collective action problems (Axelrod 1984; Davidsson 2002; Epstein and Axtell 1996; Li et al. 2008; Schelling 1978). In economics, it has been used to understand and forecast market dynamics emerging from the interaction of self-interested agents (Albin and Foley 1992) and more recently to help guide the development of financial policies (Farmer and Foley 2009). Public health has also benefited from ABM for evaluating and forecasting public health policy outcomes in the control of infectious diseases epidemics (Liu et al. 2015; Marathe et al. 2011). The ability of ABM to help understand these kinds of phenomena originates from its capacity to (i) represent individual and social entities (i.e., human individuals, groups, and institutions) and their nonlinear interactions; (ii) represent multiple scales of analysis ranging from individuals' behaviours (i.e., microlevel) to social level (i.e., macro-level); and (iii) capture the emergence of structures resulting from the nonlinear interactions of these entities (Bonabeau 2002). Second, ABM not only helps us to understand how social systems, like criminal organisations, work, but it also enriches our knowledge of how to influence their activity. For example, they can be used to testbed policies – a luxury rarely afforded to empirical researchers – and assessing hypotheses in a controlled artificial setting. Third, ABM is particularly suited for studying dynamics that result from the integration of mental and social processes as it allows the explicit representation of agents' mental states (i.e., beliefs, goals, and intentions) and the analysis of how they affect, and are affected, by the agents' social interactions.

The first generation of agent-based models representing criminals' behaviour were very simple, abstract, and designed to only evaluate how different factors in isolation, like criminals' motivation or police behaviour, may affect crime rates. For example, Melo et al. (2006) proposed a model to analyse how different police patrol physical allocation in the city influences crime rates. The second generation of models incorporated a higher degree of complexity and a more realistic representation of the environment (e.g., geographical refinements), interactions (e.g., social interactions), and human behaviours (e.g., behavioural responses to crime), making it possible to analyse multiple levels of interventions and to perform more accurate real-world predictions. Dray et al. (2008), for instance, propose an agent-based model to evaluate the effectiveness of different types of law enforcement strategies – random patrolling, hotspots policing, and problem-oriented policing – on reducing the street-level drug market activity. They use the richer environment representation to specify these strategies. In the random patrolling, police navigate randomly on the environment looking for criminal activity. In the hotspots policing, some specific pre-defined locations are patrolled, while in the problem-oriented policing strategy data generated during the simulation is used to proactively identify problematic locations and adapt the policing strategies. This study shows that the problem-oriented policing is the most effective in disrupting street level drug markets because of its higher adaptability to changes on the criminals' behaviours incorporated in the model. Similarly, Malleson and Birkin (2012), Malleson et al. (2009), and Malleson et al. (2010, 2013) use agents programmed to mimic human behaviour moving in an artificial city to understand the factors – environmental, social, and behavioural – that may influence the occurrence of burglary.

Here we describe the design principles, features, and possible applications of GLODERS-S, an innovative and configurable agent-based *simulator* that incorporates features similar to the second generation of criminal models. Distinct from models, simulators are the frameworks out of which specific agent-based models are derived and implemented. GLODERS-S is specialised in simulating the dynamics of criminal organisations that are characterised by the production and sale of protection,[1] often backed by explicit or implicit threats. We refer to these types of criminal organisations as protection racketeering groups. This grouping includes the Sicilian Mafia (Gambetta 1993), the Russian Mafia (Varese 1996, 2001), the Yakuza (Hill 2006), and the Hong Kong Triads (Morgan 1960). However, other organised groups, among them the FARC

[1] The protection that criminal groups provide ranges over a continuum from the 'protection' against harm that the extorter himself would cause, to genuine protection – nevertheless socially harmful – such as enforcing cartels.

(Revolutionary Armed Forces of Colombia) and Mexican drug gangs, to some degree also display this feature – even if the protection they provide is solely from the groups themselves (Leech 2009).

We hope that other scholars and policy-makers use and adapt GLODERS-S for understanding the dynamics of protection racketeering groups as well as other criminal phenomena. To the best of our knowledge, GLODERS-S is the first simulator whose design principles were derived both from theory and empirical data, developed with the specific aims of supporting the study of the dynamics of criminal protection systems.

The paper unfolds as follows. GLODERS-S: principles and features section describes the design principles that guided the development of GLODERS-S and its main features. We then provide an example of some possible uses and applications of the simulator in Applications section. Finally, we describe some of the main structural and conceptual limitations of the simulator and ideas for future work in Conclusions section.

GLODERS-S: principles and features

GLODERS-S is not a model of any specific protection racketeering group, rather it is an *agent-based simulator* allowing actors involved in racketeering activities and their interactions to be represented (e.g., request of extortion money, protection provision, report to the police, and punishment due to non-payment of extortion), reproduced over-time, and under different conditions. The main aim of GLODERS-S is to improve our understanding of how protection racketeering groups work, test hypothetical setups, forecast future states and trajectories of criminal organisations, and evaluate the effectiveness of measures to counter them.

To allow a more grounded understanding of the simulator, we start by briefly describing the 'Palermo Scenario' a model we implemented using GLODERS-S (Nardin et al. 2016a).[2,3,4] The Palermo Scenario model focuses on the Sicilian Mafia, a well-known protection racketeering group operating in Sicily. The model and the simulator were built under the 7th Framework Programme project 'GLODERS' that brought together four research centres and 27 experts from 10 different countries who are active on a day-to-day basis in the fight against crime. We have made use of knowledge of domain experts and empirical data to design the model and define the minimum design requirements for building the simulator. The empirical data used in the project came from several sources.[5] The first and most important is the database of

[2] The model is named Palermo Scenario because most of the empirical data used to develop it was collected in the area of Palermo. Despite its name, it is worth noting that the model is flexible enough to represent the dynamics behind other protection racketeering groups.

[3] A preliminary version of the Palermo Scenario including early results is published in a conference proceedings (Nardin et al. 2016b). In addition, a technical discussion of the full model with further results can be found in (Nardin et al. 2015).

[4] A similar model, derived during the GLODERS project, and implemented in NetLogo can be found in Troitzsch (2015).

[5] The sources are judicial documents, confiscated Mafia documents like *Libri Mastri* (accounting books used by some Mafiosi to record various information about payers and that are occasionally discovered by the police), academic studies, literature, and other sources, such as newspapers and television interviews.

more than 600 extortion cases from the last decade collected in Sicily and Calabria[6] (Militello et al. 2014). The entries in this database were extracted from police reports and court trials by the members of the project.

Palermo scenario model

The Palermo Scenario is an agent-based model of protection rackets created using the simulator GLODERS-S. Figure 1 illustrates the stylised dynamics and interactions (i.e., the arrows) between the five key types of agents (i.e., the rectangles) implemented in the simulator: Entrepreneurs, Consumers, the State, the Mafia, and the Non-Governmental Organisation (NGO).

The interactions between the Mafia and Entrepreneurs have a central role in the dynamics of this model. Consumers are the economic driver of the system, deciding which Entrepreneur to purchase goods from (*Buy* arrow). The Mafia, consisting of multiple Mafiosi, approach Entrepreneurs and request *pizzo* – protection money – from them (*Request* arrow). If Entrepreneurs decide to pay (*Pay* arrow), they may receive some benefits (*Benefit* arrow); otherwise, the Mafia may punish them (*Punish* arrow). Entrepreneurs who do not pay or are punished can report the request for money to the State (*Report* arrow). The State, consisting of multiple Police Officers, investigates criminal activities (*Investigate* arrow) and assists Entrepreneurs who have been harmed by the Mafia. If a Mafioso is captured, it is placed in custody for a fixed period, after which the State decides whether to convict and sentence it to a longer period or release it. After the prison period has elapsed, the Mafioso is released and it may return to act as a Mafia member again. Entrepreneurs harmed by the Mafia may be assisted by the State (*Assist* arrow), and at any moment, they can become members of the Non-Governamental Organisation (NGO). The NGO has a limited – yet important – scope in the model: it serves as an organisation that Entrepreneurs can join if they are not paying pizzo and works as a hub for the propagation of lawful social norms to Customers and Entrepreneurs and more generally to the civic society at large (*Social Norms Spreading* arrow). The State is also active in the propagation of an anti-mafia culture among the civic society (i.e., Consumers and Entrepreneurs) (*Social Norms Spreading* arrow).

Entrepreneurs and Consumers decide how they will behave on the basis of instrumental and normative considerations. The former are economic factors such as the amount of pizzo requested by the Mafia, the amount of punishment expected if not paying, and the assistance received from the State; while the latter consist in the recognition of the social norms ruling their social environment (see Table 1) and in their possible adoption. Normative considerations are measured as a function of the *norm salience*, a measure that indicates how active and prominent, or inactive and inconspicuous, a norm is within a group in a given context (Conte et al. 2013); the salience of the norm is updated by each Entrepreneur and Consumer based on their own behaviour and by observing the behaviour of others.

Due to the difficulty in finding empirical data of protection racket activities, to validate this model, we applied a methodology that uses empirical data that is reduced in quantity (i.e., 600 extortion cases reported in Sicily and Calabria) and only pertains

[6] The entries in this database were extracted from police reports and court trials by the GLODERS team at the University of Palermo and processed by the GLODERS team at the Universität Koblenz-Landau. The database is accessible at http://dx.doi.org/10.7802/1116.

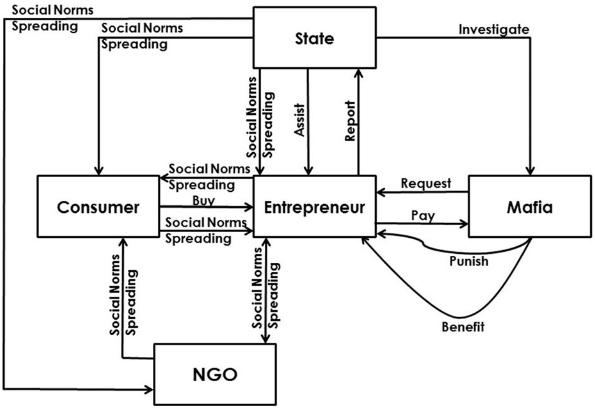

Fig. 1 Simplified diagram of the model dynamics and agents' interactions

to the output of the phenomenon being analysed. The percentages of unreported cases (i.e., cases where the police got to know about an extortion without the help of the victim) and the percentages of completed extortions (i.e., not only attempted, but also unsuccessful) that took place in the area of Palermo were calculated. We then run a large number of simulations with different input parameter values until we matched the output result of the simulation with the empirical data. For additional details of the model's dynamics and behavioural decisions as well as the validation methodology, see Nardin et al. (2016a).

Although the Palermo Scenario implements a state of affairs that occurred, and is arguably occurring, in the area of Palermo (where the Mafia is deeply enrooted and active), essentially all of the key ingredients that we identify and implement are present in other protection racketeering groups. The set of agents and their relationships implemented here can be used to examine different variants of the same phenomenon. GLODERS-S has two levels of adaptability. The first level allows the representation of different protection racketeering groups or the activation and deactivation of different intervention strategies by changing the configuration parameters value (see Configurability section). The second level corresponds to structural changes on the simulator that allows the addition of new actors or the representation of criminal activities different than protection racketeering, such as drug trafficking or terrorism. In this second level, it is necessary to involve software developers to code the adaptations using the programming language Java (see Software architecture section).

Table 1 Social norms influencing agents' behaviour in the Palermo Scenario

ID	Norm	Ruled agent	Content of the norm
N_1	Pay pizzo	Entrepreneur	Pay money to Mafioso after request
N_2	Do not pay pizzo	Entrepreneur	Do not pay money to Mafioso after request
N_3	Report pizzo	Entrepreneur	Report requests for money
N_4	Do not report pizzo	Entrepreneur	Do not report requests for money
N_5	Do not buy from paying pizzo Entrepreneurs	Consumer	Do not buy products from Entrepreneurs known to pay extortion money to Mafiosi

Configurability

GLODERS-S is configurable and allows a large number of variations of the agents' characteristics and behaviours that enables users to create different scenarios by simply changing input parameters in a configuration file using a text editor. We discuss some of the possibilities with the first level adaptation.

A possible configuration set of parameters is the number of Entrepreneurs, Consumers, Police Officers, and Mafiosi populating the scenario. The proportion among the number of these types of agents allows us to define not only the size of the population, but also the efficiency of the State. For example, a large proportion of Police Officers with respect to the size of the population increases the possibility of detecting a criminal activity happening (i.e., pizzo request or punishment), which increases the perception of the efficiency of the State among the Entrepreneurs and Consumers.

In addition to the number of Entrepreneurs and Consumers, it is possible to create subsets of these types of agents, each group with different characteristics. Consider Entrepreneurs: they can be characterised by the price of the product they sell, their initial beliefs about the efficiency of the State and violence of the Mafia, and their initial saliences for the social norms shown in Table 1. These parameters guide their decision to pay or not and whether to report pizzo requests. Using different values for these parameters, one can create two different types of Entrepreneurs. The first group composed of Entrepreneurs that recognise the Mafia as a legitimate group and who weight social ties more than economic advantages, and a second group in which the Mafia is recognised as a harmful entity, yet the Entrepreneurs also weight social ties as more important than favouring economic aspects. The former group is then configured with high initial norms salience for the 'pay pizzo' and 'do not report pizzo' and low salience to the other social norms, while the latter group has the opposite initial norms salience value. Both groups, however, give more weight to the normative aspects than to the instrumental aspects as they weight more the influence of social ties rather than self-interested gains. Similar configurations are possible for the Consumers, but in their case the social norm guides their purchasing decision.

The State can have different strategies, which are defined by the frequency they conduct investigations and the level of bureaucracy. The frequency of investigations and the level of bureaucracy have opposite consequences as increasing the frequency of investigation improves the changes of detecting an extortive activity, but increasing the level of bureaucracy reduces the time spent monitoring the environment and consequently the possibility to capture Mafiosi. State corruption and efficiency can be specified by the probability of capturing a Mafiosi and imprisoning them in case their criminal activity is detected. In addition to the coercive activities, the State can be configured to assist economically harmed Entrepreneurs that report Mafiosi punishment and to propagate lawful social norms to Customers and Entrepreneurs. Although these two actions do not act directly against the Mafia, they promote a change toward lawful social norms that may result in less pizzo payment and more extortion reporting.

These configuration parameters allow us to define a State that is very effective in countering the Mafia through investigations and imprisonment, but communicates poorly with the population. The distinction between the Italian state during the 1980s and 2000s is an example of a change in the state's approach to countering mafia. During the 1980s, the Italian state started to create mechanisms that rendered it coercively efficient to counter the mafia, but it did not put any effort on propagate lawful behaviour among the population. Observing some limitations on this approach, beginning in 2000s the Italian state started to act in changing the population mentality.

The Mafia can have different strategies that are defined by (a) the frequency and amount of pizzo requested from Entrepreneurs, (b) the regularity and severity of punishments inflicted on those that resist paying pizzo, and (c) the benefits provided to those that pay. These attributes allow us to characterise different Mafia strategies, such as a *predatory strategy* – when the criminal organisation makes a one-time request for a very high amounts of money with a low return in benefits, and punishes with certainty and severely Entrepreneurs that do not pay; a *parasitic strategy* – when the criminal organisation demands low amounts of money from a large group of Entrepreneurs, punishes slightly in case of no payment, yet provides a relatively small benefit to the payers; and a *symbiotic strategy* – when the criminal organisation and the Entrepreneur mutually benefit from the interaction.

The NGO can be enabled or disabled. If enabled, it is possible to define the proportion of the population toward whom it will promote the lawful social norms and at which frequency. For a detailed description of all the possible configuration parameters available on GLODERS-S, see Nardin et al. (2015).

Software architecture

Besides its first level configurability, GLODERS-S also has a modular architecture that allows users with reasonable skills in Java programming to adapt it to the study of other types of criminal organisations or criminal activities (second level adaptability). This possibility is guaranteed because the source-code of the simulator is freely released at https://github.com/gnardin/gloders and its documentation is available in Nardin et al. (2015).

Figure 2 shows that GLODERS-S has a modular architecture and is composed of three main modules: Simulator Tool, Agent Architecture, and User Interface. The *Simulator Tool* executes the simulation and enables agents' involved in the criminal activities to interact in a partially observable environment. The Environment is represented as a network structure abstracting the social relationships among the participating agents in the simulation. The Simulation Engine uses an event queue to execute the simulation and store the outcomes on the Data Repository.

The GLODERS-S event-based engine allows the orderly execution of a sequence of events generated by the different types of agents in the platform. This feature distinguishes GLODERS-S from many other agent-based simulators because it allows the agents to asynchronously exchange and react to events rather than follow predetermined sequence of actions executed concomitantly at each time step. In the context of criminal groups, this feature brings several advantages. First, the event-based approach allows a more *realistic* representation of the criminal activities; Entrepreneurs, for instance, are not approached at the same time by Mafiosi and each Entrepreneur also has a different reaction time. Second, agents have a higher level of *independence* concerning the scheduling of their actions. Consumers, for instance, may decide independently when to buy a product. As a consequence, the event-based approach allows an easier incorporation of new agents and new actions in the simulator due to the fact that there is no fixed sequence of operations to be changed.

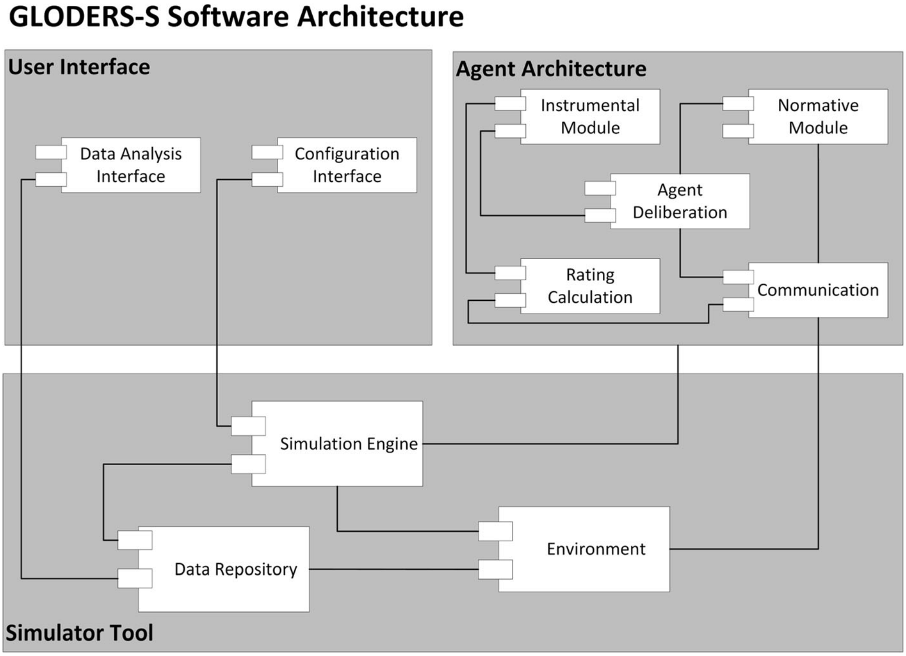

Fig. 2 GLODERS-S architecture

The *Agent Architecture* is the module that specifies the internal structure of the agents. It represents a cognitive architecture that allows agents to take decisions combining instrumental (i.e., economic) and norm-based considerations. The normative aspect implemented in the Normative Module is defined by an extended version of the EMIL-A architecture (Andrighetto et al. 2013, 2014; Conte et al. 2013), a normative architecture developed for the study and simulation of the bidirectional dynamics of norms and institutions in social systems that allows agents to recognise, reason upon, and decide whether to comply with norms or not. The economic aspect implemented in the Instrumental Module is defined by an analysis of the expected payoffs resulting from different choices available to the agents. The agents also rate the Mafia according to its level of violence and the State according to its level of efficiency (Rate Calculation). Combining data from these modules the agent decides how to behave (Agent Deliberation) and interact with the other agents through the environment (Communication).

The *User Interface* is the module through which users can interact with the simulator. It provides users an interface through which, first, they can set the configurations' input parameters, and second, they can have access to the outputs of the simulation. The interface to set the configurations' input parameters' value is an XML (Extensible Markup Language) file that can be edited using a text editor. In this configuration file is possible to adjust all the input parameters' value characterising the agents and their behaviours. The outputs of the simulation are recorded in CSV (Comma-Separated Values) text files that can be used for performing statistical or graphical analyses of the outcomes.

Table 2 shows an example of part of the Mafia's configuration parameters defining that the simulation will have 20 Mafiosi (`<numberMafiosi>`) with zero initial wealth (<wealth>), the Mafia will demand 3 % of the Entrepreneur's income as pizzo (<extortionLevel>), and if not paid may punish the Entrepreneur with 50 % probability (<punishmentProbability>) reducing in 50 % the Entrepreneur's wealth (<punishmentSeverity>). If paid, however, return as benefit between 0 % and 1 % of the payment to the Entrepreneur (<minimumBenefit > and <maximumBenefit>).

Finally, the simulator supports multiple hardware environments and is independent of external agent-based simulation frameworks like Repast (North et al. 2013) and MASON (Luke et al. 2005). The simulator is implemented in Java, a general-purpose programming language that supports object-oriented design and has few dependencies with the operating system and hardware platforms. The power of the object-oriented language allowed the development of a simulator with a modular architecture that facilitates changes of specific functionalities without affecting others. We implemented GLODERS-S to be portable across different operating systems and hardware platforms, and independent of open-source simulation frameworks that usually have a short lifespan.

Applications

Here, we discuss and extend an application of GLODERS-S. We begin with the Palermo Scenario model setup, which we previously described in Palermo scenario model section, and some questions that we have already used to explore in (Nardin et al. 2016a). In this line of research, we use the simulator, and the agents of the State, the Mafia, Consumers, Entrepreneurs, and an NGO, to explore two different strategies for countering Mafias. One, which is a more traditional policy tool, is based on incentive change and enacted as more stringent police monitoring, faster and more effective judicial processing, and more robust sentencing laws, we can call a 'legal approach'. Here the idea is to test whether, and to what extent, such a top-down approach adopted by the State can be successful in imprisoning Mafiosi, reducing the number of pizzo requests paid by the population, the amount of violence that occurs, and changing the populations norms and actions towards Mafia. The other, which is typically employed by NGOs, targets the issue from the bottom-up, working through the populations' norms. For example, by disseminating information about the harms caused by the Mafias and by promoting critical thinking among the young population

Table 2 Example of the Mafia's parameters in XML configuration

```
<mafia>
<numberMafiosi>20</numberMafiosi>
<wealth>0.00</wealth>
<extortionLevel>0.03</extortionLevel>
<punishmentSeverity>0.5</punishmentSeverity>
<punishmentProbability>0.5</punishmentProbability>
<minimumBenefit>0.0</minimumBenefit>
<maximumBenefit>0.01</maximumBenefit>
</mafia>
```

about these criminal organisations. The idea being that norm change among the population results in behaviour change towards Mafiosi and subsequently destabilising the Mafia. We call this the 'social norm approach'. Thus, we use GLODERS-S to explore whether, and to what extent, legal and social norm approaches, independently and combined, are effective in defeating the Mafia.

These experimental settings allowed us to identify that even though the 'legal approach' is effective in countering the Mafia and changing the Entrepreneurs' behaviour regarding the payment of pizzo requests; it is not effective in changing the Entrepreneurs' normative beliefs about pizzo. In contrast, the 'social norm' approach promoted by NGOs is effective in changing Entrepreneurs' behaviour; however, it increases the amount of violence the Entrepreneurs receive because the State is ineffective in combating the Mafia. Whenever the State and an NGO (combined approach) operate in the environment, Entrepreneurs change their behaviour and social norms regarding the Mafia.

Based on these results, we hypothesise here that even though both the 'legal approach' and the combined approach were successful in changing the Entrepreneurs' behaviour, the former is less resilient to changes because it was not successful in changing the Entrepreneurs normative beliefs about pizzo. To support this hypothesis, we conducted an experiment in which we evaluate the Entrepreneurs' resilience to a reduction of the strength of the State after operating initially for two scenarios: the 'legal approach' alone and combined approach. The simulation is executed with the State effectively operating for 10,000 time units, and for the others 10,000 time units with the State operating ineffectively for the 'legal approach' and combined approach, and the resilience of the Entrepreneurs to the Mafia is measured. Resilience here means that the Entrepreneurs will sustain a lower pizzo payment and a higher level of pizzo reporting to the State.

Note that we are interested in understanding the levels of pizzo payment to the Mafia and reporting to the State after the State starts operating ineffectively. Here we are not interested in comparing the individual effectiveness of the 'legal approach' and combined approach, for such comparison see (Nardin et al. 2016a).

Figure 3 shows the proportions of paid pizzo considering for the first 10,000 time units the 'legal approach' and combined approach scenarios. Note that after the 10,000 time units the strength of the State was reduced and the combined approach sustain for the next 10,000 time units a lower proportion of pizzo payment than the 'legal approach' alone.

Figure 4 shows the proportion of reported pizzo requests and it indicates that the combined approach sustain a higher level of reporting after the State strength's reduction at 10,000 time units.

These results corroborate with our hypothesis that the combined approach is more resilient than the 'legal approach' alone in case of changes like the reduction of the strength of the State due for instance by a reduction on investments or increase on bureaucratic activities. In contrast, the small difference between the stabilised levels of pizzo payment and reported pizzo an additional cost-benefit analysis should be performed to really identify whether the implementation of the combined approach has an advantage over the 'legal approach' alone. The identification of these extra analysis was possible because we could evaluate different scenarios using a computational approach before interfering on the real system.

These results also show that change on behaviour alone is not a good indicator for policy evaluation. If used alone this metric may give the wrong impression that the

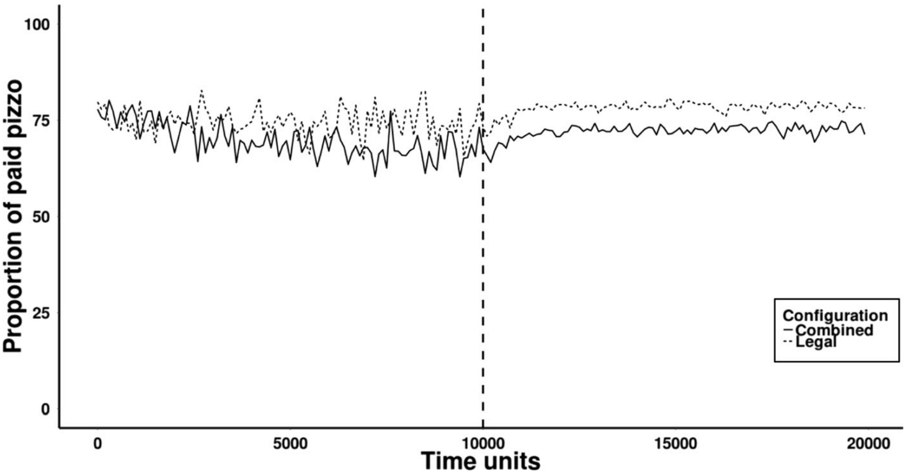

Fig. 3 Proportion of paid pizzo measured with the legal approach and combined approach assuming for 10,000 time units an efficient State and for the last 10,000 time units an inefficient State

situation has really changed, but it has only changed momentarily due to the current conditions (e.g., strong State). Once these conditions cease (e.g., the strength of the State is reduced), the Entrepreneurs change their behaviour back.

As two further examples, one may wish to explore the effect that the initial strength of the Mafia has on the level of population resistance to pay (how much easier is it to prevent a small group than a larger one?) and to what extent the initial strength and distribution of social norms in a society make it easier for a Mafia to prosper. In all of these cases, the relevant variables can be manipulated and compared to a baseline simulation.

We have discussed how to apply the simulator to the Sicilian Mafia; other protection racketeering groups can be represented instead and similar questions as above can be tested. The model should be configured to the specific protection racketeering group

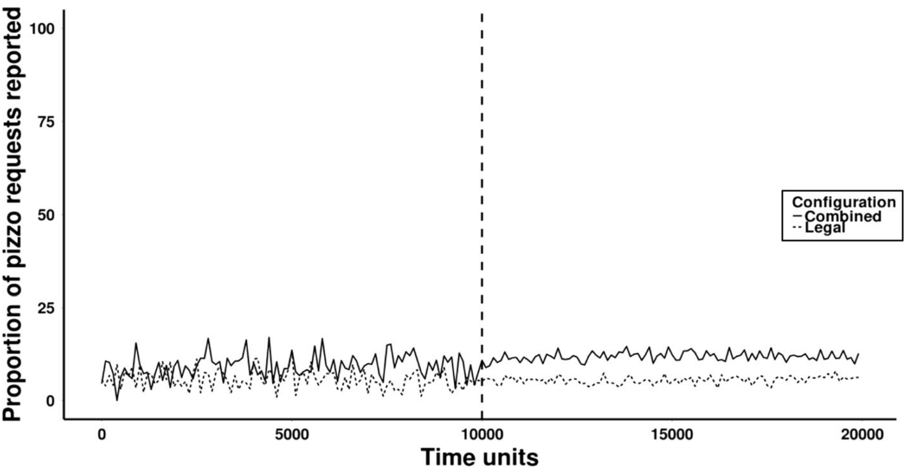

Fig. 4 Proportion of pizzo requests reported to the State measured with the legal approach and combined approach assuming for 10,000 time units an efficient State and for the last 10,000 time units an inefficient State

and context that one is interested in. Certainly some groups in Latin America can be represented in the simulator as highly extortive groups that provide no genuine benefits to victims and that use extremely strong punishment in response to resistance.

Conclusions

To the best of our knowledge, GLODERS-S is the first configurable agent-based simulator specialised in simulating the dynamics of criminal organisations, protection racketeering groups in particular. GLODERS-S configurability allows the representation of a variety of scenarios with different protection racketeering groups and population characteristics. Although this paper has been focussed on this type of criminal organisations, GLODERS-S can be applied to study a wide range of organised crime related problems. This capability is possible due to its modular architecture and the event-based simulation approach implemented.

What are the limitations of the current version of GLODERS-S? One limitation is the lack of a Graphical User Interface that allows a graphical configuration of the simulator and presentation of the outcomes. This restricts the users of the simulator to those with a reasonable computing skills and excluding those with a basic knowledge. To make this platform usable for a wider-audience, a user-friendly interface is important and is the aim of future development of it.

In addition to operational restrictions, there are other limitations. The economy and its cycles, for instance, are recognised to play an important role in the dynamics and life of criminal organisations; nevertheless, they were not modelled in detail in GLODERS-S. Moreover, the criminal system, in the example presented characterised as the Mafia, is represented as a single organisation, and yet in reality is known that the Mafia is usually structured in several small groups that may fight one another for the domain of a certain territory. These and other limitations are the target of future improvements.

Compliance with Ethical Standards

Conflict of interest The authors declare they have no conflict of interest.

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Ethical approval This article does not contain any studies with human participants performed by any of the authors.

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