Proceedings of the 2016 Winter Simulation Conference
T. M. K. Roeder, P. I. Frazier, R. Szechtman, E. Zhou, T. Huschka, and S. E. Chick, eds.

THE LINGERING EFFECTS OF PAST CRIMES OVER FUTURE CRIMINAL CAREERS

Ugo Merlone

Department of Psychology,
Center for Cognitive Science,
University of Turin
Via Verdi 10
Torino, TO 10124, ITALY

Eugenio Manassero

Department of Neuroscience,
University of Turin
Corso Raffaello 30
Torino, TO 10125, ITALY

Georgia Zara

Department of Psychology,
University of Turin
Via Po 14
Torino, TO 10124, ITALY

ABSTRACT

A criminal career is the longitudinal sequence of offences committed by an individual in his life course. Given the complexity of human behavior, quantitative and predictive models are rarely proposed in criminological psychology research. Few previous works have attempted to create mathematical models of continuity in offending i.e. recidivism through a "memorylessness" first-order Markov chain. Given that criminal careers literature, as well as risk assessment studies, have demonstrated the importance of past offences in triggering future criminal involvement, in the present paper we aim to propose a "memoryfulness" perspective which takes into account the individual offending history. We consider an agent-based model of criminal careers in which persistence in the same state reinforces itself. Our model is developed by replicating and testing two models of recidivism presented in mathematical criminology.

1 INTRODUCTION

A criminal career is defined as the longitudinal sequence of offences committed by an individual in his life course (Blumstein, Cohen, Roth, and Visher 1986). Criminal career studies represent a comprehensive framework (Farrington 1992), a paradigm that has become a staple within the field of criminology (Piquero, Farrington, and Blumstein 2003) as well as a global research enterprise (DeLisi and Piquero 2011) that aims to investigate changes and continuity in criminal behavior.

A core assumption of developmental and life-course criminology is that changes with age in delinquency and criminal activity occur in an orderly way, and that criminal continuity (or recidivism) follows an underlying pattern that manifests itself either "homotypically" or "heterotypically". *Homotypic continuity* reflects the same behavioral manifestations over time, and can be seen as a continuation of behavioural problems from early childhood. *Heterotypic continuity* reflects different behavioral manifestations of the same underlying construct of antisociality. "It describes the relationship between a problem at one point in the life cycle and a continued dysfunctioning at another point in time, but with different behavioural manifestations" (Zara and Farrington 2016, p. 56-58). Thus, much research is devoted to explore the mechanisms underlying psychological, psychopathological, familial, social, behavioral functioning, and to identify those risk factors that are responsible for criminal onset as well as to identify those criminogenic needs related to criminal recidivism. Criminogenic needs are dynamic and psychological risk factors (e.g. procriminal attitude, antisocial personality disorder, lack of self control and high impulsivity, substance abuse, etc.) that can change. They are important for risk management. "Assessing and reassessing them permits the evaluation of progress in treatment and changes in risk level during the course of [...] supervision" (Andrews and Bonta 2010, p. 341). Criminogenic needs become therefore the focus of both risk assessment and treatment because any change that involves them is associated with modifications in the probability of recidivism (Zara and Farrington 2016).

1.1 The paradigm of criminal careers

Basic knowledge about individual criminality has immediate practical impact on developing effective intervention, specific prevention and crime control policies (MacLeod, Grove, and Farrington 2012). The *criminal career paradigm* addresses the issue of individual differences in offending, applying it to a differential understanding between those who offend and those who do not (*prevalence*). The paradigm promotes the importance of examining why and when people begin to offend (*onset*); why, how, and to what extent they continue offending (*persistence*); whether their continuity in offending leads to an increase in incidence (*frequency*) and seriousness (*escalation*) in the offences; if antisocial continuity boosts offending *specialization* or *versatility* (*criminal mixage*); why and to what extent people loosen their antisocial grip before discontinuing their criminal careers (*de-escalation*); and why and when people stop offending (*desistance*) (Blumstein, Cohen, Roth, and Visher 1986; Farrington 1992; Le Blanc and Loeber 1998; Zara and Farrington 2016). In other words, the criminal career approach focuses on *within-individual changes* in criminal involvement and activity over time, and this allows for aggregating this information for groups of offenders (Zara 2010).

Antisocial onset and desistance act as the two opposite ends of a criminal career, and they are crucial in understanding criminal recidivism. *Antisocial onset* is the beginning of a criminal career; research findings are concordant with the association between age and residual criminal career, in so far as an early onset is a predictor of a longer criminal career (Farrington 2003; Farrington 2007; Farrington, Coid, and West 2009). *Desistance* is the *virtual* termination of a criminal career because, as Farrington (1997) advocates, only the death of a persistent offender is the absolute proof that his criminal career has reached its end. Furthermore, desistance should not be seen as a discrete event in the patterning of offending, but as a continuous process of a renewed choice, and a commitment towards criminal career termination (DeLisi and Piquero 2011; Kazemian 2007; Maruna 2001; Maruna 2011; Maruna 2012; Maruna and Immarigeon 2004).

A developmental perspective in criminology is essential for several reasons (Farrington 2005; Morizot and Kazemian 2015). First, understanding antisocial onset will help focus on those individuals who are more likely to remain active in offending. Second, criminal behavior takes distinct forms at different developmental periods, and research findings suggest that for the aggregate level, the *age-crime curve* has consistently shown that criminal behavior typically starts by early adolescence, reaches a peak by the end of adolescence, and rapidly decreases during adulthood (Farrington 1986; Moffitt 1993). Third, those individuals who remain active in offending tend to do so at a relatively stable rate across various periods of the life course. In other words, it seems that looking at the antisocial onset is only a part of a more complex criminal career reality. Fourth, identifying etiological factors (risk and protective factors, and criminogenic needs) that are associated with different antisocial parameters (onset, activation, aggravation, desistance) will allow for a more *Risk-Need-Responsivity* (RNR) approach to effective prevention and intervention (Andrews and Bonta 2010).

1.2 Exploring models of quantitative predictions of recidivism

Unlike models in physical sciences, models in criminological psychology and in social sciences in general, rarely make attempts at quantitative predictions (MacLeod, Grove, and Farrington 2012). There are many reasons behind this "omission". The belief that the complexity of human behavior, and the multiple possible choices of responding to life events, could not be possibly measured (or reduced) into any quantitative model, has reinforced a sort of disinvestment in this type of research. However, the criminal career paradigm offers a significant opportunity to estimate the likelihood of offending continuity and recidivism patterns. Given certain individuals, given specific criminogenic needs and risk factors involved, given some social conditions and life experiences, and assumed that certain parameters to be in place, it might be more likely that a first criminal act will become a stepping-stone for a long, serious and persistent criminal career. This will not reduce offenders into *unrealistic numbers*, but will give to criminal numbers their *human reality*. The investment interest of science is to predict tomorrow's criminals and to prevent young people from being entrapped into a life of crime (Farrington and Welsh 2007; Loeber, Slot, van der Laan, and Hoeve 2008b). The interest of the criminal justice system is to guarantee a safer society. Joining these two interests, criminological research could make a difference in our understanding of criminal recidivism, and in the attempt to improve the quality of life in society.

In the last few decades, several models were proposed for this purpose (Bloom 1979; Bramsen 2014; Greenberg 1978; Greenberg 1979; Maltz and McCleary 1977; Stander, Farrington, Hill, and Altham 1989; Wainer 1981).

Maltz and McCleary (1977) elaborated a two-parameter model i.e. the failure rate and the ultimate percentage of individuals who relapsed into offending, and Wainer (1981) presented an improved model to overcome the systematic underprediction bias, by adding a constant to the equation and by using the method of least squares to estimate the parameters.

Subsequently, Stander and colleagues (1989) tested whether the criminal careers of 698 English male offenders could be predicted by a Markov chain (for an introduction to Markov chains see Feller 1968). A Markov chain is a stochastic process that often used to model the transitions between different states of a process. The core feature of this model is a specific kind of *memorylessness* named "Markov property", according to which the conditional probability distribution of future states of a process is only affected by the current state of that process, and it is not influenced by its past states; to be more precise we mean a first-order Markov process (Ibe 2009). Hence, treating a criminal career as a first-order Markov chain means that, within a specific longitudinal pattern of offending, the future typology of offence depends on the present offence, but not on the past ones. Furthermore, a Markov chain is called "stationary" or "homogeneous" if the probability values of moving from one state to another state are maintained constant throughout the whole process. Stander, Farrington, Hill, and Altham (1989) tested whether longitudinal patterns of offending might be simulated as stationary first-order Markov chains. Their work led to exploring whether continuity into offending could lead to any form of offending specialization. Although the transition matrices they used showed that the probability to move from an offending typology to another one remained constant throughout multiple convictions, they found evidence supporting the influence of the type of previous offences on the following ones. This result showed that the emerging specialization in offending by some criminal individuals could be explained by the influence of past offending history upon future criminal outcomes, suggesting the necessity of differentiate and multiple constructs to account for differences in persistent offending behaviors.

In this paper we show how relaxing some assumptions in two well known models changes the dynamics in criminal recidivism patterns. Namely, we consider a classic model (Greenberg 1979) and a more recent one (Bramsen 2014).

Both these models are Markovian and provide a simple and elegant analysis of the criminal events without considering the criminal history of each individual. Nevertheless, in studying recidivism in career offenders the individual criminal history is extremely relevant (Piquero, Farrington, Nagin, and Moffitt 2010; Zara and Farrington 2016), therefore our model explicitly considers parameters related to the criminal history of each individual. In other words, we consider an agent-based model (ABM), which in a particular case replicates the original Markovian model. The aim of this model is twofold. First, we want to study how criminal careers are affected when assuming that the permanence in the same state reinforces itself. Second, in a future study, the interest is to introduce into the model mutual interaction in criminal careers. By starting from a simple and preparatory model, the purpose is to set up conditions for "enrichment or elaboration" of it, discussed in Morris (1967).

The remainder of the paper is organized as follows. In Section 2 we present two known models of criminal recidivism. In Section 3 we introduce our model. In Section 4 we extend our model to consider how permanence in the same state i.e. criminal recidivism, affects transition probabilities. Finally, the last section consist of the conclusion and further research.

2 TWO CRIMINAL CAREERS MODELS

A significant aspect that cannot be dismissed from a predictive model is how recidivism is defined and measured. Blumstein and Larson (1971) argued that, although to recidivate means in practice to reoffend, the probabilistic measurement of recidivism is necessarily dependent on its operationalization, i.e. one more crime committed or one more arrest or one more conviction. Therefore, in order to account for future criminal behavior, Blumstein and Larson (1972) suggested a semi-Markovian chain model that is structured in four discrete states between which criminals can move: crime, arrest, prison and no recidivism. According to the Markov property, transition probabilities are not affected by the sequence of individual past states. Given that a specific state may be reached through different sequences of states (e.g. an individual may commit a new offence with no intervening arrest, or he reoffends after being released from an imprisonment), the overall probability to move from one state i to another state j corresponds to the sum of probabilities for all the possible trajectories from i to j.

Figure 1 shows the possible transitions between states.

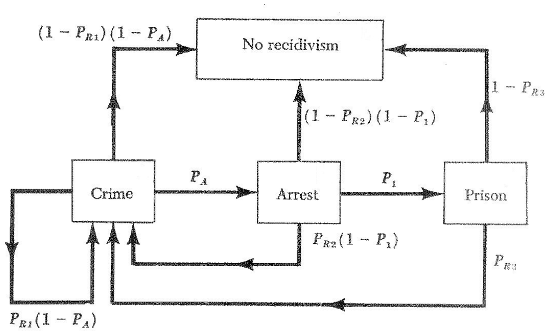


Figure 1: A diagram illustrating the Blumstein and Larson 1971 model.

2.1 The Greenberg (1979) Model

Greenberg (1979) reports the model originally developed by Blumstein and Larson (1971), where the conditional probability to reoffend is:

$$P(C|C) = P$$

Whereas the conditional probability to be rearrested is:

$$P(A|A) = \frac{P}{(4-3P)}$$

And the conditional probability to be reconvicted is:

$$P(I|I) = \frac{P}{(16-15P)}$$

It is clear that the resulting patterns of recidivism will depend on the value of parameter P. Hence, according to the following assumptions on parameters of the model:

1. $p_{R1} = p_{R2} = p_{R3} = P$
2. $p_A = p_I = \frac{1}{4}$

The transition matrix suggested by this model is the following:

$$\mathrm{M}_G = \begin{array}{c} \begin{pmatrix} 1 & 0 & 0 & 0 \\ \frac{3}{4}(1-P) & \frac{3}{4}P & \frac{1}{4} & 0 \\ \frac{3}{4}(1-P) & \frac{3}{4}P & 0 & \frac{1}{4} \\ 1-P & P & 0 & 0 \end{pmatrix} \end{array} \begin{array}{l} \text{no recidivism} \\ \text{crime} \\ \text{arrest} \\ \text{prison} \end{array} \tag{1}$$

where the entry corresponding to i-th row and j-th column is the probability to move from state i to state j in a direct single step.

2.2 The Bramsen (2014) Model

More recently, Bramsen (2014) introduced another stochastic model, based on a discrete time Markov chain.

The preliminary argument of this argumentation stresses the role of social bonds in triggering a criminal relapse, claiming that imprisonment implies a disruption of social bonds with the prosocial community. Thus, after release, an individual needs to reconnect to the prosocial subnetwork (success), while detaching himself from the criminal one (failure). As in the case of the model previously introduced, this one is also based on four discrete states:

- S_1: Struggling, but not yet failed;
- S_2: De facto failure, in having developed criminogenic, pathological social bonds;
- S_3: Safe, in having developed a supportive social network;
- S_4: De jure failure.

According to the criminal career literature (West and Farrington 1973; West and Farrington 1977) and the RNR model (Andrews and Bonta 2010), the term "pathological" associated with social bonds should be extended to include the term "dysfunctional" that refers to a broader meaning of difficult, problematic, and unstable or broken social bonds.

The transition probabilities are in this case defined as follows:

$$a = P\{\text{individual moves to } S_4 \text{ at time } t+1|\text{he is in } S_2 \text{ at time } t\} = \text{ Discovery rate;}$$

$$b = P\{\text{individual moves to } S_2 \text{ at time } t+1|\text{he is in } S_1 \text{ at time } t\} = \text{ Failure rate;}$$

$$c = P\{\text{individual moves to } S_3 \text{ at time } t+1|\text{he is in } S_1 \text{ at time } t\} = \text{ Success rate.}$$

and the transition matrix is the following

$$
\mathrm{M}_B = \begin{array}{c} \left(\begin{array}{cccc} 1-b-c & b & c & 0 \\ 0 & 1-a & 0 & a \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{array}\right) \end{array} \begin{array}{l} S_1\text{: Struggling} \\ S_2\text{: De facto failure} \\ S_3\text{: Safe} \\ S_4\text{: De jure failure} \end{array} \tag{2}
$$

The careful reader will notice that, in order to be coherent to most textbooks on Markov chains and to the model presented here in Subsection 2.1, we transpose the transition matrix originally reported in (Bramsen 2014, p. 137).

It should be noted that such static perspective is not an appropriate way of measuring and predicting the development of a criminal career, because a large body of evidence (Barnett and Lofaso 1985; Blumstein, Farrington, and Moitra 1985; Moffitt 1993; Robins 1966) suggests that one of the most robust predictors of future offending is past offending (Nagin and Paternoster 1991). That is, an individual who committed one offence is more likely to offend again, i.e. reoffending/recidivism, than for a non-offender to start offending for the first time. Thus, in order to address the dynamic nature of a criminal career, past involvement in criminal activity must be taken into account. Research on risk assessment (Monahan 2008; Monahan, Steadman, Silver, Appelbaum, Robbins, E. P. Mulvey, and Banks 2001; Quinsey, Harris, Rice, and Cormier 1998) suggests that the likelihood of reoffending is mostly affected by criminal history rather than the current offence (Monahan and Skeem 2014; Singh and Fazel 2010); hence past behavior cannot be discounted from any predictive model that attempts to join mathematical accuracy to psychological and criminological complexity.

Criminal careers involve real individuals with their idiosyncrasies, and psychological mechanisms such as decision-making processes. All these dimensions contribute to independent and unique persistent patterns of offending. Therefore, an agent-based model (ABM) might be a more appropriate one for modeling criminal careers.

An ABM consists of a collection of autonomous entities, i.e. the agents, that assess their own situations and make decisions on the basis of a set of rules, that further exhibit learning and evolution abilities. The simplest version is a system of agents in some relationships, whereas more complex versions emulate neural networks and evolutionary algorithms in a realistic and adaptive form (Bonabeau 2002). Although in this version interactions amongst agents are not yet considered, an ABM allows us to model heterogeneity of offenders.

For these reasons, in the present paper we aim to formalize a model, which considers not only their persistence in the same state (*relative stability*), but also the specificity of each agent in their criminal career (*dynamicity or absolute change*). In other words, we aim to take the first steps from a "memorylessness" perspective of predicting future recidivism to a "memoryfulness" model that takes into account the evolution of an antisocial behavior into a criminal career.

3 THE MODEL

In our simulations we consider a population in which each agent is associated to a finite Markov chain. Synchronously, at each time step, the agents' state is updated according to the transition probabilities specified by the Markov chain. Specifically, we consider a discrete-time Markov chain, i.e., a discrete-time discrete-state Markov process $\{X(t)\,|t \in T\}$ (Ibe 2009). The transition matrices have been computed using integer numbers, in other words we consider a matrix $\overline{\mathrm{M}}$ whose entries $\overline{m}_{ij}$ are integer numbers and define the entries of the transition matrix M as

$$
m_{ij} = P[X(t_n) = j | X(t_{n-1}) = i] = \frac{\overline{m}_{ij}}{\sum_k \overline{m}_{ik}} \tag{3}
$$

Given the initial distribution $\Pi(0)$, it is possible to use transition matrices (1) and (2) respectively to compute the marginal probability distribution at time n $\Pi_{\cdot}(n)$ as follows

$$\Pi(n)_G = \mathrm{M}_G^n, \qquad\qquad \Pi(n)_B = \mathrm{M}_B^n \tag{4}$$

In order to verificate (Sargent 1984) the model, we have compared the output of the average values of 1000 simulations with the prediction obtainable through equations (4). The obtained results are confirmatory.

To extend the models we now assume that transition probabilities (within the different criminal career states) may change over time. In this version when an agent remains in the same state (e.g. continuity in offending) for a longer period, the probability of entering again (persisting in this state) increases. This can be also explained by the dose–response relationship (Loeber, Slot, van der Laan, and Hoeve 2008a), in so far as the risk of future offending (the permanence in the same state) is indeed proportional to the number of criminogenic needs involved, and especially proportional to the timing and duration of their influence, and to how risk factors operate in a cumulative fashion. This assumption is formalized as follows

$$\overline{m}_{ii} = \overline{m}_{ii} + w$$

where w is a reinforcement weight. In other words we consider a *nonhomogeneous* Markov chain, which when $w = 0$ becomes homogeneous. This approach bears some resemblance to the reinforcement learning models discussed in (Sutton and Barto 2000).

4 COMPARING MODELS OF CRIMINAL CAREERS

We compared two models: in the first the homogeneous model was considered, while in the second nonhomogeneous was taken into account, in which the permanence in the same state reinforced itself.

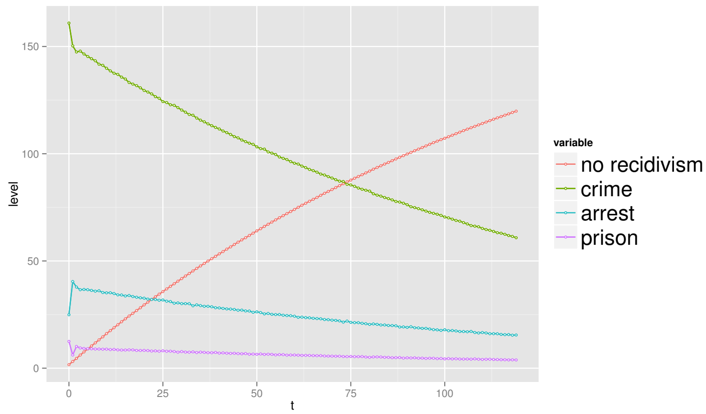
We used simulation to examine the behavior of a population of 200 virtual offenders with different weights. We considered weights $w = 0$ (corresponding to homogeneous Markov chains), $w = 1$ and $w = 10$ (both corresponding to nonhomogeneous Markov chains). Each simulation was run 1000 times and considered a 30-year criminal career length. For each simulated year we computed the number of virtual offenders in each state; this number was averaged over the 1000 repetitions we considered, and such averages are those represented in the following figures.

Figures 2 and 3 show the dynamics of the different criminogenic states. The term *criminogenic* refers to a type of conditions in which the likelihood of acting antisocially and criminally is high because of the influences of risk factors and processes (e.g. antisocial personality, substance abuse, procriminal attitude, antisocial associates, distorted thinking, etc.) that are significant in the onset and/or the persistence of a criminal career.

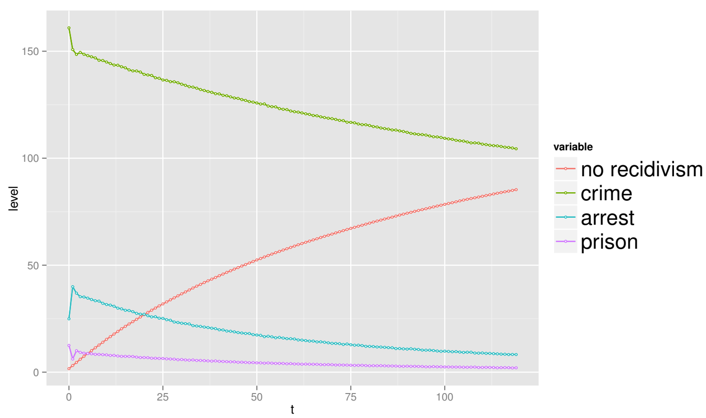
For the sake of brevity we do not report the dynamics with weights $w = 1$ as they are close to those for the homogeneous Markov chains. Nevertheless, the differences are consistent to those obtained with $w = 10$.

When comparing Figure 2a with 2b the reinforcement increases the time of permanence in the "crime state" C. According to the criminal careers literature, this can be explained by the reality of a prolific offender who is highly criminally productive, e.g. a person who commits many offences. The assumption is threefold: (a) offending does not always lead to an arrest or a conviction. Many crimes committed go under-reported, that is the *dark number* of criminality; (b) being successful in committing crimes fosters an *avoidance expertise* that is the ability of the offender to "get away with it", and reinforces the distorted thinking that "offending pays off"; (c) hence, being an active, prolific, successful offender slows down the transition towards the absorbing state, i.e. no recidivism.

When comparing Figure 3a with Figure 3b, the different dynamics of state $S2$–being ensnared in criminogenic conditions–show that the offender becomes entrapped in a "dysfunctional antisocial redundancy" because antisocial disorder and criminal offending are often entangled in a patterning of underlying risk over time (Babinski, Hartsough, and Lambert 1999; Storm-Mathisen and Vaglum 1994). This is a more



(a)



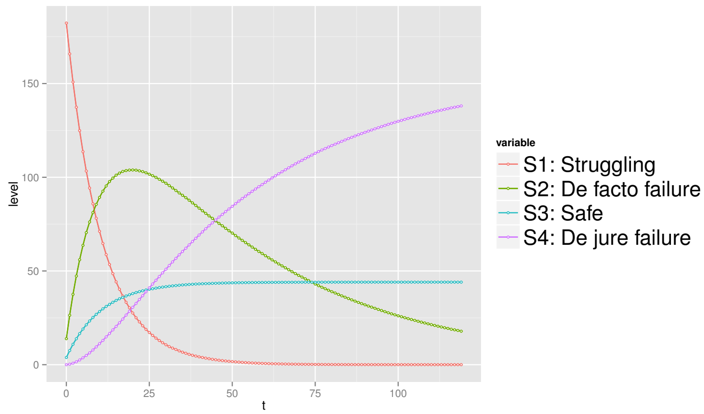
(b)

Figure 2: Greenberg model with $P = 0.99$ and different reinforcement weights (a) $w = 0$ (b) $w = 10$.

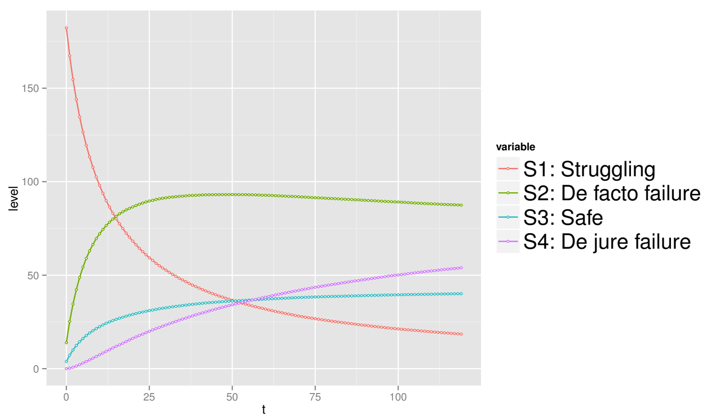
"criminal career evidence-based focus" of Bramsen's definition of state S2. In line with the criminal career paradigm (Piquero, Farrington, and Blumstein 2003; Piquero, Farrington, and Blumstein 2007; Zara 2005), being entrapped in a "dysfunctional antisocial redundancy" finds explanation in the *syndrome of antisociality*. Research findings have consistently shown how crime appears "to be only one element of this syndrome which arises in childhood and usually persists into adulthood" (Farrington 1997, p. 363), and how this syndrome "influences not only behaviour but also ways of relating to people, of taking social and professional responsibilities, of building up a family life, and of educating children" (Zara and Farrington 2016, p. 58).

5 CONCLUSION

Persistence in offending can take different paths: escalating into even more severe types of crimes over time; specializing in a type of offending, e.g. acquisitive crimes; moving into a *zigzaging* pattern of offending from one type into another it depending on the offending opportunities encountered. Our results show how, assuming that remaining in the same state (e.g. continuity in offending) for a longer period increases the probability of entering again (or not leaving ever) the same state, it is possibile to provide dynamics closer to those predicted in the literature. Furthermore, given the importance of the individual criminal history in predicting future criminal outcomes, it seems that ABM might be a more appropriate way for modeling criminal careers. In future research it will be interesting to introduce into a predictive



(a)



(b)

Figure 3: Bramsen model with $a = 0.02$, $b = 0.07$, $c = 0.02$ and different reinforcement weights (a) $w = 0$ (b) $w = 10$.

model a network structure (Dal Forno and Merlone 2007; Dal Forno and Merlone 2008) or a geographical localization (Ausloos, Dawid, and Merlone 2015) of criminal activies so as to include co−offending in recidivism. Whatever paths are taken by recidivist offenders, the permanence in a criminal career has many social, human, juridical and financial implications. Predicting future reoffending is a priority not only of scientific research in psycho-criminology, but of any government that aims to reduce persistent criminality and violence.

ACKNOWLEDGMENTS

This work was supported by PRIN (Ministry of Research and University, Italy) Prot. 2010RP5RNM_004.

REFERENCES

Andrews, D. A., and J. Bonta. 2010. *The Psychology of Criminal Conduct*. Fifth ed. Cincinnati, OH: Anderson.

Ausloos, M., H. Dawid, and U. Merlone. 2015. *Complexity and Geographical Economics: Topics and Tools*, Chapter Spatial Interactions in Agent-Based Modeling, 353–377. Cham: Springer International Publishing.

Babinski, L. M., C. S. Hartsough, and N. M. Lambert. 1999. “Childhood conduct problems, hyperactivity-impulsivity, and inattention as predictors of adult criminal activity”. *Journal of Child Psychology and Psychiatry and Allied Disciplines* 40:347–355.

Barnett, A., and A. J. Lofaso. 1985. “Selective incapacitation and the Philadelphia cohort data”. *Journal of Quantitative Criminology* 1 (1): 3–36.

Bloom, H. S. 1979. “Evaluating human service and correctional programs by modeling the timing of recidivism”. *Sociological Methods and Research* 8:179–208.

Blumstein, A., J. Cohen, J. A. Roth, and C. A. Visher. 1986. *Criminal Careers and Career Criminals*. Washington, DC: National Academy Press.

Blumstein, A., D. P. Farrington, and S. Moitra. 1985. “Delinquency careers: innocents, desisters, and persisters”. *Crime and justice* 6:187–219.

Blumstein, A., and R. Larson. 1971. “Problems in modeling and measuring recidivism”. *Journal of Research in Crime and Delinquency* 8:124–132.

Blumstein, A., and R. C. Larson. 1972. *Analysis of a Total Criminal Justice System. Analysis of Public Systems*. Boston: MIT Press.

Bonabeau, E. 2002. “Agent-based modeling: methods and techniques for simulating human systems”. *Proceedings of the National Academy of Sciences of the United States of America* 9 (Suppl 3): 7280–7287.

Bramsen, J. 2014. “On Greenbergs two-step model of criminal recidivism”. *The Journal of Mathematical Sociology* 38 (2): 133–145.

Dal Forno, A., and U. Merlone. 2007. “The evolution of coworker networks. An experimental and computational approach”. In *Social Simulation Technologies: Advances and New Discoveries*, edited by B. Edmonds, C. Hernándes, and K. G. Troitzsch, 280–293. Hershey, NY: Information Science Reference.

Dal Forno, A., and U. Merlone. 2008. “Network dynamics when selecting work team members”. In *Networks, Topology and Dynamics Theory and Applications to Economics and Social Systems*, edited by A. K. Naimzada, S. Stefani, and A. Torriero, Lecture Notes in Economics and Mathematical Systems, 229–240. Berlin: Springer Verlag.

DeLisi, M., and A. R. Piquero. 2011. “New frontiers in criminal careers research, 20002011: A state-of-the-art review”. *Journal of Criminal Justice* 39 (4): 289–301.

Farrington, D. P. 1986. “Age and crime”. *Crime and Justice: A Review of Research* 7:189–250.

Farrington, D. P. 1992. “Criminal career research in the United Kingdom”. *The British Journal of Criminology* 32 (4): 521–536.

Farrington, D. P. 1997. “Human development and criminal careers”. In *The Oxford Handbook of Criminology (2nd ed.)*, edited by M. Maguire, R. Morgan, and R. Reiner, 361–408. Oxford: Oxford University Press.

Farrington, D. P. 2003. “Key results from the first 40 years of the Cambridge Study in Delinquent Development”. In *Taking Stock of Delinquency: An Overview of Findings from Contemporary Longitudinal Studies*, edited by T. P. Thornberry and M. D. Krohn, 137–183. New York, NY: Kluwer/Plenum.

Farrington, D. P. 2005. *Integrated Developmental and Life Course Theories of Offending: Advances in Criminological Theory*, Volume 14. Piscataway, NJ: Transaction.

Farrington, D. P. 2007. “Childhood risk factors and risk-focussed prevention”. In *The Oxford Handbook of Criminology (4th ed.)*, edited by M. Maguire, R. Morgan, and R. Reiner, 602–640. Oxford: Oxford: Oxford University Press.

Farrington, D. P., J. W. Coid, and D. J. West. 2009. “The development of offending from age 8 to age 50: Recent results from the Cambridge Study in Delinquent Development”. *Monatsschrift fr Kriminologie und Strafrechtsreform* 2:160–173.

Farrington, D. P., and B. C. Welsh. 2007. *Saving Children from a Life of Crime: Early Risk Factors and Effective Interventions*. New York, NY: Oxford University Press.

Feller, W. 1968. *An Introduction to Probability Theory and Its Applications*. Third ed, Volume 1. New York, NY: Wiley & Sons.

Greenberg, D. F. 1978. “Recidivism as radioactive decay”. *Journal of Research in Crime and Delinquency* 15:124–125.

Greenberg, D. F. 1979. *Mathematical Criminology*. New Brunswick, NJ: Rutgers University Press.

Ibe, O. C. 2009. *Markov Processes for Stochastic Modeling*. London, UK: Elsevier Academic Press.

Kazemian, L. 2007. “Desistance from crime: Theoretical, empirical, methodological, and policy considerations”. *Journal of Contemporary Criminal Justice* 23:5–27.

Le Blanc, M., and R. Loeber. 1998. “Developmental criminology updated”. *Crime and Justice* 23:115–198.

Loeber, R., N. W. Slot, P. van der Laan, and M. Hoeve. 2008a. “A cumulative developmental model of risk and protective factors”. In *Tomorrows Criminals*, edited by R. Loeber, N. W. Slot, P. van der Laan, and M. Hoeve, 133–161. Surrey, UK: Ashgate Publishing.

Loeber, R., N. W. Slot, P. van der Laan, and M. Hoeve. 2008b. *Tomorrows Criminals*. Surrey, UK: Ashgate Publishing.

MacLeod, J. F., P. G. Grove, and D. P. Farrington. 2012. *Explaining Criminal Careers: Implications for Justice Policy*. Oxford: Oxford University Press.

Maltz, M. D., and R. McCleary. 1977. “The mathematics of behavioral change: Recidivism and construct validity”. *Evaluation Quarterly* 1:421–438.

Maruna, S. 2001. *Making Good: How Ex-Convicts Reform and Rebuild Their Lives*. Washington DC: American Psychological Association Books.

Maruna, S. 2011. “Reentry as a Rite of Passage”. *Punishment & Society* 13:3–27.

Maruna, S. 2012. “Elements of Successful Desistance Signaling”. *Criminology & Public Policy* 11:73–83.

Maruna, S., and R. Immarigeon. 2004. *After Crime and Punishment; Pathways to Offender Reintegration*. USA & Canada: Willan Publishing.

Moffitt, T. E. 1993. “Adolescence-limited and life-course-persistent antisocial behavior: a developmental taxonomy”. *Psychological Review* 100 (4): 674–701.

Monahan, J. 2008. “Structured risk assessment of violence”. In *Textbook of Violence Assessment and Management*, edited by R. Simon and K. Tardiff, 17–33. Washington, DC: American Psychiatric Publishing.

Monahan, J., and J. L. Skeem. 2014. “The evolution of violence risk assessment”. *CNS Spectrum* 5:419–424.

Monahan, J., H. Steadman, E. Silver, P. Appelbaum, P. C. Robbins, T. G. E. P. Mulvey, L. H. Roth, and S. Banks. 2001. *Rethinking Risk Assessment: The MacArthur Study of Mental Disorder and Violence*. New York, NY: Oxford University Press.

Morizot, J., and L. Kazemian. 2015. “Introduction: understanding criminal and antisocial behavior within a developmental and multidisciplinary perspective”. In *The Development of Criminal and Antisocial Behavior*, edited by J. Morizot and L. Kazemian, 1–16. Switzerland: Springer International Publishing.

Morris, W. T. 1967. “On the Art of Modeling”. *Management Science* 13 (12, Series B): B707–B717.

Nagin, D. S., and R. Paternoster. 1991. “On the Relationship of Past to Future Participation in Crime”. *Criminology* 29:163–189.

Piquero, A. R., D. P. Farrington, and A. Blumstein. 2003. “The criminal career paradigm”. *Crime and Justice* 30:359–506.

Piquero, A. R., D. P. Farrington, and A. Blumstein. 2007. *Key Issues in Criminal Career Research*. Cambridge, UK: Cambridge University Press.

Piquero, A. R., D. P. Farrington, D. S. Nagin, and T. E. Moffitt. 2010. “Trajectories of offending and their relation to life failure in late middle age: Findings from the Cambridge Study in Delinquent Development”. *Journal of Research in Crime and Delinquency* 47:151–173.

Quinsey, V. L., G. T. Harris, M. E. Rice, and C. A. Cormier. 1998. *Violent Offenders: Apparising and Managing Risk*. fourth ed. Washington, DC: American Psychological Association.

Robins, L. 1966. *Deviant Children Grown Up: A Sociological and Psychiatric Study of Sociopathic Personality*. Baltimore: Williams and Wilkins.

Sargent, R. C. 1984. "A Tutorial on Verification and Validation of Simulation Models". In *Proceedings of the 1984 Winter Simulation Conference*, edited by S. Sheppard, U. Pooch, and D. Pegden. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Singh, J. P., and S. Fazel. 2010. "Forensic risk assessment: A metareview". *Criminal Justice and Behavior* 37:965–988.

Stander, J., D. P. Farrington, G. Hill, and P. M. Altham. 1989. "Markov chain analysis and specialization in criminal careers". *British Journal of Criminology* 29 (4): 317–335.

Storm-Mathisen, A., and P. Vaglum. 1994. "Conduct disorder patients 20 years later: A personal follow-up study". *Acta Psychiatria Scandinavica* 89:416–420.

Sutton, R. S., and A. G. Barto. 2000. *Reinforcement Learning*. Cambridge, UK: MIT Press.

Wainer, H. 1981. "A parameterization of recidivism". *Evaluation Review* 5:810–821.

West, D. J., and D. P. Farrington. 1973. *Who Becomes Delinquent? Second Report of the Cambridge Study in Delinquent Development*. London, UK: Heinemann Educational Books.

West, D. J., and D. P. Farrington. 1977. *The Delinquent Way of Life: Third Report of the Cambridge Study in Delinquent Development*. London, UK: Heinemann Educational Books.

Zara, G. 2005. *Le Carriere Criminali [Criminal Careers]*. Milan: Giuffrè.

Zara, G. 2010. "Farrington, David P.: The Integrated Cognitive Antisocial Potential Theory". In *Encyclopedia of Criminological Theory*, edited by F. T. Cullen and P. Wilcox, 313–322. Thousand Oaks, CA: Sage Publications.

Zara, G., and D. P. Farrington. 2016. *Criminal Recidivism: Explanation, Prediction and Prevention*. Abingdon, UK: Routledge.

AUTHOR BIOGRAPHIES

UGO MERLONE (Ph.D. in Applied Mathematics, University of Trieste, Italy) is Associate Professor at the Psychology Department, University of Torino, Italy. His main area of interest is the modeling of human behavior and organizations. On these topics he has published on journals such as *European Journal of Operational Research, Physica A, Journal of Economic Behavior & Organization, Journal of Mathematical Sociology, International Game Theory Review, Organization Science, Journal of Artificial Societies and Social Simulation, Mathematics and Computers in Simulation, and Communications in Nonlinear Science and Numerical Simulation.* Further details can be found on his homepage www.ugomerlone.net. His email address is ugo.merlone@unito.it.

EUGENIO MANASSERO (Master Degree in Mind Sciences, Department of Psychology, University of Turin, Italy) is a research collaborator at the Department of Neuroscience and at the Department of Psychology, University of Turin, Italy. His main research interests are cognitive, emotional and neurobiological aspects of human memory, and the criminological implications of the human memory functioning. His email address is eugenio.manassero@unito.it.

GEORGIA ZARA (Ph.D. in Criminal Psychology, University of Sunderland, UK), is an Associate Professor of Criminological Psychology, Department of Psychology, University of Turin, Italy, and is Head and Programme Leader of the Higher Degree in Criminological and Forensic Psychology in the same Department. She has been a Visiting Scholar of the Institute of Criminology, Cambridge University, UK, since 2003. She is a Chartered Psychologist of the British Psychological Society, and a Criminologist. She is appointed an Honorary Judge in Turin Surveillance Court. Her major research interests are criminal careers, criminal persistence and recidivism, neurocriminology, psychopathy, and violent and sexual offending. Her email address is georgia.zara@unito.it.