

Foreword to the special issue of EJAM on crime modelling

H. BERESTYCKI, S. D. JOHNSON, J. R. OCKENDON
and M. PRIMICERIO

This special issue is one of the very first dedicated to crime modelling in a journal of applied mathematics. It emphasizes one of the new areas at the Social Science frontier, where modelling and mathematical tools are put to use with a view to shed light on phenomena previously thought to be outside of their reach. Pioneering research is increasingly being carried out in many different areas in the life sciences or social sciences, often under the heading of the study of complex systems. When addressing issues regarding society, individuals or the collective behaviours of humans, several questions naturally arise about the modelling enterprise. What is the nature and role of modelling in social sciences? What is one to expect from these new approaches? The case of economics, which has relied on mathematics for a very long time now, can serve as a paradigm for what is happening in other social sciences.

Before we discuss these issues, it should be noted that efforts to develop quantitative and, up to a certain degree, formal approaches to the study of crime started a long time ago. Adolphe Quetelet,¹ one of the fathers of modern statistics, introduced the idea of “social physics” in the 19th century and can be regarded as the founder of the use of statistics and sociology in the study of crime. The sociologist Gabriel Tarde² was also concerned with modelling approaches in criminology and, in a more recent period, Gary Becker’s³ seminal paper has been the starting point for studying crime and criminality from the perspective of economics.

The role of modelling in social science in general, and in criminological studies in particular, comes in several forms that reflect various purposes. First, quantitative and modelling approaches form a language that aims at having terms well-defined and providing a framework where precise statements can be made and scrutinized. In particular, it is with the aid of such approaches that statistical data – and indeed articulated theory – become better understood and appropriately used. Another purpose of the use of mathematics is to construct mathematical models of idealized situations under certain assumptions. These models aim to further the understanding of selected theoretical mechanisms and to test

¹ For example, Quetelet, A. (1835). *Sur l’homme et le developpement de ses facultés, ou Essai de physique sociale*. Paris: Bachelier. There, he writes: “la société cause le crime, les coupables ne sont que les instruments par lesquels il est exécuté.”

² For example, Tarde, G. (1886). *La criminalité comparée*. Paris: Les Empêcheurs de penser en rond.

³ Becker G. (1968). “Crime and Punishment: An Economic Approach.” *The Journal of Political Economy* 76: 169–217.

the limits of the underlying assumptions. For such complex phenomena as criminality (in its various guises), the goal is not to represent the whole reality, let alone generate precise predictions. However, the enhanced understanding of “stylized facts” that characterise a system of interest by isolating elements of a theoretical model can shed new light on a subject and contribute to new insights into the more complex global picture. With the aid of such models, one can then investigate the various effects implied by factors such as the severity of punishment, duration of imprisonment, different deterrence strategies, or the allocation of limited crime reduction resources in the most efficient way.

Considering the effects of policies, optimal control which can be used to allocate limited resources in fighting crime is indeed one of the important applications of modelling in this area. Citing the example of optimal patrolling, at a conference on hotspots of crime, the now San Francisco police Chief George Gascon⁴ emphasized the importance of modelling for practical issues of police decision making.

The development of such theories relies on the analysis of data (even as stylized facts) either at the start of the model building process, or at the validation stage. However, specific difficulties arise concerning data. First, in many countries or cities, data is very difficult to access because it is highly sensitive, sometimes for political reasons, sometimes to keep police intelligence confidential. But even where data is available, it requires extreme care in analysis and interpretation for reasons such as under-reporting and other forms of bias (institutional or otherwise). Comparisons across countries or over time may be particularly problematic as differences in what defines a particular type of crime (even homicide) may vary. These issues are widely addressed in the criminology literature and will not be discussed further here but they should be kept in mind.

The modelling of criminal activity and its reduction may involve different quantitative methodologies. As already mentioned, the statistical approach dates back to Quetelet and his “Social Physics.” Economists and game theorists employ their own methods of reasoning. Other models are based on ideas from statistical physics (like opinion dynamics), epidemiological modelling, or ecology (e.g. foraging theory) with nonlinear ordinary differential equations or reaction-diffusion equations, addressing, in particular, issues regarding the spatial distribution of crime. Most of these different approaches are illustrated by papers in this volume.

This issue is organized into three sections that collectively provide (i) an introduction to research concerned with the study of crime, (ii) examples of research that employ a statistical or inductive approach to hypothesis testing, and (iii) examples of studies that employ a deductive or mathematical approach.

In section 1, the criminologist Felson discusses common misconceptions or fallacies that people have about crime, why it occurs and how it might be prevented. He also provides examples of the types of research question that might be studied by mathematicians and discusses how a more mathematical approach to the study of crime might contribute to the precision with which criminological theories are specified. Gordon provides a very different type of overview by surveying some of the criminological theories that have been examined hitherto and the methods, both statistical and mathematical, employed

⁴ See his lecture at the conference of IPAM, Los Angeles, “Crime hot spots: behavioural, computational and mathematical models”, 2007.

to examine them. In addition, she discusses some of the issues associated with the sorts of data available for analysis and the problem of studying the nonlinearities that exist in social systems with the types of linear models that are common in criminological enquiry.

Section 2 begins with a paper by Haar and Wikström in which they outline one contemporary theory of criminality that links individual and contextual factors to crime causation. Using data collected as part of a longitudinal study of offending in Peterborough (UK), they provide an empirical test of a central aspect of that theory as it relates to violent offences. While this paper focuses on offenders and violent crime, the paper by Tseloni, Ntzoufras, Nicolaou and Pease examines how crime varies at the geographic area level, and discusses theories that attempt to explain such variation in terms of neighbourhood composition and resident routine. This paper represents a departure from previous studies because the authors differentiate between the distribution of composite crimes (those that occur concurrently) and single crime events. The final paper in this section by Johnson reviews research concerned with the concentration of crime in space and time, and reports some original analyses. In this paper, crime patterns are considered at different spatial and temporal scales and theoretical accounts of observed findings discussed.

Each of the papers in this section employs inferential statistical methods to test hypotheses, but the methods employed and the data analysed vary from paper to paper. Consequently, a quick examination of the methodological sections of these three papers provides the reader with an idea of the different types of data available, the challenges associated with their analysis, and an idea of the types of statistical methods employed in quantitative criminology.

A central aim of the final paper in section 2 is to identify substantive topics concerning spatial patterns of crime that mathematicians might seek to model, and to highlight stylised facts against which they might test their models. The first two papers of section 3 do just that. Berestycki and Nadal introduce a family of models to describe the spatio-temporal dynamics of criminal activity. They discuss a range of factors including social interaction, police deterrence and learning, that are believed to influence the timing and location of crime. They then show how these factors can be incorporated into reaction-diffusion models and consider how such models may be used to suggest optimal control strategies. In particular, they study the dynamics of crime hot spots and their reduction. Their paper, which focuses on general patterns of offending, identifies new questions and paves the way for the development of criminological theory and new mathematical models. In the second paper in this section, Pitcher describes the system of nonlinear partial differential equations to model burglar movement and offending behaviour over a spatial domain proposed by Short *et al.* (2008).⁵ She develops this model and shows how different models of police deterrence can be formalized in such a system, and how different configurations influence crime pattern formation. Whereas the Berestycki and Nadal paper takes a wider

⁵ Short, M.B., D'Orsogna, M.R., Pasour, V.B., Tita, G.E., Brantingham, P.J., Bertozzi, A.L., & Chayes, L.B. (2008). A Statistical Model of Criminal Behavior. *Mathematical Models and Methods in Applied Sciences*, 18, 1249–1267.

view of how crime patterns might form in space and time, Pitcher provides a detailed examination of the crime of urban burglary and how this might be suppressed by police action.

The final three papers in this section look at criminality through a different lens. In their paper, Nadal, Gordon, Semeshenko and Iglesias draw on an economic perspective in order to assess how the rate of crime in society is influenced by the deterrent effect of punishment and how this might influence and interact with an individual's level of honesty. Insofar as their model examines how individual differences in the propensity to commit crime might influence crime occurrence, Nadal *et al.*'s paper has parallels with that by Haar and Wikström (Section 2). However, the approach to modeling, which uses both analytical methods and numerical simulations to examine outcomes under a range of scenarios, is distinctively different, as is their goal of exploring the potential policy implications of the emergent phenomena. The fourth paper in this section also considers the role of deterrence on crime, but this time using game theory. In this paper, Andreozzi begins with a review of the general approach before presenting the results of an inspection game for different classes of models. The final paper by Nuño, Herrero and Primicerio, shows how models of population dynamics can be used to investigate the ways in which different classes of citizens contribute to the total wealth of a society. They show how the evolution is affected by a population of "cheaters" who act as parasites, and how they in turn are influenced by different intensities of police action. They also show that in some situations, the use of punishment may come at a cost which outweighs that which would have been incurred had punishment not been employed at all. They close by discussing other types of model that might be used to study these types of problem.

This issue of EJAM has been designed as a forum where criminologists and mathematical modellers meet. It is hoped that it will both stimulate further interest in the criminology community for models and more formalized approaches and attract the interest of mathematicians to delve into a subject of very high importance for society. More generally it is hoped that it will contribute to, and generate more interest in the use of formalized approaches – even ones with limited goals - in the more general area of the social sciences.