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Statistical applications in criminology

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Abstract. This paper discusses the application of statistical methods in criminology. In particular it considers issues surrounding the measurement and definition of crime and modelling the development and progression of criminal careers. Then it reviews aggregate studies of crime rates, which have sought to identify some of the determinants of crime causation; random experiments and prediction methodology, which have been used to evaluate various innovations for preventing crime or for dealing with offenders. Following that, current issues in sentencing offenders, in particular the use of imprisonment and the size of the prison population, are presented. Finally, simulation models of the criminal justice system, developed for further policy analysis, are mentioned.

Introduction

The purpose of this paper is to overview many of the major current issues in criminology together with the statistical methods that have been used to assess them. Obviously it will not be possible to review all the topics or any in great detail. Instead a flavour of current concerns is given together with an indication of research to date and some views as to possible developments. Of course much research in criminology is qualitative rather than quantitative. Such work might include, for example, participant observation or ethnographic studies of crime and delinquency. These approaches are not discussed but their contribution should not be minimised in providing insights into underlying processes and in generating hypotheses for more systematic inquiry.

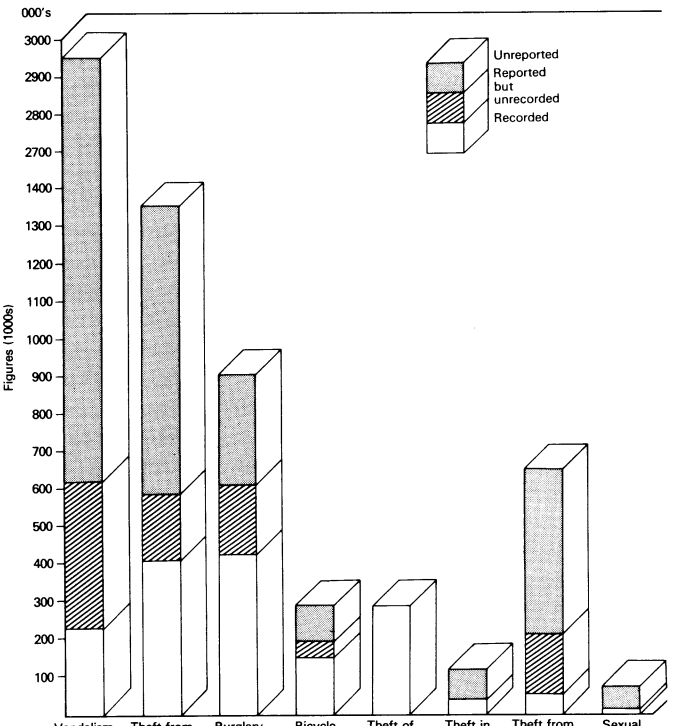
This is an apposite time to undertake a review of the application of statistical methods in criminology as recent years have seen a considerable growth in quantitative criminology, especially in the United States, but elsewhere too. This growth can be gauged by the proliferation of books on the topic, e.g. Blumstein *et al.* (1978), Carr-Hill & Stern (1979), Fienberg & Reiss (1980), Fox (1981a,b), Greenberg, (1979), Hagan, (1982), Heineke, (1978), Maltz, (1984), Schmidt & Witte, (1984) and Wellford (1978). All have sought to re-examine and extend some of the more familiar aspects of criminology and subject them to more rigorous empirical and statistical methods. In the Introduction to his book, Hagan (1982) states "If the 1960s and '70s were years of theoretical innovation in criminology—and they surely were with the rise of labelling, conflict and Marxist theories of crime, and the emergence of the Critical and New Criminologies—then the 1980s are promising to be years of methodological innovation."

Measuring crime: victim surveys

For a long time criminologists have been aware of the limitations of officially recorded police statistics as a measure of the level of crime in society. While such statistics are important and useful, especially in providing an indicator of the workload of the police and other criminal justice agencies, they reflect, at least in part, the public's propensity to report crimes and the police definition and procedures for recording them. Many countries (e.g. Australia, Canada, England & Wales, Holland, the Repub-

lic of Ireland, Scotland and the United States) have supplemented police statistics with victim surveys as an alternative index of crime. But victim surveys are not without their own limitations. They cannot easily count crimes against organisations (such as company fraud, shoplifting or fare evasion), nor 'victimless' crimes involving drug abuse, for example, or some sexual offences. And, of course, there is a set of limitations associated with any sample survey; non-response, recall, sampling errors, etc.

Typically, repeated stratified random samples of the population are selected (or, as in the case of the National Crime Survey in the United States, a panel design is used) and respondents are asked whether they have been the victim of crimes during a given fixed recall period or at any other time during their life and whether the incident was reported to the police. Victim surveys usually reveal higher levels of crime than police statistics. The two British Crime Surveys that have so far been conducted (Hough & Mayhew, 1983; Mayhew & Hough, 1985) indicate crime levels in the order of four times higher than police statistics, although this figure varies considerably between types of offence. By combining information from the BCS with police statistics (*Criminal Statistics, England and Wales*, HMSO, annually) Fig. 1 shows unreported incidents, those which were reported but not recorded and those which found their way into police records.



It can be seen that a large proportion of incidents were unreported for all categories of crime except vehicle theft. The overall reporting rate for crimes shown in Fig. 1 was

38%. Low reporting rates emerged for vandalism, theft in a dwelling, and other household thefts, where about one in five incidents came to police notice. The small number of sexual offences uncovered by the survey also had a very low reporting rate. About a third of assaults, thefts involving personal contact (robbery and thefts from the person) and other personal thefts were reported; the figure is about four out of ten for thefts from motor vehicles. Rather more than two thirds of burglaries and bicycle thefts were reported.

Victims were asked the reasons why they did, or did not, notify the police (multiple answers were allowed). Victims who decided not to notify the police most often gave as their reason the triviality of the incident; in 55% of unreported cases victims said that the incident involved no loss or damage or was otherwise too trivial to report; in 16% of cases victims felt that the police would not have been able to do anything about the incident and in 10% of cases that it was not a matter for the police or one they had dealt with themselves.

Figure 1 shows that many of the offences reported to the police do not get recorded as crimes—or do not get recorded in the crime categories shown. One likely reason for the shortfall is that the police do not accept victims' accounts of incidents: they may—quite rightly—think that a report of an incident is mistaken or disengenuous, or may feel that there is simply insufficient evidence to say that a crime has been committed. Some incidents will have been recorded, of course, but in different crime categories—where, for example, it is indisputable that criminal damage has been committed, but less clear that a burglary has been attempted. Some incidents may have been regarded as too trivial to warrant formal police action—particularly if complainants indicated they wanted the matter dropped or were unlikely to give evidence, or if the incident had already been satisfactorily resolved.

The yearly figure for crimes recorded by the police has risen continuously since the war; from half a million in the 1950s to a million in the mid-1960s, two million in the mid-1970s and to 3·3 million in 1984. It is impossible to say how much this reflects a real rise in crime, and how much changes in reporting and recording. Successive victim surveys, will, in time, also provide information on crime trends which can be compared with trends in police statistics. With only two sweeps of the BCS so far carried out little can be said from this source about the movement in crime. Nevertheless, (for offences that can be compared) the BCS showed an increase in crime of 10% between 1981 and 1983, as against 12% in police statistics. The divergence is not statistically significant, but is consistent with the increase in the proportion of these offences reported to the police (35% in 1981 to 38% in 1983). For domestic burglary, however, comparative information over a longer time period is available. In 1972, 1973, 1979, 1980 and 1985 the General Household Survey has included questions to estimate the number of households, which had been burgled. These findings together with those from the BCS suggest that domestic burglary has risen by 20% between 1972 and 1983 (the 1985 GHS results were not available at the time of writing) whilst the rise in police statistics was more than 100%. The divergence can be explained by increased reporting to the police and increased recording by the police.

In addition to simply measuring crime victim surveys are also an important vehicle for obtaining information on a wide variety of other criminal justice issues. For example, in the two BCSs respondents were asked about their lifestyle (to assess how it affected their chances of becoming a victim of crime), their fear of crime, whether or not they had committed offences, their experiences of dealing with the police and other agencies and their attitudes towards punishment and sentences imposed by the courts.

Summarising some of the main findings on these topics:

(i) Anxiety about crime was widespread. Rape emerged as a considerable source of

worry for women, followed by mugging. Both men and women worried about burglary. Two areas—the poorest council estates and multi-racial areas—showed especially high levels of fear, which were matched by high levels of crime.

(ii) Fear of crime restricted people's behaviour. Half the women in one sample only went out accompanied after dark; 41% stayed away from certain areas. More than one in ten men said that they were kept away from football matches by the threat of violence.

(iii) The survey suggested that people were ill-informed about present sentencing practice, most of the sample underestimating the proportion of convicted adult burglars sent to prison.

(iv) Victims' recommendations about punishment were broadly in line with current police and court practice, showing victims to be less punitive than might be imagined from many opinion polls.

(v) In general, people showed high levels of satisfaction with the police. However, one in five of victims who called the police expressed dissatisfaction: lack of action was the main complaint, though police manner, slow response and poor follow-up were also mentioned.

(vi) A high proportion (almost one in five) of young men complained of misconduct on the part of the police.

Criminal careers: stochastic processes

Turning from issues concerning the victims of crime, the other side of the picture is the offender who commits crime. These two topics are not separate and distinct but are more closely related than has sometimes been ackowledged. For example, analysis of the 1982 British Crime Survey (Gottfredson, 1984) found that for persons who admitted committing violence offences the chance of personal victimisation was 42%, or seven times the chance of personal victimisation for persons who had not committed violence offences. A relationship was found for other types of offences too.

Among the more specific questions addressed by criminal careers research is that of what proportion of the population commits crime. Research generally shows a high level of prevalence but a small proportion of offenders accounting for a disproportionate number of crimes. A recent study by the Statistical Department of the Home Office (Home Office Statistical Department, 1984) found that of all males born in 1953 about 30% had had a conviction for a more serious offence (that is excluding minor motoring offences) by age 28. Between 5 and 6% of males accounted for 70% of all the convictions amassed by this cohort. However, 86% had no more than one conviction by age 28.

Other matters of interest include the rate at which offenders commit crime and variations in this rate amongst offenders. (Application of these rates to estimating the incapacitation effect of imprisonment are discussed later.) At what age do people start committing crime, when do they stop and what is the residual career length? How do criminal careers develop, progress and what are the transition probabilities from committing one type of offence to committing another, that is to what extent do criminals specialise? The answers to these questions have important policy implications in formulating appropriate strategies for dealing with offenders and are behind the recent resurgence of interest in criminal careers research. Here is a typical example of a fundamental criminological issue being revitalised and extended by the application of more sophisticated statistical analysis. In the past information on criminal careers has only been forthcoming from biographical accounts of known, usually atypical, offenders. Data collected from large samples, or from longitudinal studies or cohorts of the general population or of offenders, has made possible the application of

stochastic processes to model the pattern of events over time in a much more detailed and informative way. Much of this work is still in its infancy but a more detailed account of the application of survival models in criminology appears later in this paper.

Determinants of crime: aggregate studies of crime rates

Much of the concern of criminologists is to identify the factors which determine crime rates. Models of varying degrees of complexity, from simple correlation analysis to linear models to simultaneous equation models, have been employed either to test specific theories of crime causation or for the more pragmatic purpose of forecasting future crime rates. More specifically, such studies and analyses have sought to examine, for example, the effects of demographic changes on crime rates (most crime is committed by teenage males) or, to take a particularly relevant issue, the effects of unemployment on crime. The relationship between police manpower, police effectiveness in solving crime, sentencing and crime rates has also been studied.

The problem here, however, is that many of these factors are interrelated. More expenditure on the police or more police officers on the street may deter offenders from committing crimes. On the other hand more police may result in more crimes being discovered, reported or recorded. Econometricians will recognise this as an example of simultaneous causation and would specify a simultaneous equation model using appropriate estimation procedures (e.g. TSLS, FIML) to avoid the obvious pitfalls and biases resulting from single equation estimation methods. Models have been fitted to time series data; Fox (1978) used national U.S. data for the period 1950–1974; however, the more common approach has been to compare data across geographical areas or police departments. The latter was adopted by Carr-Hill & Stern (1979) who compared data across police forces in England and Wales for the three census years 1961, 1966, and 1971. A brief description of their work will amplify what these kinds of studies seek to accomplish.

After reviewing criminological theory and much previous research, Carr-Hill & Stern specified the following model.

$$y=f(p, c, f, a, w, u, rv, e) \tag{1}$$

$$p=f(y, c, a, w, n, e, v) \tag{2}$$

$$c=f(y, p, m, v, d, u) \tag{3}$$

where the endogenous variables are:

y number of recorded offences per capita,
p probability of detection,
c number of police officers per capita,

and the exogenous variables are:

f proportion of convicted males given custodial sentences,
a proportion of young males (15–24) in population,
w proportion of population that is working class,
rv total rateable value per acre (i.e. value of property),
e total police expenditure per officer,
n total population,
v proportion of offences that are violent,
m proportion of population that is middle class,
d population density,
u unemployment rate.

Looking at the first equation, hypothesised significant negative coefficients for the variables p, the proportion of crimes cleared, and f, the proportion of sentenced offenders given custodial sentences, are quoted as evidence of deterrent effects. While not all studies find a negative or significant coefficient invariably the association between the crime rate and p is stronger than the association between crime rates and f. This has reinforced the belief that for deterrent purposes it is more important to catch criminals than the sentences imposed when caught. Age distribution is invariably found to be an important determinant of crime rates.

The second equation provides some indication of the effects of police manpower and resources and other factors on police performance in clearing crime. The third equation (which has usually been omitted in most other studies) models the demand and supply of police officers.

While macro studies such as these using aggregate data can be suggestive of the factors affecting crime and police performance they are not without severe limitations. Firstly they are, by necessity, restricted to easily obtainable and readily available data so do not take into account the many other factors influencing crime. But there are complications even with the data available. Changes in reporting practice, changes in legislation or alterations in the way crimes are counted may affect the level of crime. (Some of the other exogenous variables may be similarly affected.) These factors may well have produced some discontinuities in crime rates at certain points in time and may be a particular problem for time-series analyses. Moreover, it is a matter for conjecture to what extent increases in recorded crime which have occurred are due to changes in the public's inclination to report crime (evidence on this is emerging from victim surveys). Furthermore, the police may define, record or clear-up crime in different ways as many ethnographic studies of police practice reveal. Another possible drawback to aggregate studies is the ever present possibility of the 'ecological fallacy'. For example, even where the overall level of unemployment is correlated with the overall recorded crime rate it does not necessarily follow that the unemployed are committing the crimes. Another problem is that many of the exogenous variables are themselves highly interrelated so the importance of any one is dependant on which other variables are included; that is, the inferences are often influenced by the specification of the model itself.

Despite the limitations the method itself remains sound and it at least acknowledges and explicitly addresses the problems of simultaneous causation. What is needed is to complement this basic approach with research at the micro level.

A similar conclusion emerges from an examination of the literature on the relationship between unemployment and crime. A recent paper reviewed some 30 or more studies on this issue (including Carr-Hill & Stern's) and found "the results of these studies do not satisfactorily resolve the question of the impact of unemployment on crime and no discernible pattern amongst the results emerges. On balance rather more found no evidence of a significant relationship ... than found some evidence of a significant relationship ... Obviously the studies varied in their quality and sophistication, but even applying the most rigorous standards and eliminating those that did not meet them did not produce consistent findings" (Tarling, 1982). (Since I wrote this, work carried out by an expert group of the Council of Europe has come to a similar conclusion.) More cogent evidence of any relationship between unemployment and crime, would, I argued, only be forthcoming from detailed research at an individual level which monitored employment records, other important factors affecting criminality and criminal activity over time (something which could form part of an ongoing programme of research on criminal careers). Micro research could then specify appropriate relationships to be incorporated in macro models.

The value of research at the micro level has further been evidenced in the police field. Ethnographic research in individual police forces in England and Wales clarified

the extent to which the police used alternative methods to clear crime. This enabled Burrows & Tarling (1982), using additional data for all forces, to test alternative indices of police performance and other exogenous factors within the framework of Carr-Hill & Stern's model. We found that the type of crime with which the police have to deal proved to be the main determinant of a force's clear-up rate.

An advance in aggregate studies of the determinants of crime is to use results from victim surveys as an alternative measure of crime in order to overcome the influences of reporting and recording. This is beginning to occur in the U.S. but for most other countries victim surveys are a relatively recent innovation which precludes their use in any time series study and the sample sizes have not been large enough to allow cross-sectional analysis. Nevertheless, as more evidence becomes available on people's reporting habits and on police recording practices one possibility, so far underexplored, could be to model the relationship between official statistics and victim surveys.

Evaluation

Inevitably much criminological research is devoted to evaluating programmes, new innovations or changes in legislation intended to affect crime or criminal behaviour in some way. Examples might be the evaluation of schemes to rehabilitate offenders by counselling, group therapy or supported work schemes, or the evaluation of the effectiveness of different forms of sentence in achieving rehabilitation or some other end. The criterion most usually chosen is whether such schemes result in a reduction in subsequent offending. Several crime prevention initiatives, such as property marking (engraving on goods the owner's name and address) or neighbourhood watch (in which neighbours join together to keep watch on each others' homes and their immediate surroundings) have also been evaluated. Here the criterion is whether crime rates or the value of property stolen falls, or whether stolen property is more readily recovered. Changes in police operations, such as, changes in the level and type of police patrol or in the practice concerning the tape recording of interviews with suspects provide further examples of innovations criminologists are required to evaluate.

The results of evaluations of initiatives intended to rehabilitate offenders have often been disappointing. The conclusion often drawn is that 'nothing works'. In the light of this pessimistic view the National Academy of Science in the U.S. convened a panel of experts to review the current state of knowledge on programmes to rehabilitate offenders (Sechrest *et al.*, 1979; Martin *et al.*, 1981). The Panel endorsed the view that there is little in the reported research literature that demonstrably works, but considered that the conclusion 'nothing works' may be premature. They pointed out that many possible initiatives have not been tested and the interventions that have been tested were usually weak, or not propertly implemented, or unfocussed and not specifically directed at those who might profit from them. Furthermore, the evaluations were often deficient and inadequate in methodological respects. The panel concluded that research should be pursued "more vigorously, more systematically, more imaginatively and more rigorously" and also recommended that more emphasis should be placed on developing appropriate methodologies for use in evaluation research. Since then Klien & Teilmann (1981) have produced a handbook with much practical advice to programme organisers and researchers. But some of the statistical issues in evaluation research have been less thoroughly considered.

The main methodological approaches adopted fall into two broad categories: (1) randomised experiments and (2) retrospective matching, statistical controls or prediction. Each will be briefly discussed.

Randomised experiments

Although many simulated experiments have been conducted, for example, the organisation of students into mock juries or the presentation to a group of sentencers of hypothetical or real cases for adjudication (the latter being particularly useful in training courses), there have been relatively few experiments in real life settings. In his review, on which I draw heavily here, Farrington (1983) identified about 40 randomised experiments although a few more could now be added to his list.

From the statistical point of view most experiments were fairly simple in conception and design. They invariably involved just two treatments or one treatment and a control group, subjects being randomly allocated to either treatment (or control). There are no examples of anything more sophisticated in terms of factorial designs, Latin squares or related techniques and little replication. A failure to use such designs makes the study of interactions between different factors difficult if not impossible.

The lack of development of randomised experimentation has much to do with the ethical and practical considerations of experimentation in the criminal justice context. For example, it is considered unethical, inequitable and unjust for courts randomly to ascribe sentences to offenders appearing before them. This has meant that most experiments have been limited to narrow ranges of alternative disposals within sentences, where ethical considerations are less paramount. For example, in Shaw's (1974) study 176 male prisoners were randomly allocated to receive some form of counselling while in prison or to a control group which did not receive counselling. In Folkard's *et al.* (1976) study 900 probationers were randomly allocated to intensive probation (where they met probation officers about 3 times per month) and regular probation (where they met probation officers about 1·5 times per month).

Even when ethical issues can be surmounted, many practical problems remain. It is often difficult to ensure that the experiment is carried out according to the researcher's intentions. There are many examples of random allocation procedures being influenced or tampered with in some way usually by permitting certain exemptions; and it is virtually impossible to achieve 'double blind' conditions. Inmates in institutions, for example, are soon aware that they are being subjected to a different programme from others. This awareness can produce a Hawthorne effect—the special concern or attention given to subjects could itself be leading to an improvement in their behaviour. Again some subjects may simply refuse to participate. Furthermore, it is often unclear what the intended treatment was or whether it was in fact carried out other than in name. In addition, after a short time the treatment may become dissipated or introduced to the controls, that is, some contamination of the two groups often occurs which is difficult to prevent in the absence of double blind conditions.

Prediction

Given the difficulty of conducting randomised experiments a far more common approach when comparing different sentences or groups exposed to different programmes has been to control statistically, ex post facto, important selection and background variables and to construct prediction models. Regression type analyses are carried out on significant variables and the predicted value of some response measure is used as a covariate in statistical analysis using covariance adjustments.

Prediction instruments have also been developed to guide administrative decisions. For example, both in the U.S. (Gottfredson *et al.*, 1978) and in England and Wales (Nuttall, 1977) prediction instruments have been derived which estimate an offender's chances of reoffending or being reconvicted whilst on parole licence following release from prison. The American Salient Factor Score and the British reconviction predic-

tion score are used by the appropriate authorities as one input guiding the decision whether to grant an offender parole. Recently these ideas have been extended into other areas noticeably to develop sentencing guidelines in the U.S. (a topic which will be covered more fully in the next section of this paper). A full review of the development of prediction methodology in criminology and examples of its application, are given in Farrington & Tarling (1985). Here there is space only to just concentrate on the major methodological and statistical issues: the specification and measurement of the criterion; the statistical methods that have been used to construct prediction instruments and their calibration and shrinkage.

The dependent variable most often used in these studies and the criterion used in any evaluation (including randomised experiments) has been a simple dichotomy, success or failure; failure being reconvicted during some follow-up period. But this criterion may be inadequate. Firstly, reconviction may not be a true measure of reoffending depending as it does not only on reoffending but on being caught and prosecuted for the offence. Nor does it reflect the type of reoffending, for instance, a reconviction of minor shoplifting will often be counted the same as a reconviction for armed robbery. There are several ways round these problems. Alternative measures can be used such as rearrest, self-reported reoffending or reconvictions of an equally serious or more serious offence. However, ranking the seriousness of offences poses problems and there is no unambiguous agreement as to how this should be done.

Binary dependent variables pose other well known problems, OLS regression is not theoretically justified in this situation and a more appropriate technique is logistic regression (or a log-linear model which, appropriately specified, gives the same results). Criminologists have readily embraced these theoretically superior methods, but have found them to produce approximately the same estimate of $\hat{p}$ (the probability of failure) as regression. Furthermore, in comparing all forms of linear models and some clustering or numerical taxonomy techniques researchers have found them to be no better (however defined) and in many cases inferior to simple more intuitive point scoring methods developed many years ago by Burgess (1928) and Glueck (1950). In the Burgess method each subject is given a score of either 0 or 1 on each of a number of predictors depending on whether he falls into a category with a below or above average failure rate. The Glueck method is slightly more complex in that instead of contributing a score of 0 or 1 each category of each predictor is weighted according to the percentage of subjects in it who fail.

Experience indicates that point scoring methods are more robust and shrink less than the more sophisticated methods when applied to a second, validation, sample. This, together with their simplicity accounts for their continued popularity in practice (both the Salient Factor Score and the reconviction prediction score used one of these methods) despite the criticisms that they are intolerably crude and have no statistical foundation.

The latter criticism was investigated by Copas & Tarling (1985) who noted that point scoring methods have their parallels in standard statistical theory—the 'independence Bayes method'. In fact they showed that Burgess & Glueck are not separate and distinct methods but are, in fact, simple loglinear models in which all the predictor variables are treated as independent. For example, it can be shown that the Burgess method reduces to:

$$\frac{P(F(\text{failure})|\,\text{x})}{P(S(\text{success})|\,\text{x})} = \frac{q}{1-q}\,\frac{\pi P(x_i|\,F)}{\pi P(x_i|\,S)}$$

where q is the overall failure rate and so log-odds for F after observing x

$$=\log\frac{q}{1-q}+\log\Sigma\log\frac{P(x_i|F)}{P(x_i|S)}$$

which can be written as

$$k+\Sigma W_i x_i$$

where

$$W_i=\log\frac{g_i(1-h_i)}{(1-g_i)h_i}$$

where

$$g_i=P(x_i=1|F) \text{ and } h_i=P(x_i=1|S)$$

which is just the log-odds ratio for the 2×2 table classifying $x_i=1$ or 0 against F and S. However, given independence the Burgess method is only optimum if the cross product ratio is the same for each factor (that is, each x_i gives the same amount of information about F or S).

Thus the simple and intuitive methods developed by criminologists can be accommodated within standard statistical theory. Follwing this Copas & Tarling advocated the use of the formal independence Bayes method in preference to the more *ad hoc* Burgess & Glueck procedures because it has the advantages of being based on a more coherent statistical theory; it provides a direct estimate of $P(\text{failure}|x)$ (whereas the scoring methods have to be separately calibrated on the data) and, furthermore, it permits certain extensions (not permissible for Burgess & Glueck) which have been considered in the medical literature under the name of 'computer-aided diagnosis models', many of which have been reviewed by Titterington *et al.* (1981).

Another criticism levelled at binary response variables is that an offender reconvicted after the end of the follow-up period would, erroneously, be counted as a success. The statistical theory of censored survival data could have much to contribute here. Firstly, measuring time to failure is more informative (merely recording whether an offender was reconvicted during a fixed period wastes information because it only examines what is essentially one point on the survival curve). Secondly, techniques such as logistic regression are only appropriate when the data are not censored.

Although failure rate or survival models have generally not been used in criminology there have been several notable exceptions and, in these instances, they have been found to be quite powerful, leading to inferences not permitted following the application of more familiar methods. Analysing recidivism as a failure rate process has recently been discussed by Maltz (1984). Maltz reviews previous work and sets out the major distributions available. One consideration in modelling recidivism is that not all individuals fail. He therefore dismisses the exponential, the log-normal and the Weibull distributions because these assume that every individual will fail given time. Because of its versatility, interpretability and its success on several data sets, Maltz concludes that the incomplete exponential distribution is the most suitable for studying recidivism. The incomplete exponential distribution is

$$P(t)=\gamma[1-\exp(\phi t)]$$

where γ is the probability of an individual eventually failing and ϕ is that person's failure rate should he or she do so.

The exact nature of the failure rate distribution is still under-explored in criminology. In the meantime it may be better to employ the non-parametric failure rate model proposed by Cox (Cox, 1972, Cox & Oakes, 1984), especially as it readily

accommodates censored data and independent variables which vary over time. In Cox's model (also known as the proportional hazards model) the failure rate $\lambda_i(t)$ at time t for the ith individual is related to the independent variables as

$$\lambda(t,x)=\lambda_0(t)\exp(x',\beta)$$

where $\lambda_0(t)$ is an arbitrary (and unknown) non-negative function of time, x is the vector of independent variables and β is the vector of coefficients. The factor $\exp(x'\beta)$ is the risk associated with value x for the regression variables relative to the value $x=0$. The relative risk can vary with survival time by allowing components of x to depend on time, i.e. $x=x(t)$.

So far there has been one application of this model in criminology. Barton & Turnbull (1979 and 1981) applied it to rearrest data for samples of offenders from two institutions in Connecticut. The proportional hazards model is for continuous time and, in theory, ties should not exist. However, in practice they often do as failure times might be grouped (e.g., offenders rearrested in each month). Various adaptions to the basic model have been proposed for grouped data and Barton and Turnbull compared three of them. They found that the three gave very similar results suggesting that there is probably little to choose between them.

It is likely that, in the near future, failure rate regression methods will become standard procedures in criminology. In order to facilitate their adoption Barton & Turnbull make two specific recommendations for the future. Firstly, that more attention should be given to understanding many of the underlying distributions of criminal behaviour as this will enable researchers to choose between and capitalise on parametric techniques (something that criminal careers research could illumine). Secondly, more accurate recording of failures (e.g. by day or week) in future studies would reduce the problem posed by tied data.

As pointed out one of the concerns in prediction research has been the degree of shrinkage found when models developed on a construction sample are tested on a second, validation, sample: large values of y tend to be overestimated and small values of y tend to be underestimated. One of the empirical findings has been that more complex models, which take into account the joint distribution of the x's, shrink more than simpler 'independence methods' when tested on a validation sample. This has led criminologists to eschew more sophisticated methods in preference to the point scoring methods described earlier.

The phenomenon of shrinkage has, however, been subject to rigorous examination in recent times by Copas (1983). He has shown how the expected degree of shrinkage can be estimated. For example, for multiple regression it is possible to predict the size of the validation correlation from that of the retrospective correlation by the formula:

$$\tilde{R}=\frac{(n-1)R^2-m}{(n-m-1)R}$$

where R is the correlation in the construction sample, n is the sample size and m is the number of predictive factors (where $m\geqslant 3$).

Further extensions to this theory enable researchers to derive 'preshrunk' predictors, $\tilde{y}$
where

$$\tilde{y}=\hat{y}+\hat{K}(\hat{y}-\bar{y})$$

where $\bar{y}$ is the overall observed average of y and $\hat{K}$ measures the deterioration.

$$\hat{K}=1-\frac{m-2}{mF}$$

where F is the usual F-statistic associated with multiple regression. The value of $\hat{K}$ lies between 0 and 1. In the case of logistic regression:

$$\hat{K}=1-\frac{m-2}{X^2}$$

Further developments lead to estimates of the additional shrinkage expected when a subset of variables are selected as in stepwise regression. However, before applying these formulæ the validity of the assumptions on which they are based should of course be examined (see Copas, 1983).

Copas states that the view often held by criminologists, that a simple model is preferable to a more complicated one solely because it shrinks less, cannot be sustained. Proper statistical principles should be used in assessing fit to data; any shrinkage problems which arise should be allowed for by preshrinking rather than by distorting the models being fitted. When Copas' ideas have been applied to criminological research methodology they should illumine future evaluation and prediction work. Their application should thus avoid certain potential pitfalls.

Sentencing, imprisonment and the size of the prison population

Recent years have seen much research activity into aspects of sentencing. In the preceding section it was suggested that attempts to rehabilitate offenders had so far been disappointing. This, together with a growing emphasis, at least, in the U.S., on the theory of 'just deserts' (making the punishment fit the crime rather than tailoring it to the needs of the individual) and a growing concern over disparity in sentencing, has resulted in moves towards mandatory or more determinate sentences in the U.S., and to a greater limitation of judicial discretion in sentencing. At the same time, disenchantment with the ability of sentences to rehabilitate offenders has resulted in more attention being given to some of the other aims of sentencing: deterrence and incapacitation (the latter being the extent to which offenders are prevented from further offending during their time in custody). Much of the task of empirical researchers, therefore, has been to assess the effects of legislation and administrative changes, in particular their impact on the size of the prison population. The growing prison population in many countries has also provoked policy and research interest in its own right, independently of wider concern with sentencing reform.

One way to control discretion which has gained favour in many states in the U.S. has been to develop decision aids or sentencing guidelines. This is a simple adaptation of the prediction methodology discussed earlier. Although details vary between jurisdictions the principles underlying such projects have been broadly similar. First regression analysis is undertaken to identify the important factors influencing the choice of sentence. Consistently, the most important seem to be the seriousness of the

offence and the number of previous convictions. (Age is another important factor but analysis is often undertaken separately for juveniles and adults and separate guidelines produced.) Sentencing guidelines are then set out as a matrix; the rows and columns being an offence score and an offender score. For each combination (the cells of the matrix) a guideline sentence—or more accurately, a narrow range of sentences—is stated. This sentence indicates whether or not the offender should be imprisoned and if so the minimum and maximum term allowed. The guideline sentence is descriptive in that it is the range of sentences which have been imposed in the past on the majority of cases with that combination of scores.

Although many guidelines have been produced, little attention has been paid to validating them or to assessing their structure. Sparks (1983) describes some of the problems in their use and offers some solutions. One question is whether guideline sentences 'step up' in a reasonably orderly fashion. Are the effects of offence and offender score reasonably consistent across the matrix or are guidelines in some of the cells markedly different in some irrational or surprising manner? Visual inspection of the guidelines may reveal such potential problems but they may not always be totally obvious. Sparks suggests applying EDA techniques, in particular a simple additive model of row and column effects, calculating the residuals for each cell, in order to gain greater insights into the recommended practice and to identify any anomalies.

Studies of the impact of sentencing reforms lead on to studies which attempt to forecast the size of the prison population. This is important not only as a measure of the effects of sentencing but also (and perhaps even more importantly) to prison capacity. The two issues are intertwined in that projections of future levels of imprisonment may themselves prompt wider sentencing reforms.

The simplest way to forecast the prison population is to extrapolate existing trends linearly. Slightly more sophisticated methods might include ARIMA models. These techniques may be adequate in the short term but given the lead time in building prisons planners also want good estimates for the medium and longer term. Multiple regression models have been proposed to take account of the independent factors determining imprisonment. Independent variables that have been suggested include demographic variables, unemployment rates, sentencing variables such as Q the probability of being sentenced to prison) and S (the average sentence length). However, such a model would require future projections of the independent variables and these may be more problematic than projecting prison populations themselves. It therefore seems preferable to rely on such variables as age, race and sex which can be projected more accurately, and which are known (at least in the U.S.) to relate to imprisonment rates. For example, U.S. data for 1979 shows that the peak imprisonment rate for white males occurs at age 23 and is 2·2 times that at ages 35–39 and 8·8 times that at age 40 or older. The imprisonment rate for black males reaches its peak at ages 25–29 and is 7·5 times the peak for white males. The age falloff for black males is comparably fast, the peak being 2·5 times the rate at ages 35–39 and 9·1 times the rate at age 40 or older. Imprisonment rates for all males is 25 times that of females. Blumstein *et al.* (1981) capitalised on these differences to develop forecasts of the prison population. Using their notation the first step is to estimate the number of offenders committed to prison.

$$C_{tjo} = N_{tj} \times a_{tjo} \times c_{tjo} \times Q_{tjo}$$

where:

C_{tjo} = number of commitments to prison in year t for offence o of people in demographic group (age, race, sex combinations) j;
N_{tj} = number of people in the general population in year t in demographic group j;

a_{tjo}= demographic-specific arrest rate for offence o in year t;
c_{tjo}= probability of conviction given arrest;
Q_{tjo}= probability of commitment to prison given conviction.

Then, P_t, the number of prisoners in any year t, depends on the number of prisoners in the previous year, $P_{(t-1)}$, the average time served per commitment, S and the number of commitments, C. Assuming that prison receptions arrive according to a Poisson process and that time served is exponentially distributed

$$P_{tjo}=P_{(t-1)jo}\times e^{-1/S_{tjo}}+C_{tjo}\times S_{tjo}\times(1-e^{-1/S_{tjo}}).$$

The total prison population is then

$$P_t=\sum_j \sum_o P_{tjo}.$$

Using the above, projections for Pennsylvania until 2000 indicated that arrests should reach a peak at about 1980 (when the 1962 birth cohort reached age 16–18 (the peak age for arrests)). Commitments to prison would peak at about 1985 (the lag is because juveniles or first time offenders are not likely to be sent to prison only adults in their mid-twenties who have accumulated several previous convictions). Prison populations would peak at about 1990; this lag reflects the fact that the prison population will still accumulate even after the input flow has peaked because it will take several more years before the departure rate (reflecting time served) exceeds the declining arrival rate.

This method at least gives some weight or sensitivity to demographic changes and is particularly appropriate when significant demographic changes are taking place. But Q and S may also change over time. This can be seen in England and Wales where the sentenced population in prison (that is offenders found guilty and sentenced to imprisonment) actually went down by 100 during the 5 years 1979–1983. This resulted from as light decrease in Q due to the introduction of diversion measures but more especially to reductions in S, the average sentence length (partly because of shorter sentences being imposed by the courts but also due to changes in parole eligibility). However, the total prison population went up in that period by about 1200 and this is attributable to an increase in the number of persons in prison awaiting trial.

Analysis by Morgan (1983) showed that the increase in the number awaiting trial stems from several factors; an increase in the number of defendants remanded and an increase in the length of time they spent in prison awaiting trial because of the congestion at courts in hearing cases. This then suggests some possible extensions to the Blumstein *et al* model to incorporate some parameters which reflect the numbers of unsentenced prisoners. Predicting the prison population is an area of criminology where improved statistical models have much to contribute. Further changes are evident since 1983. The number of persons in prison awaiting trial has continued to increase (by about 2000) but so too has the sentenced population (up by about 700), particularly the number of adult males serving medium and long term sentences.

International comparisons of prison populations

International comparisons of the size of the prison population are another area of study. Though illuminating these comparisons are not simple, since definitions of prisons and prisoners vary from country to country. Nevertheless, attempts are worthwhile for the insights they provide enabling each country an opportunity to put

its own domestic response to crime into a wider context and to learn from the experiences of others. One recent attempt was that of the Council of Europe who collected information from each of its members on the size of the prison population as at 1 February 1983 and the number of persons sent to prison in 1982. From these two figures they derived an indicator of the average time spent in prison. Statistics were expressed as a rate per 100,000 of the population. Information for a selection of countries are presented below (details for all countries are available from *Prison Information Bulletin*, June 1984, Council of Europe).

Country	Prison population per 100,000	Number of Persons committed to prison per 100,000	Indicator of average time spent in prison (months)
Belgium	55	212	3·0
Denmark	66	378	2·0
England and Wales	88	316	3·3
Federal Republic of Germany	104	200	6·2
Ireland	37	188	2·4
Netherlands	27	202	1·6
Switzerland	59	167	4·2

Considerable further work needs to be done to obtain truly comparative international statistics of imprisonment and there are critics of even these figures. But leaving those aside, the table again serves to illustrate the importance for the size of the prison population of S, average sentence length, and Q (although Q is the imprisonment rate per capita rather than the proportion of convicted offenders). Taking England and Wales as a reference point it can be seen that only the Federal Republic of Germany had a higher per capita prison population (104) which results from the longer average sentences imposed there (6.2) rather than its greater use of imprisonment. On the other hand, Denmark has a lower prison population per capita than England and Wales despite its greater use of imprisonment. This is achieved by a lower average sentence length. Not surprisingly, given its very low prison population, The Netherlands has attracted most attention from commentators and researchers (e.g. Downes, 1982). It can be seen that the use of imprisonment in The Netherlands is not dissimilar to that in many other countries (although much lower than for England and Wales) but a lower prison population ensues because of a very low average sentence length, when compared with British practice.

Incapacitation

A further topic, attracting considerable research interest is the extent to which prison prevents crime by incapacitating offenders. The argument runs that even if prisons do little to rehabilitate offenders and perhaps little to deter them or other potential offenders they at least have a more general preventive function. Furthermore, if the

objective is to reduce the prison population (by reducing Q and/or S) this would be at the cost of increases in crime as some offenders would be at liberty and committing further crimes when they would otherwise have been in prison. Brody & Tarling (1980) attempted to estimate the number of additional convictions that would result if prison sentences were reduced, either by increasing remission from its present level of one-third to one-half, or by reducing the time served by each offender by four months. Data from a random sample of 770 prisoners who were in prison on a particular day were analysed. The rate at which each offender was convicted while at liberty, λ_c, was calculated by:

$$\lambda_c = \frac{\text{Number of convictions}}{\text{Age at current conviction—[Age of criminal responsibility (10 in England and Wales)+total length of time previously spent in custody]}}$$

Having calculated the rate of convictions, λ_c, for each offender it was possible to estimate the extra number of convictions each would be likely to accumulate in a given period. But to assess what effect the two policies would have on the overall number of convictions in any one year the estimates for the sample had to be extrapolated to the number of offenders leaving prison during the year. To do this the sample had to be re-weighted accordingly, because being drawn on a particular day, it was only representative of offenders in prison on any one day, not of offenders leaving prison during the year. (Obviously those leaving prison have a lower average sentence length, S, than those in prison at any point in time). Having made the necessary adjustments it was found that increasing remission to one-half would be likely to increase the annual number of convictions by 1·2% and reducing the time served by each offender by four months would have increased convictions by 1·6%. Furthermore, increased remission would have reduced the time spent in prison of those leaving by 25% and shortening the time served by each offender would have reduced the time spent in prison by 40%. Similar kinds of results have been obtained by other researchers (see, e.g. the review by Cohen, 1978).

Such results demonstrate that significant reductions in the prison population can be achieved at the cost of relatively modest increases in the number of convictions. This imbalance is intuitively obvious, since only a relatively small proportion of convicted offenders are sentenced to imprisonment and most are only in prison for a relatively small proportion of their lives. The converse is also true: large increases in the prison population are needed to make any significant reductions in crime rates unless prison sentences can in some way be reserved for the small proportion of offenders who are responsible for the majority of crimes. This strategy is sometimes described as 'selective incapacitation'. Unfortunately it demands that the small proportion of high rate offenders can be identified accurately and their behaviour predicted in advance. The search for such predictive knowledge is, in part, the motivation behind the interest in criminal careers research and the further interest in prediction methodology. Leaving to one side the important issues about the ethics and justice of sentencing offenders for crimes they have not committed but might do, research so far suggests that it is much easier to identify high rate offenders retrospectively than prospectively at an earlier point in their career. One last point, often forgotten, is that courts already operate a selective incapacitation policy when sentencing offenders, thus any alternatives must be gauged in terms of their improvements over existing practices.

Interdependence: modelling the criminal justice system

This paper has so far discussed many current criminological issues together with the statistical analysis that has been carried out. In the course of this discussion I have given several examples of how changes in one part of the system produce effects elsewhere. More police, or different police tactics, may deter or prevent crime but may also result in more crimes being reported or recorded. Different sentencing policies can affect the size of the prison population and an increase in the number of defendants appearing at court will increase waiting times and the length of time defendants spend in prison awaiting trial. Shorter prison sentences will lead to some, if small, increases in crime, arrests and convictions. These examples illustrate the many interactions that can occur and highlight the interdependence of the various components of the criminal justice system.

To understand these complex inter-relationships and to assess the impact throughout the system and the resource implications of alternative policy options a model of the criminal justice system is needed. The approach adopted in several countries (Canada, England and Wales and the U.S.) is to construct a computer simulation model. There are several advantages to this: it may be impossible or extremely costly to observe certain processes or the result of certain policies in the real world; the system may be too complex to be described by a 'closed form' analytic model and the process is usually subject to continuous change and is nonlinear in its behavioural patterns.

The model developed for England and Wales is described by Morgan (1986) from which this brief account is drawn. The basic structure of the model is depicted in Fig. 2. The model is constructed as an overall flow model linking the five sub-models, one for each of the main components (police, magistrates' courts—the lower courts, Crown Court—the higher courts, prison and probation). The flow model handles the passage of defendants through the system from the point of prosecution by the police until the point of acquittal or sentence and performs any necessary transformations of data between the sub-models (for example the change from Crown Court circuits to prison regions). The recidivism feedback loop shown on the left has not yet been implemented. The sub-models are mainly concerned with the availability and use of resources and estimate, for example, the cost of providing any new resources which are required, or the deterioration in service which would be expected if no more resources were made available. Where appropriate, the sub-models also determine the throughput of cases and hence the number of cases (or defendants) passed on to subsequent stages in the system.

The simulation proceeds by generating individual or groups of cases which are made to take different paths through the model in proportions that reflect actual practice. Constraints imposed by limited resources can be represented, and, in the courts, have the effect of limiting the number of cases that can be processed—and hence passed on to the next stage—in a given time period. Delays which result from these contraints, or bottlenecks, in the system can be recorded, as also can various other statistics about the passage of the cases. The likely effects of alternative policies can be examined by simply altering the proportions taking different paths through the system (or changing the 'branching ratios'). A detailed description of the magistrates' courts sub-model is given by Rice (1984), the police sub-model by Barton (1984) and the flow model by Pullinger (1986).

Simulation models have already been beneficial in assessing many problems. Blumstein's research presented earlier on projecting prison populations and the likely effects of different sentencing policies was carried out with the aid of his JUSSIM model. Morgan, too, used the English model to disentangle the effects of waiting times at court on the number of people in prison awaiting trial. In addition, this model is

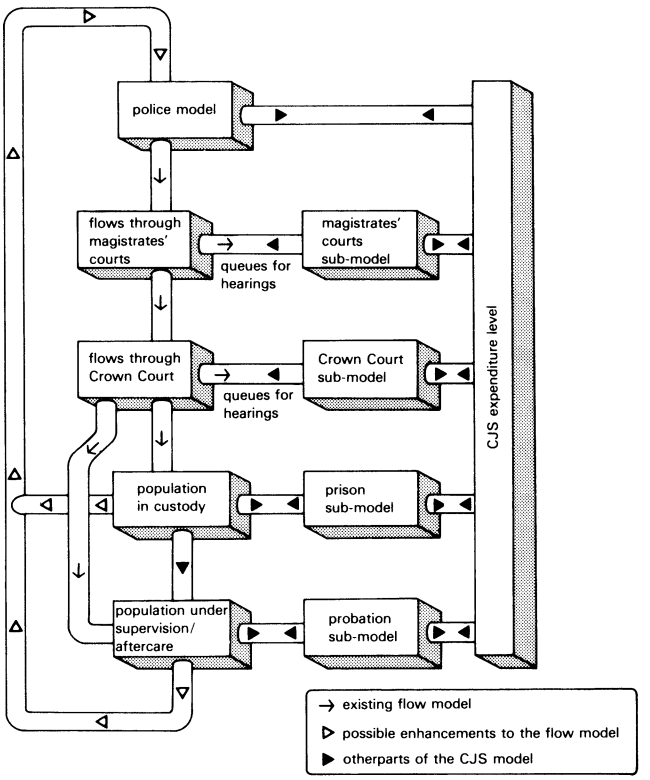


Fig. 2. The structure of the CJS model.

currently being employed to assess alternative policies for dealing with the problem. For example, if cases involving defendants in prison awaiting trial were accorded higher priority by the courts what effect would this have on the numbers in prison and how would this affect waiting times in hearing cases where the defendant is on bail (that is in the community and not in prison)? There is another confounding factor, legislation has recently been introduced in the U.K. which will extend fixed penalties (a mandatory fine which is simply paid by post) to many minor motoring offences instead of being dealt with by the courts. This, itself, should alleviate courts' workloads and release resources for other cases. To give some impression of their possible impact simulations are being run specifying different assumptions about the effects accruing from the introduction of fixed penalties and of different priorities attached to 'custody' cases. Results will indicate the effect on the prison population and the possible increases in delays in hearing bail cases.

Another approach to modelling the criminal justice system is to construct a simultaneous equation model of the sort described earlier. Simultaneous equation models are still in their infancy in criminology compared with macro models of the economy which extend to several hundred equations. Carr-Hill & Stern's model with just three equations is typical. Orsagh (1981) has recently specified a 12 equation model but this is still fairly primitive by comparison. Nevertheless, in addition to their role in testing hypotheses of crime causation and in forecasting crime rates, these models can be extremely useful in estimating key parameters or weights which can then be incorporated within simulation models. The relationship between police resources and the proportion of crime cleared by the police established by Burrows &

Tarling is used by the police sub-model and Rice carried out regression analyses to estimate the number of staff required to handle certain combinations of cases at court.

Before leaving this section it should be stressed that the models so far presented (of whatever sort) operate, of necessity, at a high level of aggregation and can address broad policy objectives. However, can such policy options identified by these models be implemented in practice? For example, is it feasible or practical to accord higher priority to custody cases or are there some other reasons, intrinsic to custody cases, which inhibits the policy or sets limits to what can be achieved? It may be that delays are caused by the complexity of these cases, the amount of evidence to be assembled or the problems of finding a mutually convenient date for all the many witnesses and other participants who need to be present. In addition to these models, therefore, complementary research is needed at the micro level to establish the causes of delay and to test whether officials responsible for operating the system can implement any policies proposed. Several projects of this nature are currently underway in England.

Conclusions

This review of the major current issues in statistical criminology has inevitably been brief. But even a review of this length demonstrates the richness of new ideas and techniques currently extant. Statistical criminology has much to tell us in the fields of victim surveys, recidivism, incapacitation the effectiveness of treatment and the effects of policing. Modelling work, either by simulation or by econometric technique, can illumine the workings of the whole system. There are issues here in plenty for other scholars both inside and outside Government. It is hoped this paper will stimulate further work.

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