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Abstract

Why is it that some offenders get arrested quickly, while others manage to evade arrest much longer or are never arrested at all? What characterizes serial offenders who continue to escape arrest? To be able to answer these questions, arrested (identified) offenders must be compared with never arrested (unidentified) offenders. DNA data offer a unique opportunity to compare crime series of identified offenders with crime series of unidentified offenders. In this paper, data from the Dutch DNA database are used to study whether the geographical dispersion of the crime locations of serial offenders influences the probability of arrest. Results show that the probability of arrest decreases with increasing geographical dispersion, measured as the number of police regions in which the offender's crimes have been committed.

Keywords

Clearance, Cox proportional hazards model, DNA traces, geographical dispersion, serial offenders

Why is it that some offenders get arrested quickly after committing their first crime, whereas others manage to evade arrest much longer, and still others continue to offend for many years without ever being caught? The present paper suggests that offenders who have a geographically dispersed offending pattern have a relatively low risk of being arrested compared with offenders who commit their crimes close together in space.

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The percentage of reported crimes that lead to arrest (the clearance rate) is low in many Western countries: around 20 percent (Dodd et al., 2004). Studying what influences the clearance of crimes or the probability that an offender is arrested is important for many reasons. First, clearance of crimes is seen as an important measure of police performance (Addington, 2006). Moreover, solving crimes is crucial to maintain the legitimacy of the criminal justice system and the effectiveness of its sanctions, and low clearance rates have a negative influence on public confidence in the criminal justice system (Jiao, 2007; Litwin and Xu, 2007; Riedel and Jarvis, 1999; Roberts, 2007). A last important function of clearance is deterrence. Both specific and general deterrence depend on the certainty and swiftness of punishment (see, for example, Blumstein et al., 1978; Nagin, 1998): if offenders are punished with greater certainty and speed, they themselves and others are less likely to offend (again). Unsolved crimes might make offenders think they can escape justice and continue to commit crimes (Paré et al., 2007). Therefore it is important not only to understand the factors that influence whether individual crimes are solved, but also to understand what characterizes offenders who continue to escape arrest despite their enduring involvement in crime. A limitation of previous studies on the determinants of clearance is that the large majority of these studies focus on single incidents and on murder cases: one offence (murder) committed by one offender (see, for example, Alderden and Lavery, 2007; Davies, 2007; Jiao, 2007; Keel et al., 2009; Litwin, 2004; Litwin and Xu, 2007; Paré et al., 2007; Regoeczi et al., 2008; Roberts, 2007). In these studies the *crime* is the unit of analysis, and clearance is the dependent variable. To study what characterizes offenders who escape arrest, the current study focuses on the *criminal* as the unit of analysis and on the *time until arrest* as the dependent variable. In other words, we establish how long it takes to arrest a serial offender, and attempt to assess why some offenders are arrested quickly whereas others remain under the radar for many years, and why still others are never arrested at all. To be able to answer these questions, arrested (identified) offenders must be compared with not arrested (unidentified) offenders. The current study realizes this by using data from a national DNA database. If an offender leaves his DNA behind at multiple crime scenes it is possible to study the crimes he committed, and when and where he committed them even if this offender is not arrested.[1] It is therefore possible to compare crime series of identified offenders with crime series of unidentified offenders and to study what characterizes offenders who escape arrest. More specifically, this paper will use data from the Dutch DNA database to reconstruct the offending patterns of serial offenders (offenders who have committed at least two crimes) and it will study whether the geographical dispersion of locations in a crime series has an influence on the probability and the swiftness of arrest.

Theory

The current paper will examine whether the geographical dispersion of a serial offender's crime locations decreases the probability and swiftness of his arrest. The geographical dispersion of a serial offender's crimes has been the object of a number of previous studies, but none of these included unsolved series or aimed to investigate the relationship between geographical dispersion and the arrest of the offender. Most prior work has been inspired by the wish to learn about the distances that offenders travel between their anchor points and the locations of their crimes. Some have used the geographical dispersion of crime series to distinguish marauders – local offenders who reside within a circle that encompasses all of their crimes – from commuters – offenders who live outside that circle (Canter and Larkin, 1993), a question that is highly relevant for geographical profiling (Canter et al., 2000; Rossmo, 2000) in criminal investigations. Others have focused on the *consistency* of the distances that serial offenders travel to the crime locations, a topic that is relevant to linkage analysis, in which detectives have to decide whether or not a series of offences involves the same offender (see, for example, Goodwill and Alison, 2005; Lundrigan et al., 2009; Tonkin et al., 2011). It must be emphasized that the present study is truly agnostic about the location of the offender's residence, the distances between residence and crime sites or the stability of the offender's home address. We do not assume any relationship between offender residence and crime locations, but the locations of crimes tell us something about who is held responsible for solving it.

We will focus especially on dispersion across different police regions, because of what Egger (1984: 353) describes as a 'total lack of sharing or coordination of investigative information relating to unsolved murders and the lack of adequate networking among law enforcement agencies'. Egger focuses on what he calls 'linkage blindness': failing to link multiple crimes to one offender. The different law enforcement agencies fail to see similar patterns of crimes or similar modus operandi across different areas of the country, because important information about these crimes is not shared (Egger, 1990). As a consequence, the police are not aware that the same offender is responsible for different crimes. The lack of information-sharing not only might cause linkage blindness but can also apply to other investigative information. Crimes might be successfully linked by DNA traces, but investigative information about these crimes is not shared between different law enforcement agencies. Rossmo describes that, when police investigations have to cross jurisdictional or even geographical boundaries, 'issues of coordination, cooperation, and competition arise' (Rossmo, 2000: 51). Information is crucial to the police if they want to arrest serial offenders; however, they fail to share information with colleagues from other agencies. The exchange of information between different law enforcement agencies is very poor and therefore unsolved crimes remain unsolved (Egger, 1984). According to Egger (1990), the travelling criminal who commits crimes in different law enforcement jurisdictions profits from this lack of information-sharing, which contributes to immunity from detection and arrest. Egger (1984) and Rossmo (2000) describe this problem as applied to serial murder cases, but the same problem might hold for serial offenders in general (Egger, 1984). If issues of coordination, cooperation and competition arise when a serious crime such as serial murder is investigated, these issues will probably also arise when less serious crimes such as serial burglary are investigated. The consequences of not solving serial burglaries are less severe than the consequences of not solving serial murder cases, so the need to cooperate is less compelling in a serial burglary case.

Although the analysis of Egger (1984) applies to the United States, suboptimal information-sharing between police agencies and jurisdictions might also apply to other countries. The Netherlands is a small country, but every Dutch police region has its own administration. The Netherlands consists of 25 different police regions and a National Police Service Agency (KLPD). These police regions are geographical areas in which different police forces have responsibility for policing (see Figure 1 for the different regions).

The management of the police forces is determined regionally and the main policy decisions are taken by the regional executive, which comprises all the mayors of a region and the chief public prosecutor (Ministry of the Interior and Kingdom Relations, 2004).

Figure 1. Dutch police regions.
Note: A, B and C are the three regions in which the crimes listed in Table 1 were committed.

Because every region has its own administration, problems of cooperation might well occur, including a lack of information-sharing.

Because of the possible problems of cooperation and the potential lack of information-sharing between different law enforcement agencies, we expect that offenders who commit their crimes in two or more different police regions will be less likely to be arrested than offenders who commit their crimes in only one police region. The main hypothesis tested in this study is therefore:

H1. As the number of police regions in which an offender commits crimes increases, the probability of arrest decreases.

However, it is not just the number of police regions that might influence the probability of arrest. The number of regions is the most clear and simple characteristic of geographical dispersion as defined in this study, but this characteristic can be expanded to other characteristics that specify the nature of the dispersion. These characteristics are the spatio-temporal ordering in which crimes are committed in different regions, and the distances between the regions in which crimes are committed.

Spatio-temporal ordering can be defined as the number of times an offender commits the current crime in a different region from the previous crime. Two offenders might both commit five crimes in two regions, but these crimes might be committed in different orders (see, for an example, Figure 2). If an offender continuously switches between different police regions when committing crimes (pattern B), the probability of arrest might be smaller than if an offender first commits some crimes in one region, and then commits all other crimes in another region (pattern A). Therefore the second hypothesis is:

H2. As the number of times an offender commits the current crime in a different region from the previous crime increases, the probability of arrest decreases (all other things being equal, including the total number of crimes committed).

Another aspect of geographical dispersion that might have an influence on the probability of arrest is the distance between the regions in which crimes were committed. If regions are adjacent or nearby, cooperation between police regions might be more likely than if the regions are further apart. Distance is measured as the number of region borders that have to be crossed to get from one region to another when using the shortest possible route. The third hypothesis is:

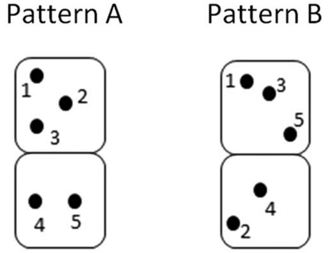

Figure 2. Spatio-temporal ordering.

H3. As the number of borders between regions in which an offender commits crimes increases, the probability of arrest decreases (all other things being equal, including the total number of crimes committed).

Data

Using DNA traces for serial clearance research

To study factors that influence crime clearance it is necessary to compare cleared crimes with crimes that have not been cleared. In previous research on crime clearance, data from official police records have been used, which allow only the study of single incidents. In regular police records, the offender is unidentified if a crime is not cleared, and therefore it is not possible to know if this unidentified offender has committed other crimes and, if so, what type of crimes and where and when they were committed. Although regular police data do offer some opportunities to link multiple unsolved crimes to a single offender (sometimes crimes are linked based on behavioural similarities; see, for example, Hazelwood and Warren, 2003; Tonkin et al., 2008; Woodhams and Toye, 2007), crime linkage analysis has not reached a level of certainty that operational usage would require. As a result, with regular police records it is not possible to study crime *series* committed by an unidentified offender, and thus it is also not possible to compare crime series of identified offenders with crime series of unidentified offenders and to study whether or not (geographical) characteristics of these series have an influence on the probability that the offender will be arrested.

DNA traces offer the opportunity to link multiple crimes to one offender with great certainty and reliability, even if the offender is unidentified. Thus DNA traces do give us the opportunity to compare crime series of unidentified offenders with crime series of identified offenders and to study whether characteristics of these series influence the probability of arrest of the offender. Lammers et al. (2012) use DNA traces to investigate whether the number of committed crimes, the seriousness of the committed crimes and crime specialization have an influence on the probability of arrest.

Data from the Dutch DNA database

The data used for this study were retrieved from the Dutch DNA database, which was established in 1997 (Schneider and Martin, 2001) and is managed by the Netherlands Forensic Institute (NFI). Although there are 25 different police regions in the Netherlands, there is a single national DNA database that contains all criminal justice DNA data. In this DNA database, two types of DNA profiles are stored: subject profiles and crime scene traces. DNA can be retrieved from a suspect to compare it with DNA found at a crime scene, if this suspect is arrested for a crime for which the Dutch criminal law allows custody. The database contains information about matches between different crime scene traces and whether the crime scene trace(s) match(es) the DNA profile of a person. For every crime scene trace, the database contains information about the type of crime that was committed, the police region in which the crime was committed, the date on which the crime was committed, and whether a suspect was arrested for the crime.

Before 2001, the Dutch law allowed DNA to be taken only from suspects arrested for committing offences for which the prison sentence that could be imposed was eight years or more. A law amendment in 2001 made it possible to collect DNA from suspects arrested for crimes for which a prison sentence of four years or more can be imposed. Under this law, DNA can be collected from offenders who commit a high-volume crime, such as burglary. As a consequence of the law amendment, police started to collect DNA traces from crime scenes of high-volume crimes. The database (and therefore the data set used in this study) does thus contain not only (serious) violent crimes but also high-volume crimes. Until 2002, the number of DNA crime scene traces that were loaded onto the database was on average 690 per year. The law amendment caused an increase in this annual number, which is now on average 4650 (NFI, 2010).

We collected data on all DNA crime scene traces that had been loaded onto the database between 1 January 2002 and 31 December 2009. The original data set contains 8861 offenders, of whom 4431 left only one crime scene sample behind. We chose to leave these offenders out of the analysis because we want to study the characteristics of crime series and not of single incidents. The police region is unknown for 21 crimes; these crimes and the series of crimes of which they are a part are deleted from the sample. This leaves 4414 offenders who committed 14,135 crimes to analyse. Of these 4414 offenders, 2282 (or 51.7 percent) had not been arrested on 31 December 2009.

The DNA database contains information on whether a crime series has been cleared and, if so, when it was cleared. Clearance of a crime is often defined as the offender being either arrested or convicted (see, for examples of different definitions, Regoeczi et al., 2008, and Paré et al., 2007). In this paper, serial clearance is defined as the DNA profile of the arrested offender matching DNA traces found at the different crime scenes. The date of clearance is the date on which the DNA profile of the offender is loaded onto the DNA database and is found to match the crime scene traces. Time to clearance is measured as the number of days between the date that the first DNA trace of the series was loaded onto the database and the date of arrest of the offender.

Serial offenders can be identified in two ways. First, the offender is arrested for committing a crime. If custody is allowed for this crime, the police will take a DNA sample from the offender. The DNA sample is sent to the NFI, where a DNA profile is extracted from the sample and this profile is loaded onto the database. In the database, the sample from the offender will match DNA traces found at crime scenes of previously committed crimes. These crimes were already linked to each other and formed a series. This series is now considered cleared: the offender has been identified. This arrest does not necessarily happen directly after the last crime was committed, so there might be some time between the last committed crime in the series and the serial clearance date. A second way in which a crime series can be cleared is a result of a law that was introduced in 2004. This law made it possible to collect DNA samples from offenders who had previously been sentenced to either a prison sentence or community service for committing a crime. As a consequence of this law, DNA profiles of known offenders, from whom DNA samples had not been taken before, are now taken. The DNA profiles of these offenders are loaded onto the database and they might match crime scene traces of previously committed crimes. These crimes were not solved before because the DNA of the offender was not previously collected.

It is, of course, possible that an offender commits another crime after the crime series is considered cleared. The DNA profile of the offender remains in the database, which means that when this offender commits another crime and leaves DNA behind, this crime will be cleared the moment that the crime scene trace is loaded onto the database. We did not include these crimes in our research because they were committed after the crime series was considered cleared (by our definition).

The crimes that are present in the data are violent crimes (extortion, threatening behaviour, manslaughter, homicide), sex offences (rape, sexual assault, sexual abuse), and high-volume crimes (residential and commercial burglary, theft and theft of or from a car). The majority of the committed crimes are high-volume crimes.

Method

Measures of geographical dispersion

Geographical dispersion of crime locations is the distribution of crime locations in a geographical area. This paper focuses especially on geographical dispersion across police regions. The first and most important measure is the number of police regions in which the crimes are committed. Two more measures are used to specify the nature of the dispersion: spatio-temporal ordering, measured as the number of times the current crime has been committed in a different region from the previous crime; and distance, measured as the number of borders between the regions in which crimes are committed. The number of borders is measured by taking the shortest possible route between regions, that is, the route that crosses the least number of borders. The longest possible route between two police regions in the Netherlands crosses seven borders.

Time-varying independent variables

All the measures that we use to quantify geographical dispersion are time-varying, which means that they can change each time the offender commits an additional crime after the initial crime. This implies that the independent variables do not have the same value at every time point (as, for example, a person's sex would), but that they have values that change over time (an example of this is a person's age). At every point in time that the offender commits a crime, a new location is added to the set of crime locations in the series, and therefore the values of the independent variables (can) change.

The number of police regions in which the crimes of a series are committed is cumulative. It initially takes the value 1, and with each crime that is committed in a different police region (that is, a police region where the offender had not committed *any* prior crime) it increases by 1. Each crime in the series is compared with every other crime in the series. If, for example, the first and third crimes were committed in the same region and the second crime was committed in a different region, the value of this measure will remain at '2' for the third crime because the offender has already committed a crime in this region. If an offender commits all of his crimes in the same region, this variable will have a value of 1 for the entire series.

The second measure is the number of police region changes between consecutive crimes. This variable measures the number of times that an offender commits the current crime in a different police region from the last crime. The measure is cumulative and increases by 1 every time a crime is committed in another region than the previous one. Unlike the first measure, this measure distinguishes between offenders who commit crimes in the same number of police regions but have a different spatio-temporal ordering. See, for example, Figure 2: both offenders commit five crimes in two police regions but they commit the crimes in the two regions in a different order.

The third measure of geographical dispersion is distance, measured as the number of region borders crossed between regions. As an overall measure of the distances between the regions in a crime series, we calculated the average inter-region distance between all pairs of crimes in a series at time *t*. Figure 3 illustrates this.

In Figure 3, two offenders are shown, both of whom have committed five crimes. The number of borders crossed between any two successive crimes is for both offenders 1. Therefore, the number of borders crossed equals 1 for the second crime, 2 for the third crime, etc. Both offenders have the same scores on this measure throughout their series. However, the crime locations of offender A are more geographically dispersed. This is recognized by taking into account not only distances between consecutive pairs but distances between all pairs in the series (for example, between crimes 3 and 5, between crimes 2 and 5,and so on). The average distance (in terms of the number of borders crossed) between all pairs of crimes in a series is calculated for each point in time using the following equation:

$$\hat{A} = \frac{\sum_{i=1}^{n} \sum_{j<i} d_{ij}}{.5N(N-1)} \tag{1}$$

in which $\hat{A}$ is the average distance between all pairs of crimes in a series, N is the number of crimes in a series and d_{ij} is the distance between the locations of crime i and crime j. The numerator calculates the sum of the distances between all pairs of crimes in the series (the $j < i$ condition in the inner summation ensures that pairs are counted only once, and also excludes the distance of a point to itself). The denominator calculates the total number of crime pairs in a series.

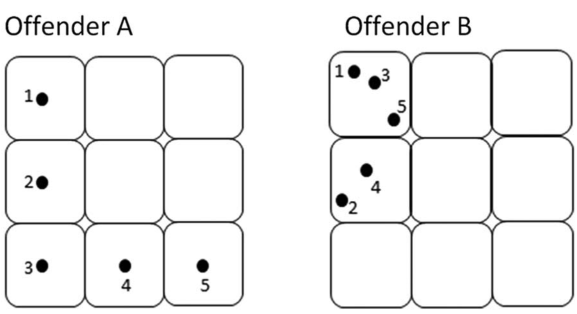

Figure 3. Distance: Number of region borders crossed.

An example of how the three measures of geographical dispersion can change over time is shown in Table 1. Table 1 deals with two offenders, the dates on which these offenders committed crimes, the police regions in which these crimes were committed, the measures of geographical dispersion and whether the offender was arrested or not. The first variable is the number of crimes the offender committed, which is taken into account in each analysed model and is a cumulative measure. This variable initially takes on the value 1 and when, after some time, a second DNA trace is added that matches the first, the variable takes on the value 2, and so on.

The three regions in which the crimes in Table 1 were committed are shown in Figure 1. Offender 1 committed three crimes. The first two crimes were committed in the same police region (A), the third one in a different region (B). Therefore the cumulative number of regions is 1 for the first two crimes and 2 for the third crime. The cumulative number of changes between regions is 1 for the last crime, since the offender committed this third crime in a different region from the second crime. One border needs to be crossed between the two regions (there is a dike over which people can travel between these two regions). To calculate the number of borders crossed for the third crime, equation (1) is used:

$$\frac{0+1+1}{0.5*3*(3-1)} = 2/3.$$

The second offender committed four crimes, with a region pattern of A B C B. For the first three crimes the number of regions increases by 1, since every crime is committed in a different region. The fourth crime was committed in the same region as the second crime, so the cumulative number of regions stays at 3. Since every current crime is committed in a different region from the previous crime, the cumulative number of changes increases by 1 for every committed crime. To travel from region A to region B, one border needs to be crossed, from region B to region C three borders, and from region A to region C four borders. For the second crime, one pair of borders is compared, thus the denominator of equation (1) is 1, so the value is simply the number of borders crossed between that one pair (between the first and the second crimes). To calculate the number of borders crossed between all pairs for the third and fourth crimes, again equation (1) is used:

Table 1. Example of time-varying independent variables

ID	Date of offence	Police region	Offender arrested?	Cumulative no. of crimes	No. of regions	No. of changes between regions	Mean no. of borders between all pairs
1	06/08/2003	A	No	1	1	–	–
1	13/07/2004	A	No	2	1	0	0
1	21/08/2004	B	Yes	3	2	1	1
2	03/12/2002	A	No	1	1	0	–
2	15/01/2003	B	No	2	2	1	1
2	23/02/2003	C	No	3	3	2	4
2	26/02/2003	B	No	4	3	3	2

Third crime:

$$\frac{1+4+3}{0.5*3*(3-1)} = 8/3.$$

Fourth crime:

$$\frac{1+4+1+3+0+3}{0.5*4*(4-1)} = 2.$$

Descriptive statistics

This paper compares crime series of identified offenders with crime series of unidentified offenders to study whether the geographical dispersion of crime locations has an influence on the probability that an offender will be arrested. We will first present descriptive statistics. However, simple descriptive statistics have two limitations. First, these statistics do not take into account that there is a possibility that offenders who are currently unidentified might be identified in the (near) future; that is, descriptive statistics of the independent variables do not take the possibility of censored durations into account. A second limitation is that descriptive statistics measure the geographical dispersion measures only at the end of the study period, considering all the crimes of the series together, whereas these measures can change over time when the offender develops his criminal behaviour.

Cox proportional hazards model

The two limitations of descriptive statistics and the fact that we want to analyse not only the differences between the two groups of offenders but also which of these differences influence the probability of arrest make it necessary to perform survival analysis. Survival analysis studies how long it takes for an event of interest to take place, given that the individual is still at risk of experiencing the event, and it efficiently utilizes censored durations. Applied to the current study on arrest of offenders, survival analysis considers the time that it takes for a crime series to be cleared and not just whether or not a series is cleared (Roberts, 2008), and it recognizes the possibility that the arrest of the offender can still happen after the end of the study period.

The parameter estimate of a survival analysis is a hazard ratio. The hazard ratio is an indicator of the effect of the independent variable on the hazard (or risk) of the event of interest. The hazard ratio can be interpreted as the change in the hazard (or risk) of experiencing the event of interest that is the result of a one-unit change in the independent, explanatory variable. For instance, the independent variable is ‘age in years’, the dependent variable is committing an offence and the model shows that the hazard ratio is 1.20. This means that a one-year increase in age increases the hazard of committing an offence by 20 percent (Cleves et al., 2008). In this paper, the event of interest is the arrest of the offender and the independent variables are the measures of geographical dispersion. The hazard ratio can thus be interpreted as the change in probability of arrest as a result of a one-unit change in the measures of geographical dispersion.

For this paper we use a semi-parametric form of survival analysis: Cox proportional hazards model (Cox, 1972), which has the possibility of using time-varying independent variables. Another advantage of the Cox proportional hazards model over a parametric form of survival analysis is that it does not require any specification of how the hazard ratio depends on the passage of time (Roberts, 2007).

Results

Descriptive statistics

The descriptive statistic of the dependent variable (number of days between the first crime in a series and the date of arrest) is a survival curve. Figure 4 shows the Kaplan–Meier estimate of the survival curve: the percentage of offenders who remain unarrested over time. The x-axis shows the number of days and the y-axis the percentage of offenders. The curve shows that, after eight years (around 3000 days), 65 percent of the offenders have been arrested. This means that 35 percent are not arrested after eight years and might possibly not be arrested at all.

Table 2 shows the descriptive statistics of the independent variables, the measures of geographical dispersion. These statistics are measured at the end of the study period and cover the entire series. The first column shows statistics on the unidentified offenders, the second column on the identified offenders. The table shows that on average the unidentified offenders commit fewer crimes (2.9) than the identified offenders (3.5). There is only a small difference in the number of police regions in which both groups of

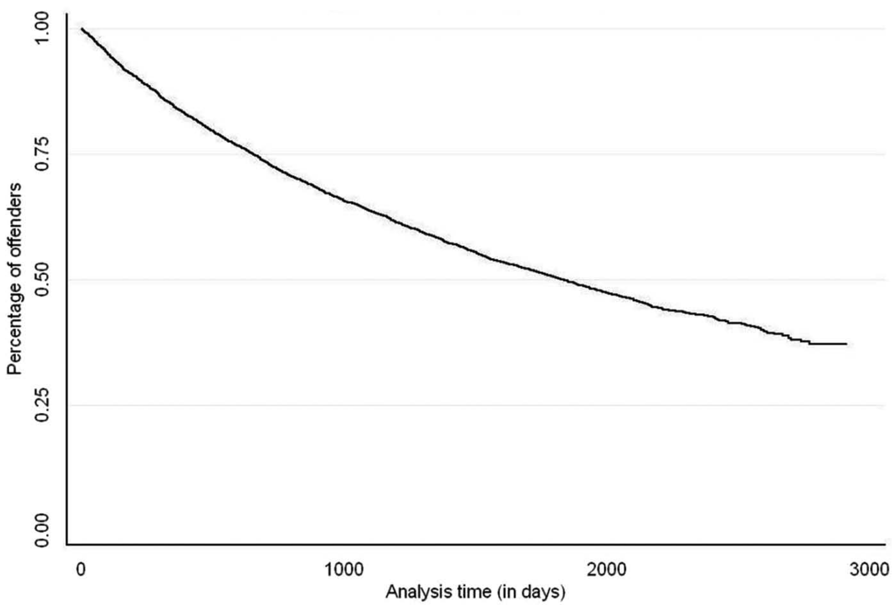

Figure 4. Kaplan–Meier survival estimate.

Table 2. Descriptive statistics

	Unidentified offenders N = 2282				Identified offenders N = 2132			
	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.
No. of committed crimes	2.90	1.90	2	22	3.53	2.74	2	35
No. of police regions	1.50	0.83	1	10	1.49	0.85	1	10
No of changes between regions	0.59	1.13	0	14	0.64	1.32	0	18
No. of borders crossed between all pairs	0.61	1.03	0	6	0.48	0.88	0	6

offenders commit their crimes, and the same is true of the number of changes between regions. The number of borders that the offenders cross between all their crimes shows a small difference between the two groups. Looking at these descriptive statistics, there does not seem to be a large difference between the identified and unidentified offenders.

How does the geographical dispersion of crime locations influence the probability of arrest?

First, three separate Cox proportional hazard models are analysed, one for each of the measures of geographical dispersion. Each model contains the cumulative number of crimes, so that the number of committed crimes is controlled for. The results of the different models are shown in Table 3. As described before, the hazard ratio shows the change in the probability that the event of interest (arrest of the offender) will happen as a result of a one-unit change in the independent variable.

The first model analyses the number of crimes committed and the number of police regions in which the crimes are committed. The hazard ratio of the number of crimes is 1.21, which means that, for every extra crime that an offender commits, the probability that he will be arrested increases by a factor of 1.21, or 21 percent. The number of police regions has a hazard ratio below 1, which means that, as the number of police regions in which the crimes are committed increases, the probability of the offender getting arrested decreases. The hazard ratio is 0.91; thus, for every extra police region in which a crime is committed, the probability that the offender will be arrested decreases by a factor of 0.91, or 9 percent.[2]

The second model analyses the number of crimes and the number of changes between police regions. The hazard ratio of the number of committed crimes is the same as in the first model. The hazard ratio of the number of changes is 0.87. Thus, every time an offender commits a crime in a different police region from the region in which the previous crime was committed, the probability of him getting arrested decreases by a factor of 0.87, or 13 percent.

In the third model the number of crimes and the number of borders that are crossed between all pairs of crimes in a series are analysed. The hazard ratio of the number of crimes is a bit smaller than in the previous two models: 1.15. For every extra crime that is committed, the probability of arrest increases by 15 percent. The hazard ratio of the number of borders crossed is 0.93; so, if the number of borders crossed between crimes increases by 1, the probability of arrest decreases by 7 percent.

We also tested separate models: one model that takes only the first two committed crimes into account; one model that takes the first three crimes into account; and so on. These analyses produce the same results as Model 1 in Table 3: as the number of police regions in which offenders commit their crimes increases, the probability of arrest decreases.

The main hypothesis of this study is that, if an offender commits his crimes in multiple police regions, the probability of his arrest decreases. One more model is analysed, to test whether the number of police regions in which crimes are committed still causes an increase in arrest probability if the distance between regions is controlled for. This model thus contains (besides the number of committed crimes) the distance, measured as the number of borders crossed between police regions. The results are shows in Table 4.

The results of the last model show that the number of police regions still has a significant influence on the probability of arrest if the distance is controlled for. The hazard ratio of the number of regions is 0.88, so an increase by 1 in the number of police regions causes a decrease in the probability of arrest by 12 percent. Distance no longer has a significant influence on the probability of arrest. The following example elucidates these results.

> Offender A commits one more crime, in *the same* police region as the other crime(s) he committed. The probability that he will be arrested increases by a factor of 1.17, or 17 percent, after committing this one extra crime.

Table 3. Results of the Cox proportional hazards model (1)

	Model 1		Model 2		Model 3	
	HR	SE	HR	SE	HR	SE
No. of crimes	1.21**	0.01	1.26**	0.01	1.15**	0.01
No. of police regions	0.91*	0.03				
No. of changes between regions			0.87**	0.02		
No. of borders crossed					0.93*	

Notes: HR: hazard ratio; SE: standard error; **p* < .01; ***p* < .001

Table 4. Results of the Cox proportional hazards model (2)

	Model 1	
	HR	SE
No. of crimes	1.17**	0.01
No. of police regions	0.88*	0.03
No. of borders crossed	1.01	0.04

Notes: HR: hazard ratio; SE: standard error; **p* < .01; ***p* < .001

Offender B commits one more crime, in *a different* police region from the other crime(s) he committed. The probability that he will be arrested changes by a factor of 1.17*0.88 = 1.03; in other words, the probability that he will be arrested increases by 3 percent after committing this one extra crime.

A similar analysis could be done for the number of regions and the number of changes between regions. However, the correlation between these two variables is larger than .9 thus they cannot be analysed in the same model without causing serious and degrading collinearity issues. This also means that, given the size of the series and the number of police regions where the crimes were committed, there is very little variation in the spatio-temporal ordering of the crimes.[3]

Conclusion and discussion

Informed by Egger (1984) and Rossmo (2000), who emphasize that issues of coordination, cooperation and competition may jeopardize police investigations of crime series that cross jurisdictional or geographical boundaries, this paper investigated the hypothesis that offenders with a more geographically dispersed pattern of crimes have a smaller probability of getting arrested than offenders who commit geographically clustered crime series. The empirical findings seem to confirm this hypothesis. More specifically, the results demonstrate that (1) the probability of arrest decreases as the number of police regions in which the offender commits his crimes increases; (2) the probability of arrest decreases as the number of times an offender commits the current crime in a different region from the previous crime increases; and (3) when the number of police regions is controlled for, the probability of arrest is not influenced by the distance between the regions in which an offender commits his crimes.

Of course, the confirmation of these hypotheses does not automatically imply that the proposed causal mechanisms, that is, limited cooperation and information exchange between regionally organized police forces, are valid. There may be other causal mechanisms that drive the observed associations. For example, there may be a positive correlation between an offender's mobility and the amount of self-control he exercises when planning and executing crimes, and the latter characteristic is likely to reduce the risk of arrest. Nevertheless, even if issues of information exchange and cooperation are limited, there are good reasons to believe that mobile criminals who cross jurisdictional or regional boundaries do benefit (Egger, 1990).

Whether or not the relationship between geographical dispersion and arrest rate is linked to the organization of police investigations, our findings may have consequences for the interpretation of the results of studies on offender mobility. Most importantly, because less geographically dispersed offenders have a greater probability of being arrested and thus a greater probability of being present in official police data, studies based on official arrest data might underestimate the geographical range of offenders, and might therefore also underestimate the distance that offenders travel between their homes and the locations of the crimes they perpetrate (see also Van Daele et al., 2012).

Remarks on using DNA traces for (serial) clearance research

Although DNA traces offer unique opportunities to study crime clearance, they also have their limitations. DNA traces are not secured at every crime scene the police visit and not all crimes are reported to the police. Using DNA traces thus implies considerable selections at various phases of the investigative process. Moreover, not every type of crime leaves DNA traces behind and the offender has to leave something behind that contains his DNA (for example, a cigarette butt or a piece of chewing gum) or there needs to be contact between the offender and the victim, otherwise there will be no DNA traces to secure. If no DNA traces are found at a crime scene, this crime is not present in the data set used for this study. This selectivity of the data could have influenced our measurements. An offender who appears to commit his crimes in one police region might in reality commit his crimes in many regions.

When the police visit a crime scene, they will try to make sure that the collected DNA trace is indeed DNA from the offender. They do this by reconstructing what happened and using information that is already known about the crime and they will eliminate the victim(s) or witnesses as donors of the DNA (Meulenbroek, 2008). When using DNA traces for criminological research, another important point to consider is the reliability of a match between DNA crime scene traces, or between a crime scene trace and a person's profile. Every DNA profile is extremely rare, but it is impossible to know with 100 percent certainty whether a DNA profile is unique. Therefore there is always a small probability that a match between two crime scene traces (or a match between a crime scene trace and a person's profile) is a coincidence. The NFI calculated, however, that the probability of a match between two traces being a coincidence (when using a complete DNA profile) is always smaller than 1 in 1 billion (Meulenbroek, 2008). Although there is a probability that a match between two crime scene traces is a coincidence, one has to keep in mind that such a false positive has very different implications in court than in research. In court, an error margin of 1 percent may be unacceptable, whereas in the social sciences an error margin of 1 percent is negligible.

Although there are a number of limitations to be considered when DNA traces are used for criminological research, they also have one major advantage: they give us the opportunity to study characteristics of crime series of offenders who were never arrested and compare these with characteristics of crime series of offenders who were arrested. By doing so we have the opportunity to study which characteristics of these series influence the probability that the offender will be arrested.

Future research

Little systematic research is available on how the police collect DNA traces from crime scenes, and on in how many of the crime scenes visited by the forensic department DNA traces are secured. Of course, standards for DNA collection exist, but how it is done in reality remains unclear. Some research on this has been undertaken (see, for example, Bond and Phil, 2007; Bond et al., 2008), but interesting future research might focus more on the process of collecting DNA traces at crime scenes: how are decisions made about whether or not to collect DNA; when are these decisions made and by whom? This type of research could provide insights into the nature and extent of the selectivity of the DNA data.

It might also be interesting to use DNA data to study offenders who operate internationally. Issues of cooperation and information-sharing between states in the USA or between regional police forces in the Netherlands are dwarfed by the barriers that hinder cooperation and information-sharing between different countries. Unfortunately, international comparison of Dutch DNA profiles is currently possible only by means of an official international legal request, and a permanent exchange for research purposes is thus not (yet) possible.

A last type of future research might focus on how the fact that an offender's DNA profile is present in a DNA database influences the probability of clearance. In the present study, crimes were not taken into account that had been committed after the offender was arrested and after a DNA sample had been taken from them and loaded onto the database. Does the storage of a DNA profile in a national DNA database influence deterrence? In an analysis of data from the UK National DNA database (NDNADB), Leary and Pease (2003) show that there is no increase over time in the proportion of crime scene samples that match an offender profile. This indicates that the pool of active offenders is unstable: many of the offenders for whom DNA profiles are stored in the NDNADB no longer offend and many of the offenders who do offend have not yet been included in the NDNADB. Future studies might expand on this type of research.

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Notes

1. To prevent awkward stylistic constructions, we use only male pronouns when referring to persons.
2. Clearance rates of the different police regions between 2005 and 2009 do not show large differences between regions or between years. The mean clearance rate for 2005 is 25.66 (SD 4.03), for 2006 25.79 (SD 3.71), for 2007 25.31 (SD 3.69), for 2008 24.63 (SD 3.34), and for 2009 25.06 (SD 3.33). The regions thus seem to be generally equally effective in clearing crimes (Statistics Netherlands, http://www.cbs.nl).
3. Models were also tested for offenders who committed only a single type of crime (specialized offenders). Only the group specialized in burglary and the group specialized in theft of or from a vehicle contain enough offenders (>100) to be analysed. The analysis of the group of offenders who are specialized in burglary shows almost the same result for the first three models (Table 3) in terms of the direction of the hazard ratio and significance levels. The only difference is that the hazard ratio for distance (the number of borders crossed) is not significant for the group of specialized offenders. The result for the model in Table 4 is the same for the group of offenders who are specialized in burglary. Analyses of the offenders who are specialized in vehicle crime do not show significant results for the number of regions in which crimes are committed, the number of changes between regions and distance (both for the models shown in Table 3 and for the model in Table 4). However, the hazard ratios of these variables do have the same direction as the ones shown in this paper. The number of crimes that are committed do show the same results in terms of the direction of the hazard ratio (>1) and significance levels. Taking into account that *p*-values of statistical significance must necessarily be larger in subsets of the sample, we interpret these findings as confirmation that the substantive conclusions on the whole sample generalize to subgroups of specialized offenders.

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