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Concentrations of railway metal theft and the locations of scrap-metal dealers

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A B S T R A C T

Metal theft has become a substantial crime problem in many areas. In response, several countries have introduced legislation to regulate scrap-metal recycling yards. However, at present there is little evidence to support this use of the market reduction approach (MRA) in preventing metal theft. The present study sought to test the underlying assumption of the MRA that the presence of a market for stolen property (in this case provided by scrap yards) drives thefts in a local area. This study tested for a spatial association between the locations of scrap yards and those of metal thefts. The density of industry, local burglary rate and road-accessibility of an area were controlled for. Metal thefts from railway lines in England were shown to be significantly more common in areas with more scrap-metal yards, high road accessibility and high population density. The results support the use of the MRA in relation to metal theft.

1. Introduction

The theft of metal items for their scrap resale value has become a substantial crime problem in many areas, likely driven by increases in the wholesale price of many scrap metals compared to historical averages (Sidebottom, Ashby, & Johnson, 2014, Sidebottom, Belur, Bowers, Tompson, & Johnson, 2011). As well as the cost of replacing stolen metal, thefts from infrastructure networks in particular can cause widespread disruption, which has led to pressure on governments in many countries to take action to prevent metal thefts.

Such action has commonly focused on implementing the market reduction approach (MRA) to crime reduction (Sutton, Johnston, & Lockwood, 1998, see below), particularly through increasing the regulation of scrap-metal dealers (SMDs). As of mid-2014, laws to regulate SMDs exist in all 50 United States (US) states and in at least 14 European Union (EU) countries (Institute of Scrap Recycling Industries, 2014), with new measures including a ban on paying cash for scrap metal, waiting periods for payment and increased record keeping (for a survey of measures, see Waterfield & Short, 2014).

Although enhanced regulation of SMDs has become commonplace, there is presently little evidence that applying the MRA will help prevent metal theft, due to the difficulty of measuring the involvement of SMDs in metal theft and the regulations having only been recently introduced. Given these difficulties, the present study tested for a link between the locations of metal thefts and those of SMDs.

1.1. *The market reduction approach to crime prevention*

The idea that thefts can be prevented by reducing societal demand for stolen goods is not a new one — it was considered old even in the 1790s (Colquhoun, 1797, 173). The general hypothesis is that, since offenders usually steal in order sell the proceeds for money, fewer thefts will occur if it is harder to sell stolen goods. The MRA seeks to change the environment to create a belief among thieves and those who buy from them (universally called ‘fences’ in the literature) that selling stolen goods is likely to be both difficult and risky (Sutton, Schneider, & Hetherington, 2001, 5). The MRA is based on the assumption that offenders behave in a purposive and rational way, making a sequence of crime-specific decisions at different stages in committing a particular offence (Cornish & Clarke, 2008, 24). In the context of thieves disposing of stolen goods, this rational-choice approach suggests that thieves will try to maximise profits and minimise the risk of apprehension by selling goods quickly, and therefore nearby.

Although the MRA appears intuitive, it is supported by surprisingly little empirical research. Albers-Miller (1999) found that survey respondents were more willing to buy stolen goods when

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prices were lower, but that the perceived risk of criminal punishment had no influence on willingness to buy. This supported earlier findings by Sheley and Bailey (1985, 407) that the potential buyer's perception of the likelihood of criminal sanction was not associated with their willingness to buy stolen goods. Hale, Harris, Uglow, and Gilling (2004) found no significant reduction in residential burglary following two trials of the MRA. However, Schneider (2004) reported that some burglars interviewed after an MRA trial reported switching sales of stolen goods from those fences targeted by the intervention to their own networks of friends.

A recent study by Mares and Blackburn (2014) reported the results of a natural experiment of the MRA in the context of metal theft. The city of St Louis enacted a law prohibiting SMDs from paying cash for scrap, as well as restricting the purchase of certain high-risk metal items and introducing purchase records. By studying the volume of metal thefts reported to the police before and after the law was introduced, they found that the frequency of metal theft decreased when the law was introduced, compared to the frequency of other thefts. Since that study used data from only one city, the extent to which the results are generalisable is not known.

1.2. *The scrap-metal industry and stolen goods*

SMDs act as a link between generators and users of scrap metal. Scrap often exists in very small quantities – for example a car being disposed of by its owner or copper piping from a house being renovated – which SMDs must aggregate. Many smaller SMDs pass metal onto ever-larger SMDs until enough metal has been aggregated to enable it to be processed, melted down and re-used (Fletcher, 1976, 153). The smallest participants in the industry are itinerant collectors, who buy scrap from any available source or simply collect dumped metal from road sides and wasteland (Sibley, 1976).[1] Prices are typically negotiated on the spot without an existing contract (Office of Fair Trading, 2014), except for large purchases of scrap from industrial users of metal.

The scrap-metal market has notable similarities with stolen-goods markets. Both are based largely on cash payments with prices agreed at the time of sale rather than by prior contract. Both SMDs and some types of fence (especially pawn brokers) may have little or no prior knowledge of sellers and therefore little knowledge of the provenance of the goods on offer (e.g. McIntosh, 1976, 257). Both are also fragmented, with many small businesses offering to buy goods from an even larger number of small suppliers.

The similarities between the two markets make SMDs vulnerable to exploitation by criminal groups. This is not a new problem: a US court judgement from 1930 described the industry as

> “a legitimate business, meeting a public demand, but [which is] sometimes conducted in a dubious fashion and becomes a place where thieves turn into cash their ill-gotten plunder. [It is,] more often, an innocent receiver of contraband” (quoted in Zimring, 2004, 90).

SMDs are particularly vulnerable to being offered stolen goods for two reasons. Firstly, there are many types of metal (for example bare copper wire) for which it is impossible to distinguish one batch (which might be stolen) from another (Spendlove, 1961, 3). Secondly, unlike many stolen goods that can be sold in bars or to friends, scrap metal can often only be sold to SMDs (Posick, Rocque, & Whiteacre, 2012; Price, Sidebottom, & Tilley, 2014). Except in the (presumably unusual) circumstance of a thief being able to melt-down old scrap and resell it as new, the only alternative to selling it to an SMD locally would be to export it directly to an SMD in another country.[2]

Although there is no published evidence (of which the authors are aware) on the prevalence of handling stolen goods by SMDs, there is evidence of substantial crime concentration in relation to other types of potentially criminogenic facility. Wilcox and Eck (2011, 476–7) described the “iron law of troublesome places”: that within any group of places with a similar function, a small number of locations – dubbed “risky facilities” by Eck, Clarke, and Guerette (2007) – will account for most crime, while most places in the group will have no crime at all. As such, it is possible for some SMDs to be heavily involved in handling stolen metal while most are honestly carrying on a business that has very-low profit margins (Krajick, 1997, 42). SMDs can also be victims of metal theft.

The only previous study (of which the authors are aware) to consider these issues was by Whiteacre and Howes (2009). They compared the number of metal-theft insurance claims with the number of SMDs (both normalised per 100,000 population) in the 51 US cities with the highest number of such claims. To account for alternative explanations of any correlation, the model controlled for the rate of burglaries and the payroll of manufacturing businesses in those cities. Both the number of SMDs and the burglary rate were found to be significant predictors of the frequency of metal-theft insurance claims in a city.

As the only previous study of its kind, the work reported by Whiteacre and Howes (2009) provided a valuable insight into the relationship between SMDs and metal theft. However, due to the paucity of available data on metal theft at the time, the study has some limitations. Lists of SMDs were obtained from telephone directories, which include only those businesses that pay to advertise in them. This may be particularly problematic in a fragmented industry such as scrap-metal dealing. Metal-theft records were obtained from National Insurance Crime Bureau (NICB), and so only included thefts of insured property for which a claim was made. This may be problematic because many frequent victims of metal theft (e.g. railways and utility companies) may find it less expensive to self-insure, meaning thefts against them will not be recorded by NICB (Burnett, Kussainov, & Hull, 2014). Studying only those cities with the highest frequency of metal theft may also limit the generalisability of their results.

Whiteacre and Howes (2009) were only able to consider correlations at the city level. Given that intra-city variations in the relationship between SMDs and metal theft could not be explored, it may be that the results reported include an element of aggregation bias due to the modelling of the decision-making of individual thieves and fences at the aggregate level. Clark and Avery (1976) showed that regression models using aggregate spatial data were likely to result in inflated correlation coefficients, and that these issues can be minimised by using smaller spatial units of analysis. Furthermore, a growing body of research has shown the importance of considering small units of analysis when studying crime (for a recent review, see Weisburd, Groff, & Yang, 2012).

2. The present study

Many jurisdictions have recently increased the regulation of

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[1] Some itinerant collectors are from traveller communities, and there has been some suggestion that such communities may be involved in crime (e.g. Gmelch, 1986). However, the authors have been unable to identify any data that would allow exploration of this issue, so it is not discussed further.

[2] Discussions with officials dealing with metal theft suggest that such exports occur, but little is known about them and they are outside the scope of the present study.

SMDs in an attempt to reduce metal theft. These measures are commonly based on the central assumption of the MRA that by increasing the effort and/or risk involved in selling stolen metal, thieves will be dissuaded from stealing metal in the first place (see, for example, the comments of law-makers reported by Amirfazli & Hyndman, 2012, 251).

Direct measurement of the flow of stolen metal through the scrap-recycling process is not presently feasible. It is usually impossible to identify the origin of any particular piece of metal once is has begun to be processed by an SMD, because the first stages of processing involve stripping any non-metal sheathing (Sijstermans, 1997). Although research is currently being undertaken to improve the traceability of scrap metal (e.g. by Dettman, Cassabaum, Saunders, Snyder, & Buscaglia, 2014), the long metal life-cycle (Spatari, Bertram, Fuse, Graedel, & Rechberger, 2002, 37) means that almost all metal being recycled today is not traceable.

Police data are also likely to be of limited use. Handling stolen goods is an "intangible crime" (Chappell & Walsh, 1974, 494), i.e. one that is known about by people other than the perpetrators only when detected by the police. Given that prosecuting handlers of stolen goods has often proved more difficult than prosecuting thieves (Chappell & Walsh, 1974, 488), it is unlikely that those offences that are detected by the police are a substantial or representative sample of all offences.

Since direct measurement is not possible, an alternative method is required. The discipline of applied geography "is concerned with the application of geographical knowledge and skills to the resolution of real-world … problems" (Pacione, 1999, 1). This approach has been used extensively to provide useful information for crime-reduction policy-makers and practitioners (Wilson & Smith, 2008), for example in identifying protective effects of certain road configurations (Johnson & Bowers, 2010) or probabilistically profiling offender addresses based on offence locations (Rossmo, 1999). Applied geography is an explicitly problem-oriented approach, with research methods selected based on what is required to solve a particular problem (Briggs, 1981, 4). In the present case, the problem was how to measure any relationship between SMDs and metal theft when direct measures of such a relationship are not possible. This is a "real-word" problem because in order for policy-makers to decide whether or not to increase the regulation of SMDs it is necessary for them to know whether or not there is any relationship between scrap dealers and metal thefts.

The MRA is based upon the assumption that the frequency of theft depends partly upon the availability of outlets for thieves to sell their stolen goods. If this assumption is true in the case of the theft of metal, it may be possible to identify this by testing for a spatial relationship between the number of SMDs in an area and the number of metal thefts allowing an indirect test of an SMD–theft link.

3. Data

British Transport Police (BTP) is the national, public police force – consisting of around 3000 officers – responsible for policing railways in Great Britain. The present study used records of 8207 metal thefts in England recorded by BTP between January 2007 and December 2012, representing all known metal thefts from the National Rail network during that period. This source of data was chosen because BTP began recording metal thefts much earlier than most law-enforcement agencies, and because the data cover an entire country. The main limitation of these data is that all crimes are recorded as occurring at the nearest passenger station on the same line as the location at which the crime is believed to have been committed. This is because most other railway locations, such as bridges, tunnels, gantries and signal cabinets are "non-addressables" (Chainey, 2002, 7) – locations that cannot be identified using standard gazetteers. BTP is now seeking to determine the locations of metal thefts more precisely using key fobs that show co-ordinates from the global positioning system (Loewenberger, Newton, & Wick, 2014, 195), but these efforts post-date the data used in the present research. Since BTP previously did not collect more-precise location data, it was not possible to determine the extent of the error that this recording practice might cause. However, the median length of railway line around a station was 3.8 km, with an inter-quartile range of 4.7 km. The unit of analysis in this study can therefore be thought of as being analogous to a local neighbourhood, substantially smaller than the city-level unit used by Whiteacre and Howes (2009).

Given that the locations of metal thefts were only known at the resolution of the nearest station, it was necessary to translate any other variables into the same spatial resolution. Calculating the nearest station to a particular location (e.g. a metal-theft site) is complicated because the nearest station (by Euclidean distance) to a particular line-side location may not be on the same stretch of track. For this reason, the railway network was divided into polylines (one for each of the 1974 stations in England) where every point on each polyline was closer to one station than to any other (Fig. 1). Other points of interest (such as SMDs) could then be counted by determining which polyline the point was closest to. This allowed the study to programmatically replicate the method that BTP officers use to determine at which station the crime should be recorded as having happened. The distance from a feature to the nearest line was considered to be more important than the distance to the nearest station, since it is from the line-side that most metal is stolen (Ashby, Bowers, Borrion, & Fujiyama, 2014).

The Environment Agency (EA) provided data on the locations of 2020 SMDs in England (a map of the density of these is shown in Fig. 2). These data represent all registered SMDs as of December 2013, except those that only handle metal from agricultural sources or dismantle used motor vehicles.[3] The list was derived from the licences that SMDs are required to have as dealers in waste. There are two main limitations of this dataset. Firstly, some SMDs will be operating illegally without the appropriate permit and so will not be present in the data. Secondly, the EA data do not include the dates on which each SMD started and finished operating, because there is no requirement to notify such information to the authorities. As such, it is possible that some of the SMDs in the data had ceased trading.

To estimate the quality of the data in this regard, two checks were carried out. Firstly, the date on which each SMD had last updated their registration (for example to change the name of the registered dealer or notify a change of location) was ascertained. The median date on which SMDs had updated their EA record was March 2012, twenty-two months before the data were extracted. However, 555 SMDs (27%) had last updated their records more than five years before data extraction. To ascertain what proportion of that 27% of dealers was still trading at the same location, a random sample of 200 addresses were checked using Google Maps satellite imagery (Google, 2015).[4] In 92% of cases, scrap metal was visible at the location, while in 2% the premises appeared to be industrial. The remaining 6% of addresses appeared to be a residential, suggesting that the land had been re-used or that a SMD had registered their business at their home address. The apparent longevity of SMDs at one location was also evident in statistics produced by the Office for National Statistics (2013b, table B3.3), which showed that

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[3] These premises were excluded because checks on a sample of them suggested that they accept metal only for specific purposes.

[4] This imagery is believed to be no older than three years (Vandeviver, 2014, 2).

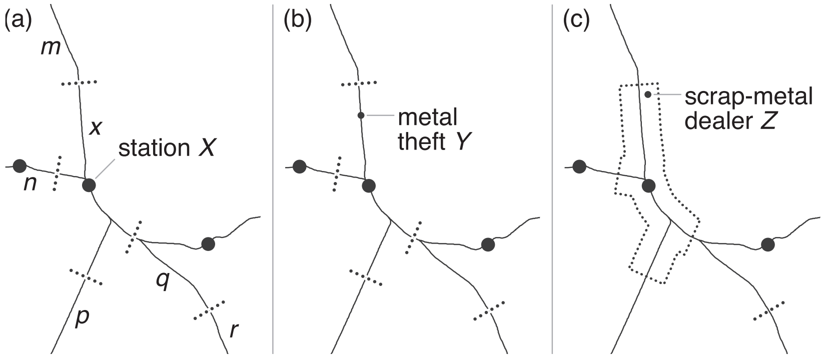
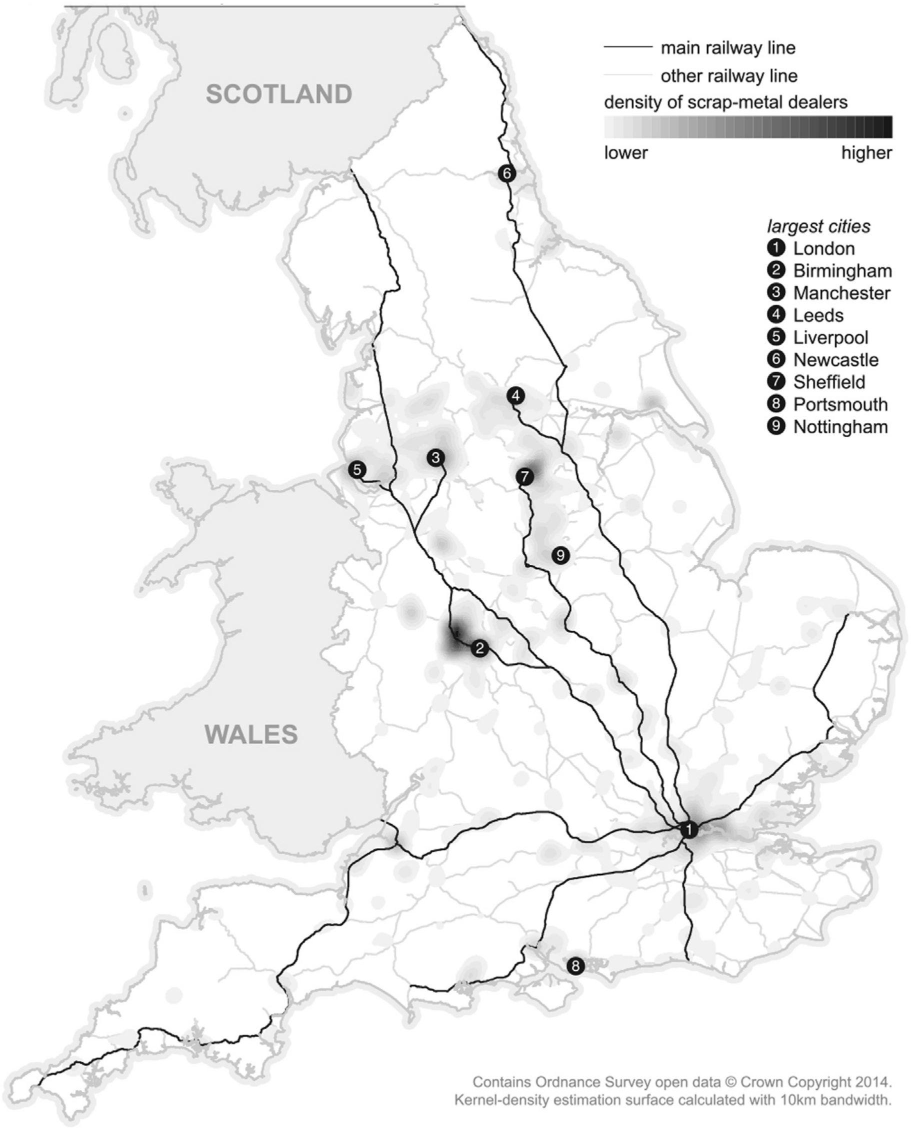


Fig. 1. Method for constructing buffer areas. The Voronoi polyline *x* for station *X* extends half-way to the next station in each direction (a). Metal theft *Y* is closer to station *X* in network distance than to any other station, so it is counted as occurring within polyline *x* (b). Likewise scrap-metal dealer *Z* is counted as being within the buffer area surrounding polyline *x* (c).

64% of United Kingdom (UK) companies classified as engaged in “wholesale of waste and scrap” had been in business for ten years or more, compared to 44% of all UK businesses. This longevity may be due to many SMDs being family businesses, as well as the noise and dust generated by scrap recycling making it difficult to establish new sites without local opposition.



Contains Ordnance Survey open data © Crown Copyright 2014.
Kernel-density estimation surface calculated with 10km bandwidth.

Fig. 2. Density of SMDs, England.

3.1. Hypotheses, alternative explanations and the unit of analysis

The main hypothesis explored with these data was that thefts of metal from the railway network will occur more frequently in areas where there are more SMDs to which thieves can attempt to sell the metal. This hypothesis tests both the basis of most recently introduced regulations of SMDs, and the central underlying assumption of the MRA that the frequency of theft depends in part upon the availability of potential fences for stolen goods. The latter is particularly relevant because of the paucity of existing evidence to support the MRA.

Several alternative explanations for any link between the locations of metal thefts and SMDs had to be accounted for. The first is that both SMDs and railway lines might be more common in areas with many industrial and other premises that use high volumes of metal, increasing the availability of metal and the number of SMDs. To control for this, data were obtained from Ordnance Survey (the national mapping agency for Great Britain) on the locations of manufacturing, energy-production, waste-disposal and mining premises. A count was taken of the number of such premises within the buffer surrounding each network polyline, and then converted into a rate per square kilometre of land within the buffer. The choice of buffer distance was inherently arbitrary, since it was not possible to know how far the awareness space (Brantingham & Brantingham, 1981) of offenders would extend from the location of a theft. To investigate the sensitivity of the results to the choice of buffer radius, the analysis was repeated for buffer radii from 1 to 20 km in 1 km increments.

In order to include the residential character of each area in the model, buffer areas were categorised as being either urban, suburban or rural.[5] Urban areas were defined as those with more than 500 residents per square kilometre, derived from dwelling density based on the national mean household size of 2.3 people (Office for National Statistics, 2013a, 7), while suburban areas were defined as those non-urban areas with more than 150 residents per square kilometre.

The second potential alternative explanation is that metal thefts might be more common in areas that frequently suffer other types of crime. This may be particularly relevant since SMDs are often sited in poor inner-city areas (Ackerman & Mirza, 2001) that tend to experience higher volumes of theft. To control for this variable, the rate of burglaries (both residential and non-residential) per 1000 buildings was calculated for each buffer area.

The final alternative explanation considered was that both metal thefts and scrap yards may be more common in areas that have particularly good links to the road-transport network. More-accessible locations are known to experience higher levels of property crime (Beavon, Brantingham, & Brantingham, 1994; Johnson & Bowers, 2010), and are presumably also beneficial for SMDs that need to be accessible to customers. To control for this possibility, the density of major roads (expressed in kilometres of such road per square kilometre of land) was calculated for each buffer area. The road network used for this was extracted from the Ordnance Survey VectorMap District dataset, which has a nominal scale of 1:25,000. Main-road density may be a more useful measure than all-road density, both because main roads are likely to contribute more towards overall accessibility and because there will be less heterogeneity in that contribution within the density of main roads than of all roads.

Two further variables were required to account for the nature of the data. The first was the natural log of the length of railway line in each buffer area, to act as an exposure variable to account for the greater availability of metal in longer polylines. The second was a spatial lag variable designed to account for the inherent autocorrelation present in spatial data (for a comparison of similar methods, see Anselin, Cohen, Cook, Gorr, & Tita, 2000, 238–241). For each polyline, this variable was calculated as the mean number of metal thefts in directly adjacent polylines, using 'queen' contiguity. For example in Fig. 1, the spatial lag variable for polyline *x* would be the mean theft count in all polylines except *r*, which is not directly adjacent to *x*.

4. Methods

Several models are available for analysing count variables (for a review of regression methods for crime-count data, see Osgood, 2000). In common with many crime variables, the number of metal thefts at each station was found to be over-dispersed: the mean number of thefts (5.8 per station) was less than the variance (201.5). The standard Poisson model for count data is known to perform poorly when used on over-dispersed data, but several alternatives are available (for a review, see Lord, Park, & Levine, 2013). This study used a negative binomial (NB) model because, unlike alternatives such as hurdle or zero-inflated Poisson models, it does not require the assumption of the over-dispersion being caused by an underlying two-stage process. Analysis was conducted in R (R Core Team, 2013) using the 'CAR' and 'MASS' packages (Fox & Weisberg, 2011; Venables & Ripley, 2002). Spatial calculations were completed in ArcGIS 10.1 (ESRI, 2012).

All of the variables were positively skewed, as expected with counts. Log transformations were considered for all predictors, but the presence of zero values made this undesirable in several cases. The length of railway line in each buffer was logged, because it was strictly positive and extremely skewed.

5. Results

Regression models were run for buffer radii from 1 to 20 km in 1 km increments. In choosing an appropriate radius, it was necessary to balance two conflicting concerns. If the chosen radius were too small, many cases would have zero counts for predictors, for example if there were no SMDs within the buffer. Conversely, if the chosen radius were too large, a substantial proportion of places would be within the buffer of more than one station and so the predictor values would tend to be very similar between cases.[6] In order to balance these two issues, the model with the smallest buffer radius that produced stable co-efficients compared to the other models was preferred.

Below 5 km, there were large variations in co-efficients with each 1 km change in buffer radius, while from 5 km upwards the co-efficients were broadly similar across models. Table 1 shows co-efficients for the model produced with a 5 km (3 mile) buffer, along with standard errors, rate ratios (exponentiated coefficients, e^{β}) and expected percentage changes ($e^{\beta}-1$). Fig. 3 shows confidence intervals around the estimates. Generalised variance inflation

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[5] The count of residential and non-residential buildings in each area could not be used because they were highly correlated (Spearman's $\rho = 0.97$). This correlation may seem high, but it is likely to be a reflection of the organic way in which the English built environment has developed over centuries, with land use often determined before the concept of town planning had developed.

[6] It was necessary to allow buffers to overlap in order to plausibly model the factors influencing offender decision making. For example, there was no reason to think that offenders would not choose to sell metal to an SMD within the buffer of one polyline simply because that scrap yard happened to be marginally closer to a different railway line. Although spatial dependence was accounted for by including a lag term in the model, it nevertheless appeared prudent to minimise its extent.

Table 1
Regression model results based on a 5 km buffer.

	β	SE	e^{β}	Expected change (%)
Constant	-2.77^{***}	0.169	0.06	−94
SMDs per 10 sq kms	0.25^{***}	0.059	1.28	28
Industrial premises per 1 sq km	-0.06^{**}	0.019	0.95	−5
Burglaries per 1000 buildings	0.02^{***}	0.002	1.02	2
km major roads per 1 sq km	0.64^{**}	0.227	1.89	89
Urban area[a]	1.30^{***}	0.134	3.69	269
Suburban area[a]	0.64^{***}	0.136	1.90	90
km of railway line (natural log)	0.94^{***}	0.045	2.56	156
Mean thefts at adjacent stations	0.04^{***}	0.003	1.04	4

$^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

[a] Compared to rural area.

factors (Fox & Monette, 1992) were calculated to take into account the population-density variable being categorical: all the factors were less than four.

One disadvantage of NB models is that there is no single coefficient of determination equivalent to the R^2 value in ordinary least-squares regression. Various pseudo-R^2 statistics are available, of which the present study used that suggested by Cragg and Uhler (1970, 400). This compares the model under study with a null model containing no predictors. The model reported here produced a pseudo-R^2 of 0.41, suggesting that there is unmodelled variation in the data. This is not surprising, since the model was not able to take account of, for example, the fencing preferences of individual metal thieves or the willingness of individual SMDs to buy stolen metal.

The variable producing the greatest expected change in the number of metal thefts was the density of dwellings in the local area: a polyline in an urban area would be expected to have 3.7 times more thefts than a rural one, while a suburban polyline would be expected to have 1.9 times more thefts than a rural one.

The number of SMDs was positively associated with the number of metal thefts: each additional SMD per 10 sq kms was associated with a 28% rise in metal theft. Main-road density was also significant, with each additional kilometre of main road per 1 sq km of buffer area associated with a 1.89 times increase in metal theft.

Each additional burglary per 1000 buildings per year was associated with a 2% increase in metal thefts, while each additional industrial premises per 1 sq km was associated with a 5% decrease. However, the significance of these two predictors appeared to be sensitive to buffer radius, with co-efficients not reaching significance in some models; these results should therefore be treated with caution.

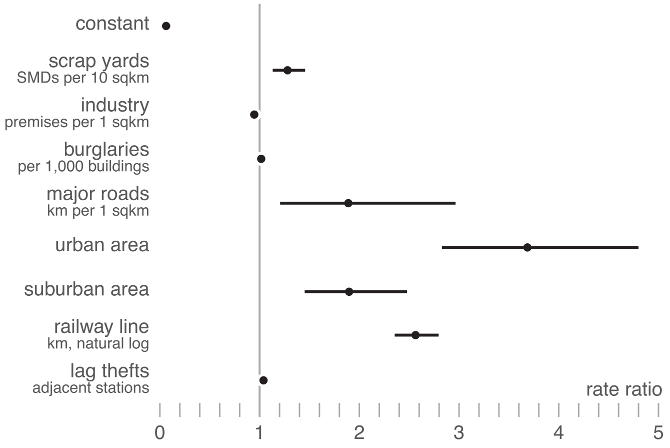

Fig. 3. Regression model 95% confidence intervals.

Fig. 4 shows how the number of thefts predicted by the model increases with the number of SMDs. The expected increase in metal thefts with each one-unit increase in SMDs count (the slope of the curve) is considerably larger in urban areas than in rural or suburban areas. Fig. 5 shows the model residuals, i.e. difference between the actual theft counts for each polyline and those predicted by the model – they are positively skewed because the counts must be non-negative. Large positive residual values appear to cluster spatially, with at least three clusters of over-prediction apparent. This suggests that the frequency of theft depends partly on variables not included in the present model and that at least some of those unmodelled variables exhibit spatial clustering.

6. Discussion

The present study found a significant positive association between the locations of SMDs and the locations of metal thefts from railways in England at the small-area level. This was the case even after population density, accessibility, industrialisation and the local burglary rate had been taken into account. Although an indirect test, and subject to the limitations discussed below, this finding is relevant to both the MRA and current efforts to reduce metal theft through a focus on SMDs. Empirical support for the assumptions underlying the MRA is particularly valuable because, although those assumptions appear intuitive, existing supportive evidence is surprisingly limited.

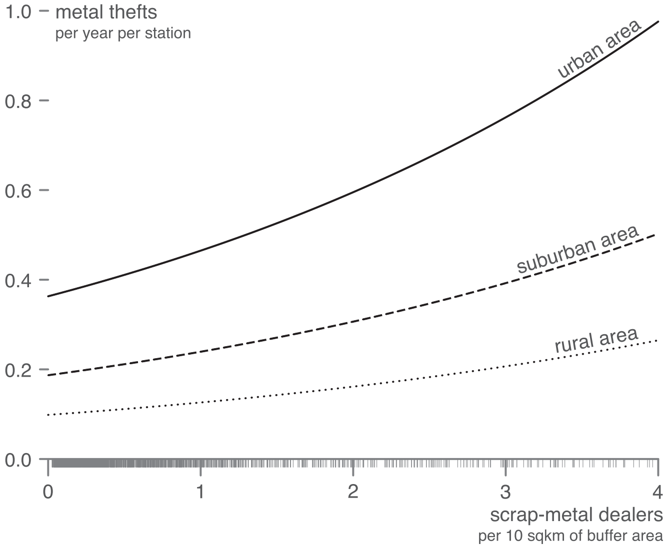

Fig. 4. Variations in predicted number of metal thefts. Variables not shown were held at their median values.

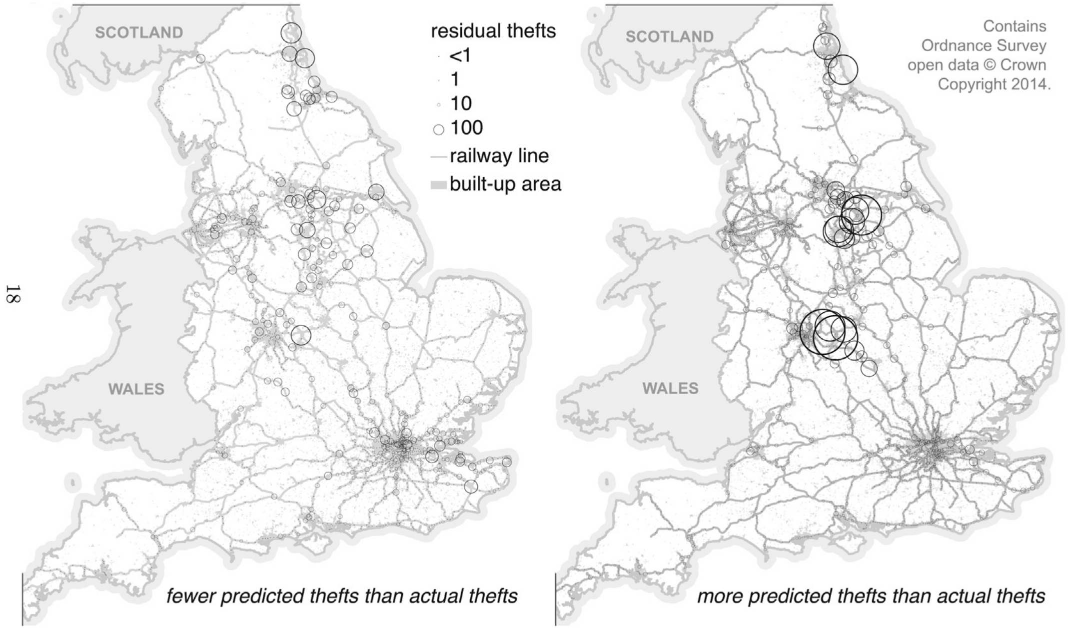

Fig. 5. Map of regression residuals.

The results presented above are for a 5 km buffer around each railway line, which may appear to be a small distance for offenders to travel after stealing metal. Existing evidence on the journey after crime is very limited, but suggests that offenders do travel only short distance to dispose of stolen property (Lu, 2003). Short journeys would be expected from a rational choice perspective because the longer thieves are in possession of stolen goods, the greater the risk of them being apprehended. It is for this reason that thieves generally try to sell-on goods within hours (Stevenson, Forsythe, & Weatherburn, 2001, 112) or even minutes (Sutton, 2008, 41), during which time they will only be able to travel a short distance. Rapid sale is likely to be particularly important for metal thieves, who may well know that police frequently stop and inspect vehicles carrying scrap metal, and will be aware that claiming innocent possession of (for example) 100 m of roughly-cut railway-signalling cable in the early hours of the morning is unlikely to be convincing.

The present results support the finding of Whiteacre and Howes (2009) that metal thefts were more common in areas with more SMDs, but also extend them in several ways. The present study controlled for the amount of metal available by including the length of railway line in each station polyline as a predictor, as well as modelling urbanisation and main-road accessibility. The results presented here also benefited from more comprehensive data on the locations of metal thefts and SMDs. The analysis considered much smaller and more-varied geographical areas, including rural and suburban areas as well as cities. Finally, this research used a regression model suited to a count dependant variable, rather than using an ordinary least-squares model that was potentially unsuitable.

Four other predictors were found to be significant predictors of metal thefts. Both stations with longer polylines and those surrounded by areas of high metal-theft were found to themselves suffer from more metal thefts. Metal thefts were also much more common in urban areas and areas with more main roads.

That a greater density of industrial premises was found to be associated with fewer metal thefts contradicts the results of Whiteacre and Howes (2009) that such premises were associated with more metal theft. There are at least two potential explanations for this. Firstly, in the specific context of railway-metal theft industrial premises may be associated with higher risk of apprehension (e.g. where factory staff are present loading freight onto trains). Secondly, since population and industry are highly positively correlated, it may be that the positive association between industry and metal theft found by Whiteacre and Howes (2009) was an artefact produced by not including a population-density variable in their analysis. However, since the significance of the industry-density variable appeared to be sensitive to buffer radius, further research is required to fully explore the direction and strength of this relationship.

That the density of main roads was a significant predictor of metal thefts was expected, since such a relationship would accord with both previous theoretical predictions and empirical results. Main roads are typically busy with traffic, meaning that more potential offenders are likely to be aware of locations close to them. Previous tests of the criminogenic effect of such greater awareness have found main roads to be associated with higher crime rates (Weisburd et al., 2012, 109). Even if an offender were to be equally aware of locations both close to and away from main roads, rational choice suggests a preference for the former if it reduces the effort of offending or (by reducing the time offenders spend near the crime scene) reduces the risk of apprehension. Butler (1994, 33) interviewed commercial burglars and found them to strongly prefer crime opportunities close to main roads.

There are several potential critiques of the present study. The first (found in any non-experimental study) is the issue of identifying causality: the presence of more SMDs in an area may attract metal thieves, the presence of more stolen metal in an area may attract SMDs, or a third factor may attract both SMDs and metal thieves. Of these options, the second is perhaps the least plausible: most SMDs are long-established businesses, so few are likely to have gone into business in order to capitalise on the recent increase in the availability of stolen metal. The authors held discussions with practitioners from both the police and the recycling industry to identify potential confounding variables, and all the potential factors raised in these discussions were incorporated into the model reported here. However, Fig. 5 suggests that there remains some clustering in unexplained variance. While the possibility of a confounding factor cannot be discounted without experimental research (which would be impractical in the present case) the presence of more SMDs in an area providing an incentive for metal theft (by making it easier to fence stolen metal) appears to be the most plausible of the three potential explanations.

The second limitation of this study is that is does not distinguish an SMD that is actively involved in metal theft from one that takes equally active steps to avoid it. Given the law of troublesome places discussed above (see Eck et al., 2007; Wilcox & Eck, 2011), it seems likely that some SMDs are heavily involved in handling stolen metal, some involved to a lesser extent and many not involved at all. How to identify those 'risky' SMDs is one of the unanswered questions in tackling metal theft.

The final limitation of this study is that it provides evidence only in relation to metal theft from railways. At the present time, this is largely unavoidable because it is only very recently that the police – and institutional victims of metal theft outside the rail industry – have begun to think of metal theft as a problem important enough to justify specific recording. Although this study used data on railway thefts, there are reasons to think that the results will apply at least to metal thefts from other infrastructure networks. Most metal thefts from railways involve theft of cable from railway telecommunications or power networks (Robb, Coupe, & Ariel, 2014), which have many similarities to the public networks operated by telecommunications and power distribution companies.

The present results appear to provide support for the central assumption of the MRA that the availability of outlets for the disposal of stolen goods will be associated with the incidence of theft. In summary, the more SMDs that are available to purchase stolen metal (wittingly or unwittingly) the more thefts there are in the local area. In turn, this suggests that there may be merit in the current attempts to reduce metal theft through a focus on SMDs. Given the existing literature on risky facilities, it remains an open question as to whether a focus on SMDs should take the form of regulatory action against them as a class of business, or targeted action against those individual sites known to be involved in or facilitating crime. The former course of action, increasingly adopted by governments in the US and EU, inevitably involves interfering with legitimate businesses and is therefore *prima facie* undesirable unless it can be justified in crime-prevention terms. Such a justification might be found if it is not possible to reliably identify criminogenic SMDs, for example due to lack of reliable intelligence or sufficient resources for monitoring scrap yards. Alternatively, if evaluation research was to establish an overwhelming benefit from regulatory action, those benefits may outweigh the costs to the scrap-metal industry. In such circumstances, it may be justifiable to target criminogenic SMDs through regulatory action covering the entire industry.

The present study adds to the literature on the market-reduction approach, on the regulation of scrap-metal dealers and on risky facilities. Further research will be required to ascertain the impact of the various MRA-based laws being introduced to combat metal theft through the regulation of SMDs, particularly since different jurisdictions are introducing different combinations of measures. Paradoxically, while such research will become easier in future (as more data become available on how such laws are operating) it may also become less valuable, since many governments will have already implemented such laws without the benefit of supporting research. It is this paradox that makes the current study valuable, by providing indirect evidence during the present period when direct tests are not possible except in those few jurisdictions that implemented SMD laws relatively early. The evidence presented here certainly has limitations, but the authors believe it is better to offer imperfect evidence (with its imperfections clearly stated) than to allow policy makers and practitioners to work in an environment devoid of any evidence at all.

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References

Ackerman, F., & Mirza, S. (2001). Waste in the inner city: asset or assault? *Local Environment: the international journal of justice and sustainability, 6*, 113–120.

Albers-Miller, N. D. (1999). Consumer misbehavior: why people buy illicit goods. *Journal of Consumer Marketing, 16*, 273–287.

Amirfazli, T., & Hyndman, E. (2012). Secondary metal recyclers. *Georgia State University Law Review, 29*, 238–251.

Anselin, L., Cohen, J., Cook, D., Gorr, W., & Tita, G. E. (2000). Spatial analyses of crime. *Criminal Justice, 4*, 213–262.

Ashby, M. P. J., Bowers, K. J., Borrion, H., & Fujiyama, T. (2014). The when and where of an emerging crime type: the example of metal theft from the railway network of Great Britain. *Security Journal*. Advance online publication 13 October.

Beavon, D. J. K., Brantingham, P. L., & Brantingham, P. J. (1994). The influence of street networks on the patterning of property offences. In R. V. Clarke (Ed.), *Crime prevention studies* (Vol. 2, pp. 115–148). Monsey, NY: Criminal Justice Press.

Brantingham, P. L., & Brantingham, P. J. (1981). Mobility, notoriety, and crime: a study in the crime patterns of urban nodal points. *Journal of Environmental Systems, 11*, 89–99.

Briggs, D. J. (1981). The principles and practice of applied geography. *Applied Geography, 1*, 1–8.

Burnett, J., Kussainov, N., & Hull, E. (2014). *Scrap metal theft: Is legislation working for states?* Lexington, KY: Council of State Governments.

Butler, G. (1994). Commercial burglary: what offenders say. In M. Gill (Ed.), *Leicester: Perpetuity: Vol. 1. Crime at work: Studies in security and crime prevention* (pp. 29–41).

Chainey, S. (2002). The importance of geography: better information for tackling social exclusion. In *Proceedings of the 8th European Commission GI and GIS Workshop. Institute for Environment and Sustainability*.

Chappell, D., & Walsh, M. (1974). Receiving stolen property: the need for systematic inquiry into the fencing process. *Criminology, 11*, 484–497.

Clark, W. A. V., & Avery, K. L. (1976). The effects of data aggregation in statistical analysis. *Geographical Analysis, 8*, 428–438.

Colquhoun, P. (1797). *A treatise on the police of the metropolis* (4th ed.). London: Dilly.

Cornish, D. B., & Clarke, R. V. (2008). The rational choice perspective. In R. Wortley, & L. Mazerolle (Eds.), *Environmental criminology and crime analysis crime science series chapter 2* (pp. 21–47). Cullompton, Devon: Willan.

Cragg, J. G., & Uhler, R. S. (1970). The demand for automobiles. *Canadian Journal of Economics, 3*, 386–406.

Dettman, J. R., Cassabaum, A. A., Saunders, C. P., Snyder, D. L., & Buscaglia, J. (2014). Forensic discrimination of copper wire using trace element concentrations. *Analytical Chemistry, 86*, 8176–8182.

Eck, J. E., Clarke, R. V., & Guerette, R. T. (2007). Risky facilities: crime concentration in homogeneous sets of establishments and facilities. In G. Farrell, K. J. Bowers, S. D. Johnson, & M. Townsley (Eds.), *Imagination for crime prevention: Essays in honour of Ken Pease number 21 in crime prevention studies* (pp. 225–264). Monsey, NY: Criminal Justice Press.

Fletcher, A. W. (1976). Review lecture: metal recycling from scrap and waste materials. *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences, 351*, 151–178.

Fox, J., & Monette, G. (1992). Generalized collinearity diagnostics. *Journal of the American Statistical Association, 87*, 178–183.

Fox, J., & Weisberg, S. (2011). *An R companion to applied regression* (2nd ed.). Los Angeles: Sage.

Gmelch, S. B. (1986). *Groups that don't want in: Gypsies and other artisan, trader, and entertainer minorities*. Annual Review of Anthropology.

Google. (2015). *Google maps*.

Hale, C., Harris, C., Uglow, S., & Gilling, L. (2004). *Targeting the markets for stolen goods: Two targeted policing initiative projects. Number 17 in home office development and practice report*. London: Home Office.

Institute of Scrap Recycling Industries. (2014). Metal theft laws in the states. *BOLONews, 19*.

Johnson, S. D., & Bowers, K. J. (2010). Permeability and burglary risk: are cul-de-sacs safer? *Journal of Quantitative Criminology, 26*, 89–111.

Krajick, K. (1997). Mining the scrap heap for treasure. *Smithsonian Magazine, 28*, 34–45.

Loewenberger, P. A., Newton, M., & Wick, K. (2014). Developing creative leadership in a public sector organisation. *International Journal of Public Sector Management, 27*, 190–200.

Lord, D., Park, B., & Levine, N. (2013). Poisson regression modeling. In N. Levine (Ed.), *CrimeStat IV: A spatial statistics program for the analysis of crime incident locations chapter 16*. Washington, DC: National Institute of Justice.

Lu, Y. (2003). Getting away with a stolen vehicle: an investigation of journey-after-crime. *The Professional Geographer, 55*, 422–433.

Mares, D. M., & Blackburn, E. A. (2014). Reducing metal thefts through the use of local ordinances: an evaluation of an impromptu market reduction approach in St Louis, MO. *Security Journal*. Advanced online access.

McIntosh, M. (1976). Thieves and fences: markets and power in professional crime. *British Journal of Criminology, 16*, 257–266.

Office of Fair Trading. (2014). *Completed acquisition by European Metal Recycling Ltd of five sites and certain assets of SITA Metal Recycling Ltd*. London: Office of Fair Trading. ME/6240/13.

Office for National Statistics. (2013a). *Population and household estimates for the United Kingdom, March 2011*. London: Office for National Statistics.

Office for National Statistics. (2013b). *UK Business: Activity, size and location – 2013. Statistical bulletin series*. London: Office for National Statistics.

Osgood, D. W. (2000). Poisson-based regression analysis of aggregate crime rates. *Journal of Quantitative Criminology, 16*, 21–43.

Pacione, M. (1999). Applied geography: In pursuit of useful knowledge. *Applied Geography, 19*, 1–12.

Posick, C., Rocque, M., & Whiteacre, K. (2012). Examining metal theft in context: an opportunity theory approach. *Justice Research and Policy, 14*, 79–102.

Price, V., Sidebottom, A., & Tilley, N. (2014). Understanding and preventing lead theft from churches: a script analysis. In L. Grove, & S. Thomas (Eds.), *Heritage crime: Progress, prospects and prevention chapter 8* (pp. 128–148). London: Palgrave Macmillan.

R Core Team. (2013). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing Vienna.

Robb, P., Coupe, T., & Ariel, B. (2014). 'solvability' and detection of metal theft on railway property. *European Journal on Criminal Policy and Research*, 1–22.

Rossmo, D. K. (1999). *Geographic profiling*. Boca Raton, FL: CRC Press.

Schneider, J. L. (2004). Stolen-goods markets: methods of disposal. *British Journal of Criminology, 45*, 129–140.

Sheley, J. F., & Bailey, K. D. (1985). New directions for anti-theft policy: reductions in stolen goods buyers. *Journal of Criminal Justice, 13*, 399–415.

Sibley, D. (1976). The location and layout of gypsy caravan sites: notions of deviancy in official policy. *Antipode, 8*, 83–87.

Sidebottom, A., Ashby, M. P. J., & Johnson, S. D. (2014). Copper cable theft: revisiting the price–theft hypothesis. *Journal of Research in Crime and Delinquency*.

Sidebottom, A., Belur, J., Bowers, K., Tompson, L., & Johnson, S. D. (2011). Theft in price-volatile markets: on the relationship between copper price and copper theft. *Journal of Research in Crime and Delinquency, 48*, 396–418.

Sijstermans, L. F. (1997). Recycling of cable waste. In *14th International Conference and Exhibition on Electricity Distribution*. London: Institution of Engineering and Technology, 3.8.1–7.

Spatari, S., Bertram, M., Fuse, K., Graedel, T. E., & Rechberger, H. (2002). The contemporary European copper cycle: 1 year stocks and flows. *Ecological Economics, 42*, 27–42.

Spendlove, M. J. (1961). *Methods for producing secondary copper. Bureau of Mines Information Circular*. Washington, DC: US Department of the Interior.

Stevenson, R. J., Forsythe, L. M. V., & Weatherburn, D. (2001). The stolen goods market in New South Wales, Australia: an analysis of disposal avenues and tactics. *British Journal of Criminology, 41*, 101–118.

Sutton, M. (2008). How prolific thieves sell stolen goods: describing, understanding and tackling the local markets in Mansfield and Nottingham. *Internet Journal of Criminology*.

Sutton, M., Johnston, K., & Lockwood, H. (1998). *Handling stolen goods and theft: A market reduction approach. Number 178 in home office research studies*. Home Office.

Sutton, M., Schneider, J., & Hetherington, S. (2001). *Tackling theft with the market reduction approach*. Home Office.

Vandeviver, C. (2014). Applying google maps and google street view in criminological research. *Crime Science, 3*, 1–16.

Venables, W. N., & Ripley, B. D. (2002). *Modern applied statistics with S* (4th ed.). New York: Springer.

Waterfield, D., & Short, J. (2014). *State metal theft statutes*. Washington, DC: Institute of Scrap Recycling Industries.

Weisburd, D., Groff, E. R., & Yang, S.-M. (2012). *The criminology of place: Street segments and our understanding of the crime problem*. Oxford: Oxford University Press.

Whiteacre, K., & Howes, R. (2009). Scrap yards and metal theft insurance claims in 51 us cities. In *American Society of Criminology Annual Meeting*.

Wilcox, P., & Eck, J. E. (2011). Criminology of the unpopular: implications for policy aimed at payday lending facilities. *Criminology and Public Policy, 10*, 473–482.

Wilson, R., & Smith, K. (2008). What is applied geography for the study of crime and public safety? *Geography and Public Safety, 1*, 1–3.

Zimring, C. (2004). Dirty work: how hygiene and xenophobia marginalized the American waste trades, 1870–1930. *Environmental History, 9*, 80–101.