Home Office

An evaluation of government/law enforcement interventions aimed at reducing metal theft

Research Report 80

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Summary

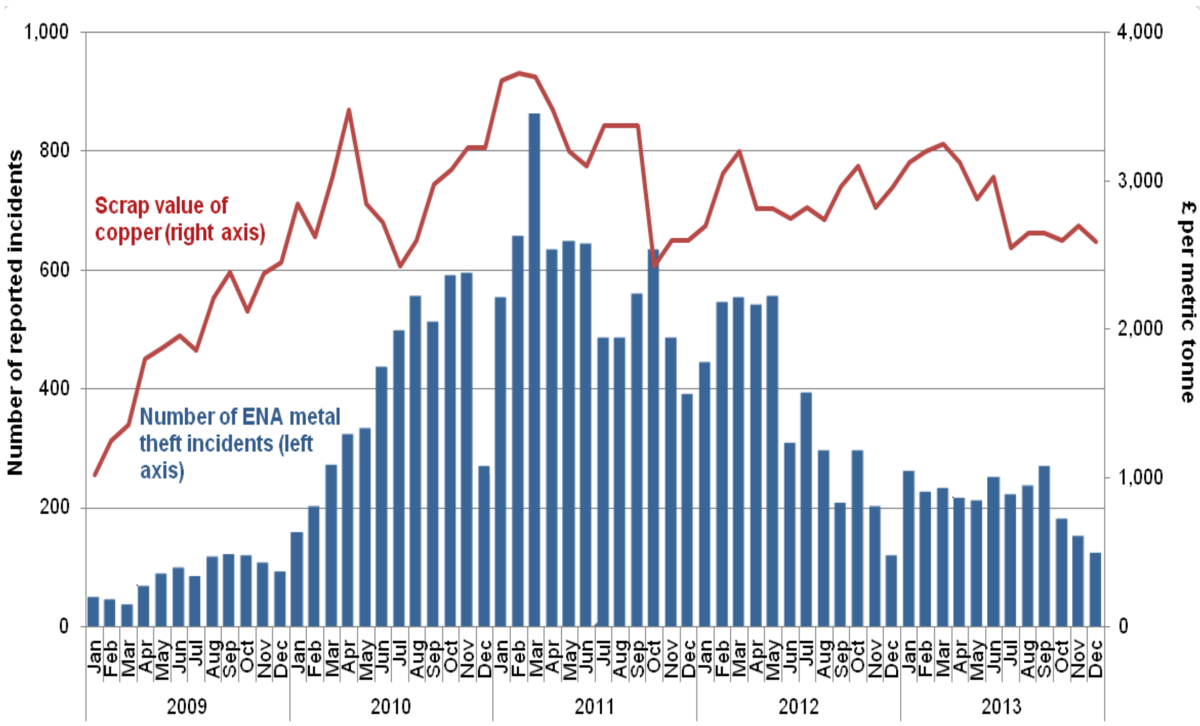
Executive summary

- While most acquisitive crimes have fallen consistently over the past five years, metal theft increased between 2009 and 2011 in line with a sharp rise in global metal prices. It then fell during 2012 and 2013.
- This paper summarises results of analyses which aimed to test whether the decline from 2012 was caused primarily by the government/law enforcement interventions launched to address metal theft, or was simply due to metal prices falling back from their peak.
- The analysis is based mainly on data for metal thefts held by the Energy Networks Association (ENA), though data from British Transport Police (BTP) are also used to verify the main results. The phased roll-out of Operation Tornado across England and Wales helps to identify the specific impact of the interventions, as distinct from other factors that might have contributed to the fall in metal thefts.
- The analysis found that metal thefts recorded by the Energy Networks Association and by British Transport Police fell to levels far lower during 2012 and 2013 than would be expected from the drop in metal prices alone.
- This implies that the interventions launched during that period, Operation Tornado and cashless trading at scrap metal dealers (described below), did contribute to a substantial reduction in the number of offences.
- Analysis showed a large, statistically significant effect for the interventions even when controlling for metal prices and other factors driving acquisitive crime.
- Scotland, which did not receive the interventions, had a rising trend in metal theft during the post-intervention period, according to the Energy Networks Association data. This adds further weight to the main finding, and suggests that some metal theft may have been displaced north of the border.
- As with most retrospective evaluations, there are necessary limitations with both the data and the methodology employed, but these findings are in line with the limited existing evidence from other nations.

Background

Against a backdrop of falling crime in England and Wales generally, metal theft rose sharply between 2009 and 2011. According to one dataset, the increase in metal thefts across this period was more than 300 per cent.[1] At the same time, global metal prices increased by a similar percentage (Figure 1). Indeed, studies analysing the relationship between levels of metal theft and the price of copper from 2006 to 2011 found a strong positive correlation, which was independent from changes in unemployment and other types of railway theft (Sidebottom *et al.*, 2011; Sidebottom *et al.*, 2014).

Figure 1: Comparison of trends in Energy Networks Association reported metal thefts with trends in copper market price, England and Wales, Jan 2009–Dec 2013.



Sources: Metal prices from letsrecycle.com; metal thefts from the Energy Networks Association.

The rise in metal theft, and the link to price, seems to have been a global trend, though robust data on metal theft are sparse. A report by the National Insurance Crime Bureau Strategic and Tactical Information Department (Kudla, 2009), using US national data on metal theft insurance claims as a proxy for metal theft, found that a rise in metal thefts between 2006 and 2008 was strongly correlated with global metal prices (aluminium and copper). Subsequent evidence has shown that US metal thefts dipped in line with metal prices through 2009 but then rose sharply with prices in 2010, such that thefts approximately tripled during that period, exactly as they did

[1] This rise is calculated from the ENA data (from 2009/10 to 2010/11), which is not the only source, see data section. But as we show in that section, trends across sources are very similar, so the 300 per cent rise probably does reflect the likely magnitude of the increase.

in England and Wales (Posick 2008; Whiteacre *et al*., 2009; Posick *et al*., 2012).

Similarly, a European report (Quercia, 2013) concluded that metal theft was: "*a crime with one of the fastest growing rates in the world and ... the most relevant emerging crime in Europe*." The evidence in the report is strongest for Italy. Italian Railway Network data show an increase in metal theft, particularly live and un-live copper cables, through the early 2000s with a preliminary peak in 2006–2008, a slump in line with prices in 2008/09, and then a sharp rise in 2010, mimicking the UK and US situation. More anecdotal evidence from the report also suggested that metal theft was an issue in Bulgaria, Greece and Spain. The German state rail company reported metal theft growing 50 per cent from 2010 to 2011, and a South African electricity company reported 446 incidents in 2005, 1,059 in 2007 and 1,914 in 2008 (Quercia, 2013).

In response to the rise in offences in England and Wales, several interventions were introduced and the National Metal Theft Taskforce, a multi-agency taskforce, funded by government and led by British Transport Police (BTP), was created. The first intervention was Operation Tornado. It required participating scrap metal dealers in England and Wales to request identification documentation for every cash sale and retain copies for 12 months. The intervention, which was backed with police enforcement, was piloted in the police forces in the North East in January 2012 before being rolled out on a phased basis across England and Wales by September 2012. This was followed by the introduction of cashless trading in December 2012, which barred scrap metal yards from accepting cash payments, and then the Scrap Metal Dealers Act 2013[2], which introduced a robust licensing scheme to ensure more effective compliance administered by local authorities, and stronger police enforcement.

The rationale for targeting scrap metal dealers came from previous research analysing the motivation for theft offences (Sutton, 1995; Clarke, 1999). These researchers found that certain goods were more desirable to thieves and that the relevant attributes could be summarised by the acronym CRAVED, which stands for: concealable, removable, available, valuable, enjoyable and disposable. For Clarke (1999), the last of these, *disposable,* is particularly important.

> *"... while each element of CRAVED may be of equal importance in describing which products are stolen, how much they are stolen seems to depend mainly on the final element — how easy it is to dispose of the goods by selling them. This is because high-volume thieves, who derive a substantial income from theft, must be able to dispose of the goods they steal. As habitual thieves are thought to commit a large proportion of all thefts, it becomes clear why disrupting markets for stolen goods is of such importance for policy."*
>
> (Clarke, 1999)

If Clarke's thinking is correct then targeting the disposal of metal – the point at which stolen metal is sold on – i.e. scrap metal dealers – makes good sense if the aim is to reduce the volume of thefts. Subsequent analysis has supported a relationship between metal theft and the proximity of scrap metal dealers. Ashby *et al*. (2014) investigated metal theft from the UK railway network and found a high degree of spatial concentration: half of all metal thefts occurred at just three per cent of railway stations, whereas there were no metal thefts at 63 per cent of stations (ibid.) The same researchers also found that the presence of a scrap metal dealer in the vicinity was a significant predictor of these hotspots (Ashby and Bowers, forthcoming). Their modelling suggested that each additional scrap metal dealer in an area was associated with a 12 per cent increase in metal thefts (ibid.). In the US, Whiteacre *et al*. (2009)

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[2] http://www.legislation.gov.uk/ukpga/2013/10/enacted

also analysed the relationship between metal theft and scrap metal yards in 51 cities. The number of scrap yards per 100,000 residents showed a positive correlation with the rate of metal theft insurance claims. In fact, the rate of scrap metal dealers was the strongest predictor of metal thefts in their model.

However, none of these results proves that targeting the disposal of stolen metal at scrap yards will reduce thefts. Just because metal dealers are found near metal theft hotspots does not show that they caused the problem. Nevertheless, data show clearly that in the latter half of 2012, in the wake of the interventions, metal thefts fell in England and Wales. But as Figure 1 shows, metal prices also fell from their 2011 peak, so it could have been prices, rather than the interventions which drove the decline in thefts. This lack of clarity provides the rationale for the current analysis. Using robust statistical methods, the aim is to disentangle the effect of the interventions from the effect of metal prices and from the other factors that might have helped drive down acquisitive crime in England and Wales, and hence to answer the question – did the metal theft interventions work?

Data and methodology

‘Metal theft’ is not a specific offence code within police recorded crime (PRC), which groups offences by crime type rather than by item stolen. So metal could be stolen in a burglary or in another type of theft but these would be recorded in the PRC statistics as ‘burglary’ or ‘other theft’ rather than as metal theft. The Home Office (HO) did start to collect data on police recorded offences involving the theft of metal during 2012/13 and two years of data have now been collected and published. The published figures show a clear reduction in theft, see Figure 2 below, but they do not cover the period before the interventions, for the most part, meaning that they are not particularly useful to evaluate the interventions. Fortunately, two other metal-theft datasets are available that have longer time series. These are metal thefts recorded by British Transport Police (BTP) and those recorded by the Energy Network Association (ENA), which collates metal-theft data relating to electricity and telecommunications networks. Data for the last five years were provided by BTP and ENA. The available data are summarised in Table 1.

Table 1: Available datasets on metal theft in England and Wales.[3]

Data series	Description	Time period covered	Percentage of total PRC metal theft
Home Office data	Monthly counts of all offences recorded as metal theft by all 44 police forces in England and Wales	April 2012 to March 2014	100%
Energy Networks Association (ENA) data	Monthly counts of all offences by police force area in England and Wales + Scotland	January 2010 to December 2013	6% approx
British Transport Police (BTP) data	Monthly counts of all offences recorded by BTP sub-divided into 7 regions including Scotland	September 2009 to December 2013	2% approx

3 Note that the coverage of HO metal theft is actually fractionally below 100 per cent as Norfolk and West Midlands forces did not submit data for some of the early months in the series. Their data for these months have been estimated for the purpose of the correlations and charts in which HO data are used.

For the most part, the analysis in this paper uses the ENA dataset. This is because:

i) the data are available over a long enough time period to make evaluation possible;

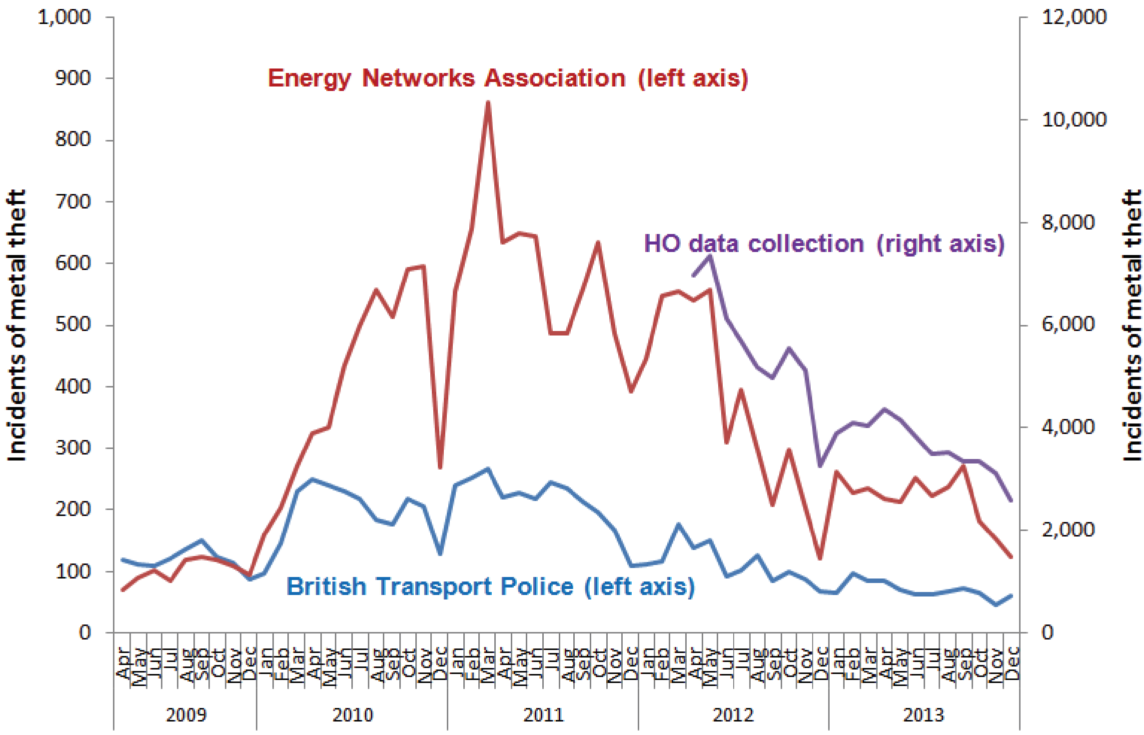
ii) data are available by police force area, which can be aggregated to match the regions corresponding to the Operation Tornado roll-out (Table 2); this allows for more robust analysis because Operation Tornado was launched in different regions at different times so it is possible to examine whether regions experiencing the intervention first also saw earlier falls in crime; and

iii) the data are independent of organisations involved with the interventions.

The main limitation of the ENA dataset is that it only captures a small proportion of all metal thefts. A comparison between the volume of metal thefts recorded by the ENA data and those recorded in the Home Office collection would suggest that the ENA data capture around six per cent of the total number of thefts. However, the ENA data are likely to account for a much higher proportion of the total cost to the economy of metal theft because many of the incidents they record result in loss of energy supply to homes. The ENA calculated that metal thefts from January 2011 to October 2011 cost the public £48.3m, which equates to around £60m annually. Two separate estimates (by the Home Office and by consultancy firm Deloitte) put the total annual cost of metal theft at around £220m at that time suggesting that energy-related metal thefts account for around a quarter of the cost of metal theft.[4] In other words, whilst the ENA data cannot strictly tell us whether the interventions reduced metal theft *in totality*, they can give us an indication of whether the interventions affected some of the most costly types of theft. Being slightly less strict, the ENA data can also be used as a proxy for total metal theft if we can be confident that they accurately capture the *trend* in overall offences. Comparison with the other data series suggests this is broadly the case, see Figure 2.

[4] See: http://www.energynetworks.org/news/public-information/metal-theft/overview.html and https://www.justice.gov.uk/downloads/legislation/bills-acts/legal-aid-sentencing/laspo-metal-theft-ia.pdf

Figure 2: Trends in incidents of reported metal thefts from the Home Office data collection, the Energy Network Association (ENA), and British Transport Police (BTP), England and Wales, Jan 2009–Dec 2013.



As the chart shows, the trends are similar across the datasets. The correlation coefficients with the monthly Home Office data for the period April 2012 to December 2013 are 0.89 for the BTP data and 0.87 for the ENA data, and the correlation between the monthly BTP and ENA data for the whole period in the chart is 0.73.[5]

Though the ENA dataset was used for the main analysis in this paper, we also explored the BTP and recorded crime datasets in an attempt to triangulate the main findings, and these results are reported below.

To try and identify the effect of the interventions, the analysis exploited the fact that Operation Tornado was launched at different times in different parts of England and Wales, see Table 2.

[5] One other limitation of the ENA data is that there may be slight variation in its coverage through the period, due to the fact that the ENA series relies on data received from energy companies. Despite this, as Figure 2 shows, the ENA data produces a similar trend to both the BTP and Home Office metal theft data collections. This suggests that any variation is not biasing the series markedly. See the technical appendix for additional robustness checks that were carried out in relation to this.

Table 2: Timetable of Operation Tornado roll-out by region and police force.

Date	Regions (forces)
Jan 2012	**North East** (Cleveland, Durham, Northumbria)
Feb 2012	
Mar 2012	
Apr 2012	**Yorkshire and the Humber** (Humberside, North Yorkshire, South Yorkshire, West Yorkshire) **East Midlands** (Derbyshire, Leicestershire, Lincolnshire, Northamptonshire, Nottinghamshire)
May 2012	**North West** (Cheshire, Cumbria, Greater Manchester, Lancashire, Merseyside)
Jun 2012	**South West** (Avon and Somerset, Devon and Cornwall, Dorset, Gloucestershire, Wiltshire) **Eastern** (Bedfordshire, Cambridgeshire, Essex, Hertfordshire, Norfolk, Suffolk) **South East** (Hampshire, Kent, Surrey, Sussex, Thames Valley)
Jul 2012	
Aug 2012	
Sep 2012	**West Midlands** (Staffordshire, Warwickshire, West Mercia, West Midlands) **Wales** (Dyfed-Powys, Gwent, North Wales, South Wales) **London** (Metropolitan Police Service, City of London)

A regression model was used to test the effectiveness of the interventions. This is described in full in the technical appendix but the main aspects of the model are set out below.

The dependent variable for the model was the monthly total of metal theft incidents as measured by the ENA data, by region, but excluding Scotland, which did not receive the intervention. Two control variables were also included: average monthly copper prices and regional totals of all other police recorded acquisitive crimes. The copper price data were sourced from letsrecycle.com and contained monthly figures of the scrap price of copper per metric tonne. This was the most appropriate series given that the scrap price measures the re-sale value to the potential thief, and given the research linking metal thefts in England and Wales to copper prices (Sidebottom *et al*., 2014.) The police-recorded crime data were sourced from the Office for National Statistics and were simply the monthly total of all other theft type crimes, by region.[6] This variable is included in an attempt to account for all other factors driving down acquisitive crime. Both the metal prices variable and the acquisitive crime variable were scaled to aid interpretation. Hence the figures for prices are given in £1,000s per metric tonne

6 To be clear, this variable was equal to total police-recorded acquisitive crime (the 'Theft' category') minus the number of thefts within 'all other theft' which is the category containing metal theft. This is the closest proxy available for capturing the total count of thefts that do not involve metal.

and the figures for acquisitive offences are given in thousands of offences. Area fixed effects were also included to account for differences between areas that are constant over time.

To model time, a standardised time variable, relative to the introduction of Operation Tornado, was used. So the month Tornado was launched (which varied by region) was coded zero in each case, with -1 being the month before and +1 the month after, etc. Viewing the data in chart form suggested that metal theft trends had already turned downwards prior to the interventions, possibly due to the fact that prices had already come off their peak at this point. This meant that it also made statistical sense to include a squared time term. This was simply equal to the standardised time variable squared. An intervention dummy variable was also included, which was set to zero for all time periods before the intervention began in each region, and set to one for all periods afterwards. The final version of the model also included the interaction between the standardised time variable and the intervention variable. This aimed to test whether the *trend* in metal thefts changed (on average) at the point when the interventions were launched within each region. It provides perhaps the most robust test of the interventions' effectiveness, as explained in the next section.

All the data series in the model run from January 2010 to December 2013, so effectively what is being tested is the *package* of interventions in each area. The analysis cannot tease out the individual effects of Operation Tornado, the introduction of cashless trading and the Scrap Metal Dealers Act 2013. Instead, the analysis treats these as one continuous intervention which is "switched on" at the point when Operation Tornado starts. The fact that this starting point varies by area makes the result more robust because it reduces the likelihood of obtaining a spurious effect driven by something else occurring at the same time as the interventions.

Results

Analysis of the raw data showed that time periods in which the interventions were in place in a region had, on average, about 50 per cent fewer ENA-recorded metal thefts compared to time periods prior to the intervention. That is, the average number of thefts dropped from 47.04 per region per month to 23.70, a reduction of just over 23 thefts.[7]

However, as demonstrated, metal prices also dropped from 2010 onwards and other factors have continually driven down acquisitive crime generally, so regression analysis is required to try and separate out the amount of that 50 per cent decline that can be attributed to the government/enforcement interventions.

Results of the first model designed to do this are shown below.[8]

Table 3: Initial model results.

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Sig*	*Lower 95%*	*Upper 95%*
Intercept	-78.69	20.71	-3.80	p<0.001	***	-119.38	-38.00
Intervention	-18.21	3.89	-4.68	p<0.001	***	-25.85	-10.56
Metal prices (£000s per metric tonne)	9.15	2.97	3.08	0.002	***	3.32	14.98
Other acquisitive crime (000s)	0.77	0.14	5.57	p<0.001	***	0.50	1.04
Time	-0.22	0.19	-1.15	0.251		-0.58	0.15
Time squared	-0.04	0.01	-6.31	p<0.001	***	-0.05	-0.03

*** indicates significance to the 1% level; ** indicates significance at the 5% level; and * indicates significance at the 10% level.

The table shows that all the main variables in the model were statistically significant at the one per cent level. The coefficient on the 'intervention' variable means that, even taking into account the fact that metal prices and other types of crime were lower post-intervention, the effect of the intervention is still significant with an average reduction of just over 18 thefts per region per month. This equates to an average fall of about 38 per cent (given by 18.21/47.04).

7 A 95 per cent confidence interval around this difference between the two means (for numbers of metal thefts before and after the intervention) was calculated. It showed that the uncontrolled fall in metal thefts was 45–56 per cent.

8 Complete tables of all the coefficients, including those on the area fixed effects and for other model specifications, can be found in the technical appendix.

However, to be absolutely sure that these lower totals would not have been observed irrespective of the intervention, in the final model we also included an interaction term (between the standardised time variable and the intervention variable). A statistically significant coefficient on this term would indicate that, in addition to the level of thefts being lower, the *trend* in thefts also changed at the point the intervention started in each area. This would provide strong evidence of effectiveness. The results of this model are shown in Table 4.

Table 4: Final model results.

	Coefficients	Standard Error	t Stat	P-value	Sig	Lower 95%	Upper 95%
Intercept	-65.36	21.21	-3.08	0.002	***	-107.05	-23.68
Intervention	-14.48	4.12	-3.51	p<0.001	***	-22.58	-6.37
Metal prices (£000s per metric tonne)	6.26	3.15	1.98	0.048	**	0.06	12.45
Other acquisitive crime (000s)	0.68	0.14	4.75	p<0.001	***	0.40	0.96
Time	-1.62	0.57	-2.83	0.005	***	-2.74	-0.49
Time squared	-0.08	0.02	-4.60	p<0.001	***	-0.11	-0.04
Interaction	2.30	0.89	2.59	0.010	***	0.56	4.05

*** indicates significance to the 1% level; ** indicates significance at the 5% level; and * indicates significance at the 10% level.

Again, all the main variables in the model are statistically significant. The coefficient on the 'intervention' variable remains significant at the one per cent level despite the inclusion of the interaction terms, but the magnitude has dropped to 14 fewer (ENA-measured) metal thefts per region per month, implying a reduction of about 30 per cent on average. Crucially though, the interaction coefficient is also significant (and of the opposite direction to the coefficients of the time variables), which demonstrates that the metal theft trend changed once the interventions were introduced. i.e. there was a "faster" reduction in offences post-intervention. We can therefore conclude that the intervention was successful in reducing metal thefts.

Both control variables were also significant, suggesting that metal theft was affected both by metal prices and by other factors driving acquisitive crime generally. The metal prices result implies that a £1,000 increase in scrap metal price per metric tonne results, on average, in just over six extra metal thefts, per region per month. To put this into context, prices increased about £2,650 per metric tonne between 2009 and 2011. The coefficient on the 'other acquisitive crime' variable implies that for every 1,000 increase/decrease in other acquisitive crimes, per region, per month, we might expect metal theft to increase/decrease by 0.68 offences, per region, per month. That is, the factors that drive other acquisitive crime also seem to have a minor effect on metal thefts.

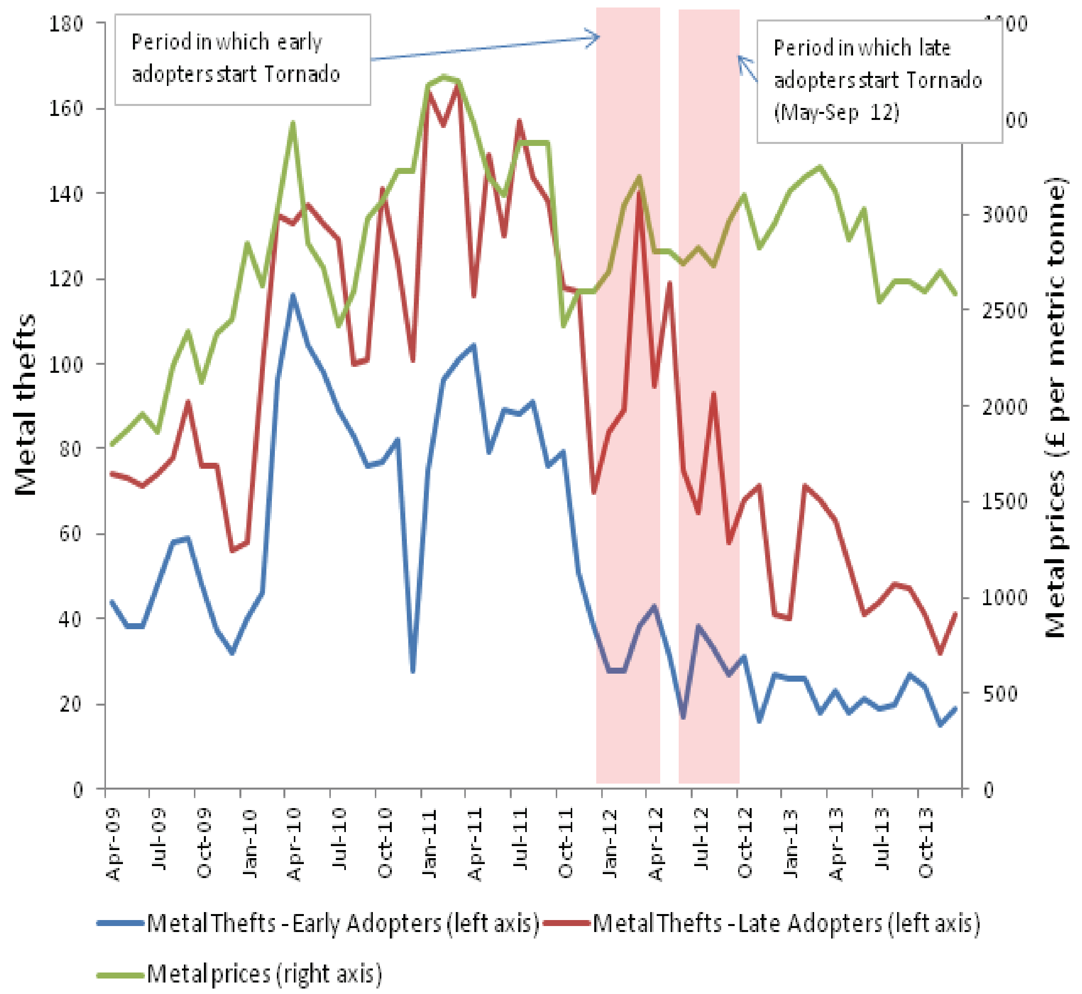
A series of robustness checks were also conducted which included: modelling the time element using a full set of time dummies rather than a standardised continuous variable; using alternative times series of metal prices; and using a subset of the ENA data to ensure consistency of reporting. More details of these results can be found in the technical appendix but the main conclusion was that the effect of the intervention remained strongly significant throughout all these variations.

These results were also triangulated using data from the other available metal-theft datasets. The Home Office dataset is the most comprehensive, in that it records all metal thefts from all forces in England and Wales. But monthly data are only available from April 2012, which as Table 2 shows, is already after the point where some forces had started Operation Tornado. For that reason it is difficult to draw too many conclusions from the HO recorded crime data in relation to the success of the interventions, beyond the fact that they show a similar declining trend, from April 2012 onwards, to the other datasets. Hence whilst the HO data cannot be used to formally test the validity of the main result, the data do not obviously contradict that conclusion.

The British Transport Police (BTP) dataset of metal theft does contain data both before and after the intervention, but it uses a different set of geographical regions, which do not map precisely onto the regions for the Operation Tornado roll-out. For that reason, and because the monthly totals in the BTP data are relatively small, the data were aggregated into two groups for analysis: those regions which began Operation Tornado between January and April 2012 (which includes 12 police forces in total, labelled “early adopters”) and those which began between May 2012 and September 2012 (31 forces, labelled “late adopters”).[9] The difference in metal theft trends in these two areas is shown in Figure 3 below. It is clear that all areas experienced a drop in thefts from the middle of 2011 to the start of 2012 in line with the fall in metal prices. However, when prices increased again in early 2012, those areas that introduced Operation Tornado early continued to see a much lower level of metal theft, while the late adopters saw another spike in thefts until they too began Operation Tornado, at which point the trends in all areas re-converged.

9 See technical appendix for more on this process.

Figure 3: Metal theft trends for the early and late adopters of Operation Tornado using British Transport Police data.



These data were also tested using a linear regression model similar to that used with the ENA data. This showed similar results with a large, strongly significant effect for the intervention and with the time/intervention interaction term significant at the ten per cent level.[10]

Taken together, the findings from the BTP data support the main result: that the package of metal theft interventions had a marked downward effect on metal thefts over and above the effect caused by a drop in prices.

10 The full set of results for this model is in the technical appendix.

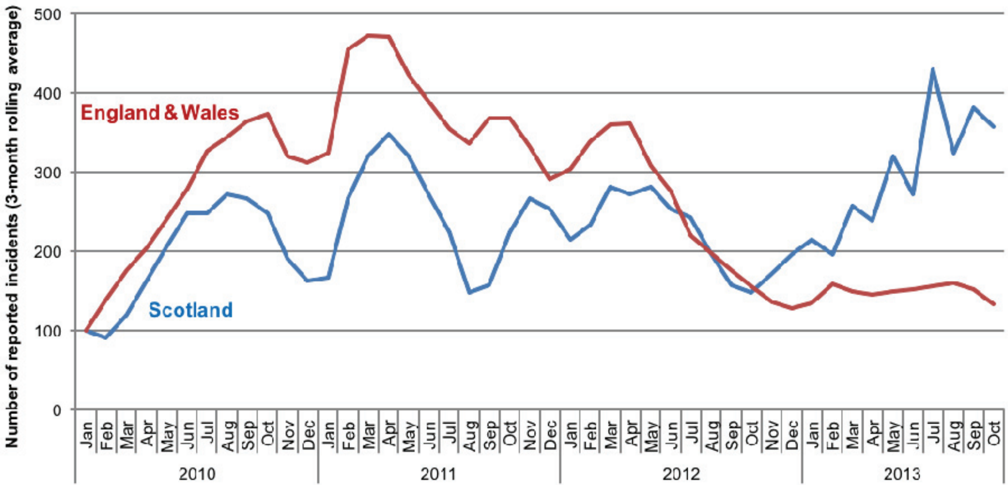
Further evidence from other nations

The rise in metal theft was very much a global problem, and many other nations have introduced measures to try and combat it. Virtually all US states have passed some form of legislation to try and combat the rise in metal theft. However, there is no systematic or reliable form of recording metal theft in the USA, and so accurately measuring the success of these interventions is problematic.

Only one evaluation of these interventions could be located. It examined the success of a similar measure to that employed in England and Wales. In St. Louis, Missouri legislation was introduced to limit anonymous cash sales of certain scrap metals. Mares *et al*. (2014) used interrupted time-series analysis to examine weekly pre- and post-intervention levels of metal theft. They found that thefts fell by 50 per cent, which was a far greater decline than for other types of acquisitive crime (burglary fell by 15 per cent over the same period), and that the effect remained even after controlling for copper prices, local foreclosure rates, unemployment rates, and local average temperatures. This is a similar result to the one identified in this paper.

Scotland provides something of a counter-example as it also saw a rise in metal theft, according to available data, but was not covered by Operation Tornado or any of the ensuing legislation. Using the ENA data, we compared Scotland's trend in metal theft with that in England and Wales, see Figure 4.

Figure 4: Indexed trends in incidents of reported metal thefts (three-month rolling average, Jan 2010 = 100) from the ENA, England and Wales, and Scotland, Jan 2010 – Oct 2013.



The chart shows a clear divergence in trends starting in the second half of 2012 as the intervention was rolled out nationally in England and Wales, but not in Scotland. This adds further evidence to the finding that the interventions reduced metal theft. But it also suggests there may have been some displacement, as thefts in Scotland actually increased in 2013[11].

[11] And this increase is not correlated with metal prices. Indeed the correlation coefficient between metal prices and ENA metal theft in Scotland was actually negative for the period from January 2012 to December 2013.

Interestingly, the divergence in trends from late 2012 onwards is not seen in the BTP data, which also has figures for Scotland. In that dataset, the trend for Scotland is similar to that for England and Wales. Hence, any conclusions around displacement must remain tentative. It could be the case that the type of thief who would travel into Scotland in order to avoid the metal theft interventions in England and Wales would be a more organised offender and one who would be more likely to target the high-value metal thefts captured by ENA data. But this is merely a hypothesis and requires further research to test.

Conclusion

Overall, we found good evidence that the package of interventions aimed at targeting metal theft did drive a reduction in offences over and above the effect of a fall in metal prices and the other factors driving trends in acquisitive crime. Areas had about half the number of metal thefts when the interventions were in place, compared to the time periods when they were not. Modelling suggests that the interventions themselves can be credited with a fall of around 30 per cent, with the rest being attributable to falling prices and other downward pressures on acquisitive crime.

The analysis was mostly directed at the more costly sub-set of thefts captured by the ENA data. But given the similarity in (post-intervention) trends between the ENA data and that for all recorded metal thefts, it seems likely that the interventions did have an effect on the totality of metal theft, though we can be less sure of its magnitude. Analysis of the BTP data also supports this by showing that later adopters of the metal theft intervention also had later drops in theft offences, on average.

We found tentative evidence of some displacement of offences into Scotland, possibly by more organised offenders, as signs of this displacement are only evident in the ENA data, which generally captures high-value offences.

There are several limitations to the analysis that need to be acknowledged. This evaluation was a retrospective one, so areas were not randomised to receive the intervention. The analysis therefore assumes that the timing of the intervention was exogenous to theft trends. We also look only at the effect on metal thefts. It is possible that the effect on overall crime may be less strong, if – for example – thieves deterred by the metal theft interventions switched to another type of acquisitive crime. Finally, data limitations mean the effectiveness of the different aspects of the intervention ‘package’ cannot be analysed separately, the results apply to the package as a whole. Trying to look at the separate effects and any possible displacement into other crimes may therefore be fruitful areas for further research.

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Technical appendix

1. The Linear Regression model

The linear regression model used for the main analysis was as follows:

$$Theft_{it} = a_0 + a_1 I_{it} + a_2 R_i + a_3 T_{it} + a_4 T^2_{it} + a_5 (I_{it} \times T_{it}) + a_6 MP_t + a_7 OAC_t + u_{it}$$

where:

- $Theft_{it}$ is the level of ENA metal theft in region *i* in month *t*. ENA data are available at force level from 2010 so the data were aggregated to regions to fit with the roll-out of Operation Tornado.
- I is a 'policy on' dummy variable equal to 0 for each area, and in each time period, before Operation Tornado came into effect and 1 afterwards.
- R is a vector of area fixed effects.
- T is a standardised time variable relative to the introduction of Operation Tornado (so -1 means one month prior to Operation Tornado, +1 is one month after Tornado, and so on).
- T^2 is simply equal to the standardised time variable (above) squared.
- $(I_{it} \times T_{it})$ is an interaction term capturing the interaction between the time and intervention variables.
- *MP* is scrap metal prices in £000s per metric tonne.
- *OAC* is the number of other acquisitive crimes in 000s.
- *U* is a random error term, following a normal distribution[12] with mean zero and variance equal to σ^2

[12] Note that the residuals were graphed to check this normality assumption.

The full results for the interim model are shown below:

	Coefficients	Standard Error	t Stat	P-value	Sig	Lower 95%	Upper 95%
Intercept	-78.69	20.71	-3.80	p<0.001	***	-119.38	-38.00
Intervention	-18.21	3.89	-4.68	p<0.001	***	-25.85	-10.56
Metal prices (£000s per metric tonne)	9.15	2.97	3.08	0.002	***	3.32	14.98
Other acquisitive crime (000s)	0.77	0.14	5.57	p<0.001	***	0.50	1.04
Time	-0.22	0.19	-1.15	0.251		-0.58	0.15
Time_squared	-0.04	0.01	-6.31	p<0.001	***	-0.05	-0.03
area1_North_East	-2.54	2.76	-0.92	0.359		-7.96	2.89
area2_Yorks_and_Humber	23.97	2.72	8.81	p<0.001	***	18.62	29.31
area3_East Midlands	-5.47	2.72	-2.01	0.045	**	-10.82	-0.12
area4_North West	21.07	2.72	7.76	p<0.001	***	15.73	26.41
area5_South West	-32.04	2.72	-11.80	p<0.001	***	-37.38	-26.70
area6_East	20.52	2.72	7.56	p<0.001	***	15.19	25.86
area7_South_East	23.21	2.72	8.55	p<0.001	***	17.87	28.55
area8_West	3.29	2.73	1.21	0.228		-2.07	8.66
area9_Wales	-25.44	2.73	-9.31	p<0.001	***	-30.80	-20.07
Area10_London	-26.58	2.73	-9.73	p<0.001	***	-31.95	-21.22

*** indicates significance to the 1% level; ** indicates significance at the 5% level; and * indicates significance at the 10% level.

The difference in the area coefficients, some of which are significant, indicates that some areas have naturally higher or lower levels (depending on the coefficient) than average. For example, Yorkshire and Humberside has about 24 more thefts per region per month than the average for all regions. The full results for the final model, which includes the interaction term, are shown below:

	Coefficients	Standard Error	t Stat	P-value	Sig	Lower 95%	Upper 95%
Intercept	-65.36	21.21	-3.08	0.002	***	-107.05	-23.68
Intervention	-14.48	4.12	-3.51	p<0.001	***	-22.58	-6.37
Metal prices (£000s per metric tonne)	6.26	3.15	1.98	0.048	**	0.06	12.45
Other acquisitive crime (000s)	0.68	0.14	4.75	p<0.001	***	0.40	0.96
Time	-1.62	0.57	-2.83	0.005	***	-2.74	-0.49
Time_squared	-0.08	0.02	-4.60	p<0.001	***	-0.11	-0.04
Interaction	2.30	0.89	2.59	0.010	***	0.56	4.05
area1_North_East	-2.47	2.74	-0.90	0.369		-7.86	2.93
area2_Yorks_and_Humber	23.83	2.70	8.81	p<0.001	***	18.51	29.14
area3_East Midlands	-5.61	2.70	-2.07	0.039	**	-10.92	-0.29
area4_North West	20.94	2.70	7.75	p<0.001	***	15.63	26.24
area5_South West	-32.14	2.70	-11.91	p<0.001	***	-37.45	-26.84
area6_East	20.42	2.70	7.57	p<0.001	***	15.12	25.73
area7_South_East	23.11	2.70	8.56	p<0.001	***	17.80	28.41
area8_West	3.51	2.72	1.29	0.197		-1.83	8.84
area9_Wales	-25.22	2.72	-9.29	p<0.001	***	-30.56	-19.89
area10_London	-26.367	2.715	-9.71	p<0.001	***	-31.70	-21.03

*** indicates significance to the 1% level; ** indicates significance at the 5% level; and * indicates significance at the 10% level.

The model was also run with a full set of time dummies in place of the standardised time variable. The coefficient on the intervention term was similar to the result in our preferred model included in the main paper. Though the coefficient of the intervention term was significant, this model did not allow for an interaction term, which is the key issue for evaluating the intervention. Another problem with this model was that it didn't converge properly because of collinearity problems. This is why a standardised time variable was ultimately used instead for the main results. Other robustness checks were also completed including using different measures of metal prices, and regional-specific acquisitive crime trends, but the main results stayed robust to all these variations.

The ENA series was also checked for underlying data consistency. This revealed that there was some variation in the contribution of different utility companies. Not all the companies contributed data through the entire period. There is a risk that this could bias results. So, an alternate version of the regression was run which only used data from companies that contributed at least one incident of metal theft in every month of the series. The results of this are shown below. Again, the main finding was that both the intervention term and the interaction term were statistically significant and implied a large crime-reduction effect for the metal theft initiatives.[13]

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[13] This model included the natural logarithm of the time-squared term (in place for the time-squared term), to allow for the reduction of metal theft prior to the interventions.

	Coefficients	Standard Error	t Stat	P-value	Sig	Lower 95%	Upper 95%
Intercept	-25.77	18.14	-1.42	0.11		-61.4	9.87
Intervention	-17.29	3.50	-4.94	p<0.001	***	-24.17	-10.41
Metal prices (£000s per metric tonne)	1.08	2.67	0.40	0.67		-4.17	6.32
Other acquisitive crime (000s)	0.52	0.12	4.22	p<0.001	***	0.28	0.76
Time	1.53	0.25	6.08	p<0.001	***	1.04	2.03
Time (ln)	3.04	1.30	2.34	0.004	***	0.49	5.60
Interaction	-3.37	0.69	-4.92	p<0.001	***	0.49	5.60
area1_Nort East	-2.30	2.42	-0.95	0.34		-7.05	2.45
area2_Yorks_and_Humber	23.32	2.38	9.80	p<0.001	***	18.64	28.00
area3_East Midlands	-3.64	2.38	-1.53	0.12		-8.32	1.04
area4_North West	18.56	2.38	7.81	p<0.001	***	13.89	23.23
area5_South West	-29.10	2.38	-12.25	p<0.001	***	-33.77	-24.43
area6_East	19.74	2.38	8.31	p<0.001	***	15.07	24.40
area7_South_East	20.49	2.38	8.63	p<0.001	***	15.82	25.15
area8_West	2.38	2.39	1.00	0.23		-2.31	7.08
area9_Wales	-22.51	2.39	-9.42	p<0.001	***	-27.21	-17.82
area10_London	-26.93	2.39	-11.27	p<0.001	***	-31.63	-22.24

*** indicates significance to the 1% level; ** indicates significance at the 5% level; and * indicates significance at the 10% level.

2. Analysis of the British Transport Police (BTP) data

The BTP data were grouped by different geographical regions from those that were used for the roll-out of Operation Tornado. So for the analysis the police forces were allocated to each region depending on the proportional coverage. For example, figures obtained from BTP showed that Leicestershire constabulary is 95 per cent covered by the region ‘North Eastern’ and five per cent covered by the region ‘London North’. So this force was coded to ‘North Eastern’ for the purposes of the analysis. Table 4 summarises the results of this process.

Table 4: BTP regions split by police force.

London North	London South	London Underground	North Eastern	North Western	Wales & Western
Thames Valley	Dorset	Metropolitan Police Service	Northumbria	Cumbria	North Wales
Bedfordshire	Hampshire	City of London Police	Durham	Lancashire	Dyfed-Powys
Cambridgeshire	Surrey		Cleveland	Greater Manchester	South Wales
Norfolk	Sussex		North Yorkshire	Merseyside	Gwent
Suffolk	Kent		West Yorkshire	Cheshire	West Mercia
Essex			South Yorkshire		Staffordshire
Hertfordshire			Humberside		West Midlands
			Derbyshire		Warwickshire
			Nottinghamshire		Gloucestershire
			Lincolnshire		Wiltshire
			Leicestershire		Avon & Somerset
			Northamptonshire		Devon & Cornwall

Unfortunately these regions still could not be analysed in a similar way to the ENA regions, which mapped directly onto the roll-out of Operation Tornado. This was because different forces within each of the BTP regions commenced Tornado at different times. For example, within the North Eastern group, Northumbria, Durham and Cleveland started Tornado in January 2012, but the rest of the North Eastern group did not start until April 2012. So the regions were grouped into just two areas for analysis: early adopters, which included all the areas in the North Eastern group (i.e. Northumbria, Durham, Cleveland, N. Yorkshire, W. Yorkshire, S. Yorkshire, Humberside, Derbyshire, Nottinghamshire, Lincolnshire, Leicestershire and Northamptonshire); and late adopters, which included all the other areas. Comparison with Table 2 shows that the early adopters started Tornado between January and April 2012 while the late adopters started between May and September 2012.

The data for these two regional blocks were used in a separate regression analysis, which otherwise employed the same variables as the model for the ENA data.[14] The results of this model are shown below:

[14] This model did not include a squared time term.

Regression Statistics	
Multiple R	0.929
R Square	0.863
Adjusted R Square	0.854
Standard Error	16.146
Observations	96

ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	6	146562.24	24427.04	93.70	0.00
Residual	89	23201.72	260.69		
Total	95	169763.96			

	Coefficients	*Standard Errors*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-227.29	39.94	-5.69	P<0.001	-306.65	-147.93
Intervention	-28.13	6.74	-4.18	P<0.001	-41.52	-14.74
Metal Prices (£000s)	28.81	5.25	5.49	P<0.001	18.38	39.24
Other acquisitive crime (000s)	1.58	0.26	6.11	P<0.001	1.06	2.09
Time	0.08	0.31	0.26	0.79	-0.53	0.69
Interaction	-0.82	0.48	-1.70	0.09	-1.78	0.14

These results are similar to the results for the main model that uses the ENA metal-theft data for the dependent variable rather than the BTP counts of metal theft. Note though, that in this specification the interaction variable is only significant at the ten per cent level, though given there were only two regions in this model, and hence less variation, that is perhaps not surprising.

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