The engine immobilizer: a non-starter for car thieves*

Preliminary

Jan C. van Ours † **Ben Vollaard** ‡

July 4, 2011

Abstract

We provide evidence for a beneficial welfare impact of a crime policy that is targeted at limiting the supply of criminal opportunities. Regulation made application of the electronic engine immobilizer, a simple and low-cost anti-theft device, mandatory for all new cars sold within the European Union as of 1998. We exploit the regulation as source of exogenous variation in use of the device by year of manufacture of cars. Application of the security device reduced the rate of car theft by an estimated 70 percent in the Netherlands and 80 percent in England and Wales, within ten years after the regulation went into effect. Based on micro-data on time to recovery of stolen cars for the Netherlands, we find that the device had a greater impact on theft for joyriding and temporary transportation than on theft for resale and car parts. The costs per prevented theft equal some 250 Euro for England and Wales and 1,000 Euro for the Netherlands; a fraction of the social benefits of a prevented car theft.

JEL Classification: K42, H11, H23

Keywords: car theft, government regulation, crime

*The authors thank Rick Brown, Richard Dubourg, and seminar participants at Universite de Lausanne and CESifo Munich for valuable comments and suggestions, and Stefan Toonen for excellent research assistance. The provision of car theft data by the Netherlands Department of Motor Vehicles (RDW) and data on car security by the Netherlands Institute for Certification of Vehicle Security Systems (SCM) is gratefully acknowledged.

†Department of Economics, CentER, Tilburg University, The Netherlands; Department of Economics, University of Melbourne, Parkville, Australia; CEPR (London), CESifo (Munich); vanours@uvt.nl.

‡CentER, TILEC, Tilburg University, The Netherlands; b.a.vollaard@uvt.nl

1 Introduction

To prevent traffic fatalities due to reckless driving, many roads through residential areas feature speed bumps, narrow passages, and sharp curves. When designed well, traffic enforcement becomes superfluous since drivers cannot reach reckless speeds even if they want to. The design of the roads makes bad behavior disappear: it is unlikely that drivers indulge in other vices now that they can no longer speed up. To paraphrase the Lord's Prayer: the driver is not led into temptation, and both the driver and the residents are delivered from evil.

Similarly, many criminal opportunities can be designed away without the intervention of a school attendance officer, police officer, or corrections officer. Many of us lock doors, keep valuables out of sight, avoid certain streets, and drive rather than walk at certain times of the day. These private actions reduce the rate of crime in society because a potential offender's knowledge of alternative criminal opportunities is limited, as is his ability to exploit alternative opportunities, if only for the fact that he can only be at one place at a time.

The notion that it takes more than a motivated offender to produce a criminal act was entertained mostly in the early economics of crime literature, including Ehrlich (1981) and Cook (1986). They modelled how the interaction between potential victims and offenders results in an equilibrium crime rate. This is the rate of crime that potential victims accept and expect. A more general model of crime along similar lines has been worked out in a related criminological literature (Cohen and Felson 1979; Felson and Clarke 1998). The overarching aim of the literature in this area is to explain where and when crime occurs rather than to study criminal behavior in and of itself, i.e. in isolation from the environment in which the offender operates.[1]

[1]For instance, Cohen and Felson (1979) argue that the sudden growth in crime in the western world in the 1960s can be seen as the by-product of socio-economic progress. Greater affluence created an abundance of targets such as cars and electronic goods. It was this increased availability of targets, combined with reduced levels of day-time home occupancy, that pushed the crime rate to much higher levels. This process has repeated itself in Eastern Europe after the fall of the Iron Curtain and in China with the advent of fast economic growth (Van Dijk 2009). Similarly, the fall in crime in the 1990s and 2000s has been attributed to the massive investment in private security in response to the high crime rates of the 1970s and 1980s

A commonly mentioned rationale for government intervention in victim precaution are externalities. Victims and property insurers may not take into account the use of publicly funded police and justice resources that are related to crime. Under-investment in precaution may result. In addition, precautionary behavior may have consequences for the crime risk of other potential victims, both positive and negative (Clotfelter 1977; Shavell 1991). Paternalistic motives may provide another reason for government intervention. Many studies find that most people make systematic mistakes when it comes to dealing with risk (Thaler and Sunstein 2009). The way people manage the risk of crime may be no exception. Rather than taking a calculated risk based on perfect information about the crime risk, the potential loss, and the effectiveness of precautionary measures, as assumed in Ehrlich (1981) and Cook (1986), victims may be poorly informed, base their decisions on rules of thumb like the availability heuristic, and be taken by surprise. The latter perspective may be better in line with the typically observed behavioral pattern of a low initial level of precaution, followed by a strong precautionary response once victimization occurs.[2] Government intervention may help people to commit to a strategy of precaution, for instance by regulating the use of built-in security (Vollaard and Van Ours 2011).

Public action that seeks to limit criminal opportunities has so far not been subjected to much rigorous empirical study. The evidence base on how government policy can contribute to reducing the supply of criminal opportunities is small, certainly when compared to the literature on bringing down crime by way of limiting the pool of motivated offenders (Cook and Ludwig 2010). Think of the numerous studies into the crime-reducing effect of deterrence, incapacitation, and policies to promote skill formation (see Levitt and Miles 2007 for a recent review of the economics literature). Most of the work into ways to reduce the creation and exploitation of criminal opportunities is descriptive in nature. The methodology that is used rarely allows for reliable estimates of the size of the crime-reducing effect. Consequently, how the benefits compare to the costs of such policies tends to remain undiscussed.[3] Exceptions can mainly be found in the recent economics literature,

(Farrell et al. 2010; Cook and MacDonald 2011).

[2]For instance, see Budd (1999: 40) for an analysis based on British data, and Averdijk and Loeber (2010) for an analysis based on US data.

[3]Policies that have been studied include publicity campaigns to raise awareness of the crime risk and

including Cook and MacDonald (2011) on legislation that charters business districts to raise funds for private security guards, and Vollaard and Van Ours (2011) on the effect of building regulations settings standards for burglary-proof windows and doors in residential construction.[4]

In this paper, we add to the scarce evidence on how shocks in the supply of criminal opportunities affect the crime rate. We provide a first estimate of the size of the crime-reducing effect of mandatory application of the electronic engine immobilizer, a simple, low-cost device to prevent car theft. The electronic engine immobilizer has been the security device of choice for legislators looking into ways to reduce car theft. Member countries of the European Union made application of the device in all new cars mandatory in 1998, Australia followed in 2001 and Canada in 2007. In parts of Australia and Canada, the legislation also extended to the existing car fleet.[5] The security device blocks a vehicle's electrical circuits when the key is not in the ignition. It prevents hot-wiring, a popular modus operandi of car thieves prior to the introduction of the immobilizer. The regulation forced application of the security measure on many car owners who would not have used it otherwise or would have installed it only later. In the absence of offsetting behavior (think of being more careless when owning a well-secured car), the regulation will result in an upward shift in the average level of victim precaution.

Whether the benefits of the regulation of built-in security exceed the costs – and whether

what to do about it, which are claimed to be of little effect (Barthe 2006), local, small-scale initiatives aimed at target-hardening such as fencing off backyards (Armitage and Smithson 2007), and nation-wide regulation of mandatory application of security features in products, including steering locks in cars (Webb 1994) and other types of car security (Maxfield and Clarke 2009; Farrell et al. 2011). In a similar vein, reduced motorcycle theft has been suggested to be an unanticipated side effect of helmet laws for motorists (Mayhew, Clarke and Elliott 1989). Welsh and Farrington (1999) review some criminological studies into small-scale policy initiatives that also discuss costs and benefits of the intervention.

[4]Related studies include Cook and Ludwig (2006) who analyze guns laws in relation to the use of hand guns as protective device against burglary; Ayres and Levitt (1998) and Gonzalez-Navarro (2008) who study cooperation between the police and a private security company to retrieve stolen cars; Lenis, Ronconi and Schargrodsky (2010) and Leigh and Neill (2010) who study the crime-reducing effect of gun buy-back programs.

[5]The legislative initiatives had an impact on other countries as well, particularly on small countries without a car manufacturing industry such as New Zealand.

this strategy compares favorably to alternative crime policies – is not a trivial question. Reducing a risk that is already low through a one-size-fits-all measure that does not discriminate between targets at high or low risk sets a high threshold for achieving positive net benefits. Theft is rare: on average, around the turn of the century, a passenger car was stolen once every 200 years in the US and Western Europe.[6] Most people face a risk that is even lower than the average; only a small group faces a highly elevated risk (Cohen and Felson 1979). As a consequence, a uniformly prescribed prevention measure may provide little protection to targets that are at high risk, and high protection to targets that are at low risk. For instance, Vollaard and Van Ours (2011) find mandatory application of burglary-proof windows and doors to have reduced the burglary risk by about a quarter. Assuming a life span of homes of 75 years, the cost per prevented burglary are some 1,900 euro. The average cost of a burglary are at least twice as high (Cohen 2004; Ludwig 2010), implying that the regulation is welfare improving.

Using data for England and Wales for 1997-2005 and for the Netherlands for 1995-2008, two countries within the European Union that made application of the engine immobilizer in new passenger cars mandatory as of 1998, we estimate the effect of the regulation on the overall rate of car theft. Mandatory application provides a natural experiment in the use of the security device. The regulation makes application of the car security device conditional on the year of manufacture rather than the risk of theft of a vehicle. The resulting exogenous shock in built-in security allows us to estimate its causal effect by comparing theft rates of cars that were manufactured before and after the change in regulation.

We find mandatory application of the electronic engine immobilizer to have been highly successful in reducing the overall rate of car theft. The immobilizer caused the rate of car theft to go down by 70 percent in the Netherlands and by 80 percent in England and Wales. The regulation reduced car theft so dramatically that the costs per prevented car theft were some 250 to 1,000 Euro, which is a fraction of the average social benefit of a prevented car theft. We show that different types of offenders react differently to the regulation. Based on micro-data on the time to recovery of stolen cars for the Netherlands, we find that the

[6] The mentioned rates of crime victimization are based on national victimization surveys for the US (NCVS), England and Wales (BCS), the Netherlands (PMB) and France (CESDIP).

device had a greater impact on temporary theft for joyriding and transportation than on permanent theft for resale and car parts. Apparently, the less skilled and determined the car thief, the greater the protective effect. Our analysis suggests that displacement of theft to older, less-protected vehicles was limited and temporary. The overall rate of car theft started to decline rapidly after the regulation came into force as older, less-protected cars were an alternative for professional car thieves for only a few years, and opportunities for temporary theft were reduced at a high rate through scrappage of old cars. We do not observe displacement towards similar crimes such as motorcycle theft.

Finding a long-lived drop in the theft rate implies that the within-crime elasticity to other modi operandi is low, at least within the first fifteen years after introduction of the engine immobilizer (this phenomenon is also referred to as 'tactical displacement'). Anecdotal evidence suggests that only a small minority of offenders switched to other modi operandi, including break-and-enter to obtain car keys. That is an important lesson for policy, since uniform regulation of a security device invites offenders to focus all their efforts on overcoming this one hurdle, which could make the protective effect of the device short-lived.

We contribute to the literature in three ways. First of all, we provide empirical evidence on the welfare impact of a route less travelled in crime policy: limiting the supply of criminal opportunities. As stated above, most of what we currently know relates to crime policies that aim to reduce the pool of offenders, and the little we know about alternative policies such as the one discussed in this paper tends to be qualitative in nature. The crime-reducing effect of the regulation is relatively large compared to what we know about other crime policies, what indicates that opportunity-focused crime policies deserve further attention. As argued by Cook and Ludwig (2010), evidence on the cost and benefits of alternative crime policies is particularly welcome now that the net social benefits of commonly pursued crime policies such as increasing sentence lengths are becoming increasingly unfavorable.

Second, we contribute to the evidence base on the causal effect of precautionary measures on the risk of crime. We exploit plausibly quasi-experimental variation in victim precaution to identify the causal effect. The otherwise highly endogenous nature of victim precaution may explain the scarcity of empirical evidence on how prevention measures affect the opportunities that offenders exploit. For instance, to the best of our knowledge, no study has shown burglar alarms – a particularly popular security device – to have an independent, negative effect on burglary (see also Cook and MacDonald 2011).

Third, we add to the small literature on externalities of victim precaution, a matter of great importance when it comes to government intervention in this area. We find displacement to older, less-protected cars to be small, which is in line with previous findings (for a recent review see Guerette and Bowers 2009).

The remainder of the paper is organized as follows. Section 2 introduces the regulation that made application of the engine immobilizer mandatory, arguing that its introduction can be considered as a natural experiment. In Section 3, we describe our data. In Section 4 we present our parameter estimates, including a wide variety of sensitivity tests. Based on our parameter estimates, we conduct an analysis of costs and benefits of the regulation in Section 5. Section 6 concludes.

2 Regulation of the electronic engine immobilizer: a natural experiment

In November 1995, the European Union (EU) adopted Directive 74/61/EEC, which made installation of an electronic engine immobilizer mandatory in all new passenger cars sold within the EU as of October 1998. The Directive contains detailed specifications for immobilizers. The legislation allowed car manufacturers less than three years to adapt their production processes. In fact, by November 1995, many manufacturers selling cars within the EU had already begun to change their manufacturing standards in anticipation of the new regulations (Brown 2004).

The EU-regulation provided a sudden push to the application of a security device that had just been introduced in the market. By the estimation of the Netherlands Institute for Certification of Vehicle Security Systems (SCM), which is tasked with certifying car security systems, the first cars with an electronic engine immobilizer appeared on the Dutch market around 1990. At that time, application of the device was mainly limited to premium makes and models. Introduction of the immobilizer happened around the same time in the UK (Brown 2004) and the US (Maxfield and Clarke 2009). Soon, application rates of the device started to diverge sharply between the US and the EU. Whereas the percentage of new passenger cars with an immobilizer only slowly expanded in the US, it experienced sharp growth from some 25 to 100 percent between 1994 and 1998 in the Netherlands. As a result, overall penetration rates experienced much stronger growth in the Netherlands than in the US. Figure 1 shows the percentage of all cars on the road with an electronic engine immobilizer installed in the Netherlands and the US during 1990-2009. Twenty years after the introduction of the engine immobilizer only 30 percent of all cars on the road in the US had the device installed, compared to more than 90 percent in the Netherlands.[7] We do not see a discrete jump in overall application rates in the Netherlands around 1995-1998 since the EU-regulation related to new cars only, and car manufacturers needed a few years before all of their models were outfitted with an immobilizer.

The shock in the application of the engine immobilizer in the Netherlands and other EU-countries in the period to October 1998 can be seen as a natural experiment. The regulation made application of the security measure conditional on the year of manufacture of the car rather than the risk of being stolen. We exploit this exogenous variation in the application of the immobilizer by year of manufacture to estimate its effect on the rate of car theft.

Given the drawn-out introduction of the immobilizer, not all of the variation in the application of the device by year of manufacture may be fully exogenous to a vehicle's theft risk. During the first years after the introduction of the immobilizer and the transition period towards full compliance with the regulation, growth in the rate of application may have been skewed towards premium makes and models. In that case, we would underestimate the effect of the regulation on crime. In the sensitivity analysis, we show our results to be robust to excluding the complete transition period towards full compliance, and to excluding premium makes from the analysis. These findings show that growth in the rate of application was primarily driven by the regulation, justifying its use as a source of exogenous variation in car security.[8]

[7]According to a newspaper report, data from the Insurance Institute for Highway Safety indicate that by 2009 86 percent of all new passenger cars sold in the US had an engine immobilizer installed (USA Today, September 19, 2009).

[8]We know retrofitting of the engine immobilizer in older cars to be rare, as conferred to us by the

The comparison with the US shows that not all of the increase in the application of the engine immobilizer in the Netherlands (and, similarly, England and Wales) is the result of the regulation. If the US provides a counter-factual, then by 2008 about two-thirds of the overall penetration rate can be attributed to the regulation.[9] If we are also willing to assume that the elasticity of the rate of application of the engine immobilizer with respect to the rate of car theft is similar between the US and the EU, then two-thirds of the overall decline in car theft through the device can be attributed to the regulation.[10] We will return to this issue in the conclusion.

Car security has improved across the board, including the application of better locks, central locking, car alarms, and, most recently, track and trace systems. In addition, car parkings may have become more secure, and, less likely, people may have become more careful in response to the wave of car thefts in the beginning of the 1990s.[11] Other types of security measures will not bias the estimated effect of the immobilizer under the assumption that the use of other security has not experienced a similar shock in its application in the

---

Netherlands Institute for Certification of Vehicle Security Systems (SCM). Further support for this assumption is found in the 2005 Netherlands Victimization Survey (VMR). In this survey, almost 90 percent of respondents owning a car reported that they did not have a car security device that did not come with the car.

[9]The US may not be a proper counter-factual if the application rate in the US is not independent from the application rate in the EU. Given the low costs of installing the engine immobilizers (see Section 5), car manufacturers producing for both the American and the European market may have installed the device regardless of the car's country of destination

[10]The estimated size of the effect of the engine immobilizer may be dependent on the fact that it was regulated. Mandatory rather than voluntary application decreases possibilities for displacement. Moreover, in the absence of regulation, the mix of car security measures may be different. Maybe cars in the US were outfitted with different security devices, rather than just fewer engine immobilizers. Different combinations of devices may result in different effects on car theft. Based on data from the British Crime Survey, Farrell et al. (2011) argue that the protective effect of the combined application of security devices is often larger than the sum of their individual protective effects.

[11]For instance, Karmen (2001, 126) cites evidence from several surveys conducted in the US suggesting that motorists tend to be rather careless and little concerned about the chance of having their car stolen. For instance, a third of motorists conceded that they did not always lock their car door; more than one-third confessed that they regularly left their vehicle unattended with the engine running to either warm up or cool off the interior or to accomplish a quick errand.

years before 1998. Based on data from an additional module in the British Crime Survey about security of the main vehicle in the household, Farrell et al. (2011, 8) show the overall penetration rate of the electronic engine immobilizer in England and Wales to follow a markedly faster trajectory than the overall penetration rate of central locking and car alarms, two of other main drivers in car security during the 1990s and 2000s. Their finding confirms the sudden impact of the regulation on the application of the engine immobilizer compared to the more steady growth in the use of other car security devices.

3 Data and descriptive statistics

3.1 Application of the engine immobilizer

For England and Wales, data on the rate of application of the electronic engine immobilizer in newly sold cars for calender years 1988-2008 are to be obtained from JATO, a private provider of automotive data. To compute the rate of application, JATO divided the number of vehicles that had an immobilizer installed per calender year by the number of new vehicles registered in England and Wales in that same calender year. The data show that the immobilizer was installed in a negligible percentage of new cars in 1988 and in all new cars in 1997.

The Netherlands Institute for Certification of Vehicle Security Systems (SCM) provided annual data on the rate of application of the engine immobilizer in new cars in the Netherlands for 1995-2008. Again, the process of going from 0 to 100 percent application in new cars happened during the period 1990 to 1997. The data from SCM may not provide a fully accurate picture of the introduction of the immobilizer, however, because of a time lag of some months in the certification procedure, compounded by a backlog, particularly around the time of the introduction of the immobilizer.

Because of the uncertainty related to these data, and previously discussed concerns that early application may not be fully exogenous to the theft risk, we also estimate the effect of the immobilizer on car theft excluding the complete transition period 1990-1996.

3.2 Rate of car theft

Source of data on car theft by year of make for England and Wales is the Car Theft Index. We use data from the Car Theft Index for the calendar years 1997 until 2005, the year the Index was discontinued.[12] We are able to match the car theft data with data on the application of the engine immobilizer for calender years 1997-2005. For each calender year, we have the theft rate and immobilizer application rate for passenger cars up to 14 years of age. Together, the 9 calender years and the 15 age cohorts provide us with 135 observations. If we exclude calender years 1990-1996 that relate to the transition period during which the immobilizer was introduced, the number of observations is reduced to 73.

For the Netherlands, annual data on the number of passenger car thefts by year of manufacture for 1995-2008 were provided by the Netherlands Department of Motor Vehicles (RDW). Annual data on the number of cars on the road for the same period were obtained from Statistics Netherlands (CBS). Combining the two data sources allows us to derive theft rates by year of manufacture. We are able to match theft data with immobilizer application data for calender years 1995-2008. Again, we have cohorts of cars up to 14 years of age.[13] The 14 calender years and 15 age cohorts equal 210 observations. If we exclude the transition period, we are left with 123 observations.

Figure 2 shows the rate of car theft for the Netherlands together with the rate of motor vehicle theft in England and Wales, both for the period 1980-2009 (these data relate to a longer period and are not used in the empirical analysis in this paper). Since cars represent some 90 percent of motor vehicles, motor vehicle theft is a good indicator of the rate of car theft. Both regions experienced a strong wave of car theft in the first half of the 1990s. Observers relate this crime wave to the fall of the Iron Curtain in 1989,

---

[12]The Index was first published by the Home Office in 1992 based on a sample of data from a limited number of police forces. A completely restyled index based on data from all police forces was published in 1998, based on data for 1997. The data are based on daily downloads from the Police National Computer on cars that have been stolen in the last 24 hours and are still outstanding as stolen at the end of the day. This means that cars that are stolen en recovered the same day are not included. To address this, there is a separate annual data collection process with police forces to obtain data on the short term thefts.

[13]The data for the Netherlands allow for a greater number of age cohorts. Using 20 rather than 15 age cohorts hardly influences the relevant parameter estimates.

which suddenly expanded the market for cars stolen in Western Europe (Van Leiden and Ferwerda 2005). The overall pattern in car theft is similar: it has been on a continuous decline since 1994/1995, to rates lower than observed in the beginning of the 1980s. Figure 2 suggests that calender time effects have had a major impact on car theft rates. Clearly, the impact of the engine immobilizer on car theft cannot be gleaned from Figure 2. In particular, we do not expect to see a discrete shock in the rate of car theft around the time the regulation was introduced, since the engine immobilizer was gradually introduced in a period spanning several years. To get a first indication of the impact of the engine immobilizer, we need to examine theft rates by year of manufacture, which we do in the below.

Figure 3 shows the rate of car theft by age for two years of manufacture, 1989 and 1997, for both England and Wales and the Netherlands. None of the cars produced in 1989 were outfitted with an engine immobilizer; all cars produced in 1997 had the immobilizer installed. For England and Wales, theft rates for cars manufactured in 1989 are available for ages 8 to 14; theft rates for cars manufactured in 1997 are available for ages 0 to 8. Although the age profiles do not overlap, data relate to different calender years, and the prevalence of security devices other than the engine immobilizer has also increased, the figure provides a first indication that cars with an engine immobilizer feature much lower theft rates (0.5 percent versus 2.5 percent or higher). The data for the Netherlands show a greater overlap of theft rates by age of car, and also suggest considerable impact of the engine immobilizer, although from a much lower base rate.

Figure 4 shows the rate of car theft by year of manufacture, calender year and age for England and Wales. In Figure 4a, we use all available datapoints to illustrate the relationship between year of manufacture and the rate of car theft. The vertical lines indicate the transition period during which application of the engine immobilizer in new cars went from 0 to 100 percent. The rate of car theft drops considerably during the transition period. Figure 4b shows the relationship between theft rates and calendar year, excluding years of manufacture during the transition period. Figure 4c shows the relationship between theft rates and age, also excluding the transition period. In all three graphs the theft rates in the cohorts with the engine immobilizer are substantially lower than in the cohorts without the immobilizer. Figure 5 presents the same data for the Netherlands. Although the rate of car theft is much lower in the Netherlands than in England and Wales, all of the relationships show a similar pattern. Again, the introduction of the engine immobilizer seems to have caused a large drop in the car theft rate.

3.3 Recovery of stolen cars

The Netherlands Department of Motor Vehicles (RDW) provided us with micro data on car theft in the Netherlands in the period 1995-2008. For every stolen car, we have a number of characteristics, including the make and model, whether the car was recovered, and the time to recovery.[14] These data allow us to calculate recovery rates for cars from different ages and makes for each calender year.

Figure 6 shows the relationship between the theft rate and the recovery rate for cars by age for the calender years 1995-2008. The recovery rate is defined as the percentage of cars that were recovered within a week. The upper-right part of the graph shows this relationship for cars which were not outfitted with an engine immobilizer; the lower-left part of the graph features cars that are all equipped with an immobilizer. Clearly, the figure suggests that the introduction of the engine immobilizer do not only lead to lower theft rates, but also to substantially lower recovery rates.

Figure 7 shows the relationship between the recovery rate and the duration since theft of the car (in days), for two construction years, 1985 and 2000. In the first construction year none of the cars was equipped with an immobilizer, in the second construction year all cars were equipped with such an immobilizer. The upper graph in Figure 7 shows that recovery rates are lower for cars with an immobilizer than for cars without an immobilizer. The recovery rate is relatively high on the day the car was stolen, peaks after one day and then drops sharply. The lower graph shows the related cumulative recovery rates for cars manufactured in 1985 and 2000. Whereas some 85 percent of the 1985 was recovered within 100 days, for the 2000 cohort this has gone down to just 40 percent.

The top graph of Figure 8 shows the 1 day and 1 week recovery rates of stolen cars by

[14] We removed smaller makes from the sample leaving us with Alfa Romeo, Audi, BMW, Chrysler, Citroen, Daihatsu, Fiat, Ford, Honda, Hyundai, Mazda, Mercedes, Mitsubishi, Nissan, Open, Peugeot, Renault, Saab, Seat, Suzuki, Volkswagen, and Volvo.

construction year. The recovery rate after the introduction of the engine immobilizer is substantially lower than before the introduction. During the transition period the recovery rates declined greatly, although the recovery rates were already on the decline before the start of the introduction period. The bottom graph of Figure 8 shows similar recovery rates by age of the car, again showing a big difference between cars with and without an engine immobilizer.

4 Empirical analysis

4.1 Effect on the overall rate of car theft

In our baseline estimates we focus on the direct effect of the engine immobilizer by relating the share of cars with an engine immobilizer in each calendar year-age cohort to the share of stolen cars in that calendar year-age cohort. We assume that car theft is a function of the age of the car and the security it has in the form of an engine immobilizer. In addition, as discussed in the previous section, calendar time effects may be important. Our baseline equation is:

$$y_{t,a} = \alpha_t + \alpha_a + \beta I(e_{t,a} = 1) + \epsilon_{t,a} \tag{1}$$

where $y_{t,a}$ is the car theft rate in calendar year t among age cohort a. I represents an indicator function that has the value of 1 if the immobilizer rate is 100% and a value of zero otherwise, α_t represents calendar year fixed effects, α_a represents age fixed effects, β is the main parameter of interest, and $\epsilon_{t,a}$ is an error term. Because the information about the exact penetration of the engine immobilizer is not available (at time of writing), we only use information about construction years earlier than 1990, where no car had an immobilizer and construction years later than 1996, in which every car was equipped with an immobilizer. So in our estimates $e_{t,au} = 0$ if construction year is before 1990 and $e_{t,a} = 1$ if construction year is 1997 or later.

The parameter estimates are presented in Table 1. The upper part of the table presents the parameter estimates for England and Wales, the lower part of the table presents the parameter estimates for the Netherlands. All of the estimates in rows 1 to 5 show that the introduction of the immobilizer caused a drop of about 2 percentage-points in the car theft rate in England and Wales. The estimate is not very sensitive to the inclusion of calendar year fixed effects, age fixed effects or age introduced as linear term or as both linear and quadratic term. The same holds for the Netherlands, where the drop is 0.4 percentage points. In rows 6 to 8 we assume that the introduction of the immobilizer rate occurred in equal-sized steps in the construction years 1990 to 1997. We assume that in 1990 12.5% of the constructed cars had an immobilizer, in 1991 25.0% etcetera. The size of the effect of the immobilizer on the car theft rate is a little higher but the parameter estimates do not change much.

Until now, we either ignored information about the penetration rate during the introduction period of the immobilizer or we assumed that penetration was proportional over the years. To get some idea about the path from 0 towards 100 percent of penetration, we estimate the penetration rate conditional on imposing that the immobilizer has a constant effect.

$$y_{t,a} = \alpha_t + \alpha_a + \beta(I(e_{t,a} = 1) + \gamma_c * (1 - d_c)) + \epsilon_{t,a} \tag{2}$$

in which d_c is a dummy variable indicating the years of manufacture in which the immobilizer rate is either 0 or 1 and γ_c is a vector of estimated penetration rates over the construction years 1990–1996. The parameter estimates are shown in Table 2.

The relevant parameter estimates are relatively robust to including calendar year fixed effects and age fixed effects.[15] For England and Wales we find a negative penetration of the immobilizer in construction year 1990. After that the penetration gradually increases to 95% in construction year 1996. If we impose the penetration rate in 1990 to be equal to zero, the estimated penetration rates do not change much. For the Netherlands we find similar results for the penetration rates in construction years 1992-1996. In the construction years 1990 and 1991 the penetration seems to have been slightly higher than in England and Wales. Both estimates show that the growth in the application of the engine immobilizer accelerated, i.e. exceeded that linear path assumed in the estimates in Table 1, rows 6 to 8. As discussed in section 3, that is exactly what we expect given the shock provided by the regulation.

[15] Note that if we introduce both calender year fixed effects and age fixed effects we cannot estimate the penetration of the immobilizer in construction year 1996. In this case, we impose the penetration to be equal to 100%.

4.2 Effect on professional versus casual theft

Recovery rates provide a signal of the purpose of car theft. Youth looking for some excitement or for a solution to a temporary transportation problem typically abandon a stolen car. In contrast, professionals who steal cars for parts or resale do not abandon stolen cars. In other words, casual offenders tend to commit temporary theft and professional offenders permanent theft. The summary statistics already suggested that the engine immobilizer not only affected the rate of car theft but also reduced the rate at which stolen cars were recovered, a finding warranting further analysis. The micro data on stolen cars in the Netherlands allow us to estimate the determinants of the recovery rate using hazard rate models. We use a Mixed Proportional Hazard (MPH) model in which in addition to duration dependence and observed characteristics x, unobserved characteristics u are introduced. The recovery rate at duration τ conditional on observed and unobserved characteristics is specified as:

$$\theta(\tau \mid x, u) = \lambda(\tau) \exp(x'\beta + \delta I(e_x = 1) + u) \tag{3}$$

where I represents an indicator function that has the value of 1 if the immobilizer rate is 100% and a value of zero otherwise. Furthermore, $\lambda(\tau)$ represents individual duration dependence, β represents a vector of parameters and δ is the main parameter of interest. We model flexible duration dependence by using a step function:

$$\lambda(\tau) = \exp(\Sigma_k \lambda_k I_k(\tau)) \tag{4}$$

where k (= 1,..,5) is a subscript for the duration interval and $I_k(t)$ are time-varying dummy variables that are one in subsequent duration intervals. We distinguish the following duration intervals: 0 days, 1–2 days, 3–7 days, 8–31 days, and $>$ 31 days. Because we also estimate a constant term, we normalize $\lambda_1 = 0$. Then, the conditional density functions of the completed recovery durations can be written as:

$$f(t \mid x, u) = \theta(t \mid x, u) \exp(-\int_0^t \theta(s \mid x, u) ds) \tag{5}$$

We assume that the random effects u come from a discrete distribution G with two points of support (u_1, u_2), related to two groups of car thefts. The first group has a positive recovery rate, the other has a zero recovery rate. The associated probabilities are denoted as follows: $\Pr(u = u_1) = p_1$, $\Pr(u = u_2 - u_1) = p_2$. Here p_j $(j = 1, 2)$ is assumed to have a logit specification: $p_j = \frac{\exp(\alpha_j + \eta I(e_x = 1))}{\Sigma_j \exp(\alpha_j + \eta I(e_x = 1)}$ and the normalization is $\alpha_2 = 0$. So, we allow the engine immobilizer to affect the distribution of unobserved heterogeneity. We remove the unobserved heterogeneity distribution through integration:

$$f(t|x) = \int_u f(t \mid x, u) dG(u) \tag{6}$$

Table 3 shows the parameter estimates. Column (1) shows parameter estimates based on cars manufactured in the years before the introduction of the engine immobilizer. Then, we estimate that eventually 84% of the stolen cars will be recovered. The recovery rate is lower for cars that use diesel or lpg rather than gasoline. The recovery rate drops substantially after one week. Column (2) shows parameter estimates based on cars manufactured in the years when all cars were equipped with an engine immobilizer. The main difference is that only 45% of all stolen cars are recovered in the end. Column (3) shows that pooling across both types of cars does not affect the main outcome. Column (4) shows that the engine immobilizer does not affect the recovery rate itself.

Based on these findings, we conclude that the engine immobilizer affects the distribution of unobserved heterogeneity, not the recovery rate itself. The introduction of the immobilizer caused a huge drop in the share of stolen cars that were eventually recovered. Within the share of cars that were eventually recovered the recovery rate is very similar. This suggests that the change in the recovery rate is due to the change in the type of car thieves.

To indicate the heterogeneity across makes of cars, Table 4 shows parameter estimates for separate makes. The table only shows the parameter of interest, i.e. the effect of the engine immobilizer on the distribution of unobserved heterogeneity and the recovery rate. All makes suffer from a drop in the share of stolen cars that will eventually be recovered. Note that for more expensive makes the recovery rate is substantially lower. Of the stolen Mercedes Benz cars before the introduction of the engine immobilizer 57% was never recovered. After the introduction of the immobilizer this increased to 68%.

It is difficult to make a hard distinction in terms of time to recovery between cars stolen by casual and professional offenders. We assume that all cars that were recovered within a week were stolen by casual offenders, while the other cars were stolen by professionals. Based on this assumption, we analyze to what extent both types of car theft were influenced by the introduction of the engine immobilizer. Table 5 shows the relevant parameter estimates. The absolute effect of the immobilizer is about the same for both types of car thefts, -0.23 percentage-point for casual offenders and -0.20 percentage-point for professionals. Note that the *relative* drop is substantially higher for casual offenders. For the latter group of offenders car theft dropped from 0.33 percent before the introduction of the immobilizer to 0.04 percent after the introduction. For professionals the drop was from 0.26 to 0.13 percent. Apparently, the more professional the offender, the lower the protective effect of the engine immobilizer.

4.3 Displacement effects

We started this paper with postulating that criminal behavior is influenced by the availability of criminal opportunities that the offender is aware of and is able to exploit. From this perspective, the sudden introduction of an anti-theft device such as the one studied in this paper is an independent factor affecting offender behavior. Displacement is not a given. If one type of opportunity of stealing a car is closed off, as is the case for most offenders who now have to bypass the engine immobilizer, then displacement to other tactics for stealing a car or to other targets is not automatic. Initially, the offender exploited the opportunity he had become familiar with, often hot-wiring to bypass the ignition interlock. Shifting towards the exploitation of another opportunity – whether that is stealing a car in some other manner or some other offense altogether – is costly and takes time. As a result, the overall crime rate is reduced. The drop may be temporary, but even temporary reductions in crime may be worth the costs (Cook 1986).

The introduction of the engine immobilizer may also have had a positive effect on the risk of theft of older, less protected cars. The engine immobilizer itself is invisible to passers-by. As argued by Clotfelter (1977) and shown by Ayres and Levitt (1998), invisible security tends to create positive externalities because it lowers the average expected haul of a particular type of theft. Targets that do not feature the security measure may still benefit from the reduction in the average expected haul. The engine immobilizer is not *completely* unobservable, however. There are ways of inferring the likelihood of installation of the device in a specific car. Clearly, cars that looked new around the time the regulation went into effect were likely to be equipped with the device. In the Netherlands, inferring the year and even the month of make is facilitated by license plates. A license plate consists of a combination of letters and numbers, with more recent makes characterized by higher numbers and letters later in the alphabet. Depending on the familiarity of thieves with the introduction of the immobilizer, a protective effect is likely to be limited to cars that were manufactured late in the transition period (for instance, 1995 or 1996) that did not yet feature an immobilizer. Some offenders may have stayed away from these cars, figuring that they are likely to feature an engine immobilizer that is close to impossible to bypass. Cars manufactured in earlier years, which are unlikely to have the immobilizer installed, may suffer from displacement effects. Some car thieves may have shifted their attention to these cars instead.

In the absence of data on the exact percentage of cars with an engine immobilizer by year of manufacture (at time of writing) we cannot conduct a test on the presence of positive or negative externalities on other cars. Our data for both the Netherlands and England and Wales suggest, however, that displacement to older, less-protected vehicles was limited and temporary. The overall rate of car theft started to decline rapidly after the regulation came into force as these older cars were an alternative to professional car thieves for only a few years, and opportunities for temporary theft were quickly reduced through scrappage of old cars.

The attention of car thieves may have shifted to other, similar targets as well. We were able to obtain data on a similar type of crime, motorcycle theft, for the Netherlands during 1995-2010. Figure 9 shows that motorcycle theft went down rather than up during this period, suggesting that displacement from car theft to motorcycle theft, if present, was minor.

5 Benefits and costs of the regulation

To assess whether or not the mandatory introduction of the engine immobilizer was welfare improving we have to compare the cost of the device with the expected benefits in terms of the reduced rate of car theft. The additional manufacturing costs related to installing an electronic engine immobilizer have been estimated by the Netherlands Institute for Certification of Vehicle Security Systems (SCM) to be at most 50 Euro per car. The costs related to drafting and maintaining the security standard are mostly fixed. Given the number of cars produced every year, these other costs are low and ignored.

For the Netherlands, based on the estimated 70 percent decline in the theft rate of 0.5 percent before the introduction of the engine immobilizer, and assuming the life cycle of a car to be 14.5 years, the costs per prevented car theft amount to some 1,000 Euro. For England and Wales, based on the estimated 80 percent decline in the theft rate of 2 percent, and assuming a similar life cycle of a car, the costs per prevented car theft amount to some 250 Euro. England and Wales had a much higher base rate of car theft than the Netherlands, and an even larger estimated impact of the engine immobilizer, which explains the relatively low cost per car theft prevented.

The costs per prevented car theft are considerably lower than the social benefits of a prevented car theft. Dubourg, Hamed and Thorns (2005) put the average ex-post social costs of a motor vehicle theft at some 6,600 Euro. The average costs of a car theft are probably in the order of 7,000 Euro as motor vehicles other than cars tend to represent lower value. Other sources provide similar or higher estimates of the benefits. Based on jury awards in the US, Roman (2009) puts the mean cost of motor vehicle theft at 15,000 US dollars (in 2008 dollars); using contingent valuation Cohen et al. (2004) put the mean cost at 5,400 US dollars (also in 2008 dollars). The median values in both studies are actually very similar: 5,400 to 6,200 US dollars.

Clearly, the regulation is welfare improving as the benefits exceed the costs by a large margin. Our findings show that a uniform, one-size-fits-all prevention measure that does not discriminate between targets that are at high or low risk can still be greatly beneficial from a social welfare perspective.

6 Conclusions

This paper provides a first estimate of the impact of the engine immobilizer, an anti-theft device whose application in cars has been made mandatory in many countries, including member states of the EU, Australia and Canada. The mandatory installation of a low-cost security device in cars is found to have dramatically reduced the rate of car theft in two EU-countries, the Netherlands and England and Wales. During the ten years after the regulation went into effect the wider application of the engine immobilizer reduced the overall rate of car theft by 70 percent in the Netherlands and by 80 percent in England and Wales. As noted before, given some use of the engine immobilizer in the US, a country that did not regulate its use, it is likely that the immobilizer would also have been used in the EU in absence of regulation, albeit to a much lesser extent and probably skewed towards cars that are most at risk of theft. By 2008, the overall rate of application of the immobilizer was three times higher in the Netherlands than in the US, suggesting that a large part of the crime-reducing effect of the immobilizer in the EU can be attributed to the regulation. Interestingly, the overall drop in car theft in the Netherlands and in England and Wales during 1995-2008 was not much different from the estimated effect of the engine immobilizer, which suggests that all other car security and criminal justice policies are likely to have had a relatively minor impact on car theft during this period.

References

- Armitage, R. and H. Smithson, 2007, Alley-gating: a review of evidence, policy and legislation, *Internet Journal of Criminology.*
- Averdijk, M. and R. Loeber, 2010, The role of self-control in the link between prior and future victimization: an indirect test, *mimeo*, NSCR/University of Pittsburgh.
- Ayres, I. and S.D. Levitt, 1998, Measuring positive externalities from unobservable victim precaution: an empirical analysis of Lojack, *Quarterly Journal of Economics*, 113 (1), 43-77.
- Barthe, E.P., 2006, *Crime prevention publicity campaigns*, Problem-oriented guides for police response guide series No. 5, COPS, US Department of Justice, Washington D.C.
- Brown, R., 2004, The effectiveness of electronic immobilization: changing patterns of temporary and permanent vehicle theft, in: M.G. Maxfield and R.V. Clarke (eds.), *Crime Prevention Studies*, 17, Criminal Justice Press, Monsey, NY, 101–119.
- Clotfelter, C.T., 1977, Public Services, Private Substitutes, and the Demand for Protection against Crime, *American Economic Review*, 67 (5), 867-877.
- Cohen, Mark A., Roland Rust, Sara Steen, and Simon Tidd, 2004, Willingness-to-Pay for Crime Control Programs, *Criminology*, 42(1), 86-106.
- Cohen, L.E. and M. Felson, 1979, Social Change and Crime Rate Trends: A Routine Activity Approach, *American Sociological Review*, 44 (4), 588-605.
- Cook, Ph.J., 1986, The demand and supply of criminal opportunities, *Crime and Justice*, VII, 1-27.
- Cook, Ph.J. and J. Ludwig, 2006, The social cost of gun ownership, *Journal of Public Economics*, 90(1), 379-391.
- Cook, Ph.J. and J. Ludwig, 2010, Economical Crime Control, *NBER Working Paper* 16513, NBER, Cambridge (MA).

- Cook, Ph.J. and J. MacDonald, 2011, Public safety through private action: an economic assessment of bids, locks, and citizen cooperation, *Economic Journal*.

- Dijk, J. van, 2009, *World of Crime*, Sage, Los Angeles.

- Dubourg, R., J. Hamed, J., and J. Thorns, 2005, *The Economic and Social Costs of Crime Against Individuals and Households 2003/04*, Online report 30/05, London: Home Office.

- Ehrlich, Isaac, 1981, On the usefulness of controlling individuals: an economic analysis of rehabilitation, incapacitation and deterrence, *American Economic Review*, 71 (3), 307-322.

- Erhlich, Isaac, 1996, Crime, punishment and the market for offenses, *Journal of Economic Perspectives*, 10 (1), 43-67.

- Farrell, G., A. Tseloni, J. Mailley, and N. Tilley, 2010, The crime drop and the security hypothesis, *Journal of Research in Crime and Delinquency*.

- Farrell, G., A. Tseloni, N. Tilley, 2011, The effectiveness of vehicle security devices and their role in the crime drop, *Criminology and Criminal Justice*, 11(1), 21-35.

- Felson, M. and R. Clarke, 1998, Opportunity Makes the Thief, *Police Research Series*, No. 98, London: Home Office.

- Gonzalez-Navarro, M., 2008, Deterrence and geographical externalities in auto theft, *mimeo*, Princeton University, Princeton.

- Guerette, R.T. and K.J. Bowers, 2009, Assessing the extent of crime displacement and diffusion of benefits: a review of situational crime prevention evaluations, *Criminology*, 47(4), 1331–1368.

- Karmen, Andrew, 2001, *Crime victims: an introduction to criminology*, 4th ed., Wadsworth Publishing, New York.

- Lenis, David, Lucas Ronconi and Ernesto Schargrodsky, 2010, The effect of the Argentine gun buy-back program on crime and violence, *mimeo*, Universidad Torcuato Di Tella/CIPPEC.

- Leigh, Andrew and Christine Neill, 2010, Do Gun Buybacks Save Lives? Evidence from Panel Data, Institute for the Study of Labor (IZA) Discussion paper, No. 4995.

- Ludwig, J., 2010, The costs of crime, *Criminology and Public Policy*, 9(2), 307-311.

- Maxfield, M.G. and R.V. Clarke, 2009, Parts marking and anti-theft devices technology study, Washington DC: National Highway Traffic Safety Administration.

- Mayhew, P., R.V. Clarke and D. Elliott, 1989, Motorcycle theft, helmet legislation, and displacement, *Howard Journal*, 28(1), 1–8.

- Shavell, S., 1991, Individual precautions to prevent theft: private versus socially optimal behavior, *International Review of Law and Economics*, 11, 123-132.

- Thaler, R. and C. Sunstein, 2009, *Nudge. Improving decisions about health, wealth and happiness*, London: Penguin Books.

- Van Leiden, Ilse and Henk Ferwerda, 2005, Georganiseerde autodiefstal als persoonsmisdrijf [Organized car theft as crime against the person], *Secondant*, 5, 32–35.

- Vollaard, B.A. and J.C. van Ours, 2011, Does regulation of built-in security reduce crime? Evidence from a natural experiment, *Economic Journal*.

- Webb, B. 1994, Steering column locks and motor vehicle theft: evaluations from three countries, in: R.V. Clarke (ed.), *Crime prevention studies*, 2, Willow Tree Press, New York, 71–91.

- Welsh, B.C. and D.P. Farrington, 1999, Value for money? A review of the costs and benefits of situational crime prevention, *British Journal of Criminology*, 39(3), 345–368.

Table 1: **Parameter estimates of the effect of the engine immobilizer on the rate of car theft**

a. England and Wales; 1997–2005

	Effect immobilizer	Age/10	$Age^2/100$	Fixed effects age	Fixed effects calendar year
1	-1.95 (40.0)**			no	no
2	-2.00 (30.5)**			no	yes
3	-2.03 (20.9)**			yes	yes
4	-2.23 (18.0)**	-0.21 (2.0)**			yes
5	-2.33 (18.0)**	0.14 (1.0)	-0.32 (2.2)**		yes
6	-2.53 (16.4)**			yes	yes
7	-2.72 (20.2)**	-0.38 (3.6)**			yes
8	-2.68 (17.8)**	-0.54 (3.0)**	0.13 (1.0)		yes

b. The Netherlands; 1995–2008

	Effect immobilizer	Age/10	$Age^2/100$	Fixed effects age	Fixed effects calendar year
1	-0.42 (22.1)**			no	no
2	-0.46 (16.4)**			no	yes
3	-0.43 (16.1)**			yes	yes
4	-0.49 (13.4)**	-0.03 (1.2)			yes
5	-0.43 (15.7)**	-0.38 (10.4)**	0.28 (7.3)**		yes
6	-0.43 (23.0)**			yes	yes
7	-0.47 (16.8)**	-0.05 (2.9)**			yes
8	-0.43 (23.1)**	-0.43 (13.5)**	0.28 (9.8)**		yes

Note: England and Wales (Netherlands) estimates 1-5 are based on 73 (123) observations; estimates 6-8 are based on 135 (210) observations; between parentheses absolute t-statistics based on robust standard errors; ** (*) indicates significance at a 5 (10)% level.

Table 2: **Parameter estimates for the penetration rate of the engine immobilizer in new cars**

a. England and Wales; 1997–2005

	(1)	(2)	(3)	(4)	(5)	(6)
Engine immobilizer	-1.95 (48.7)**	-2.10 (37.9)**	-1.82 (16.2)**	-2.02 (39.4)**	-2.15 (39.8)**	-2.04 (19.0)**
Penetration 1990	-0.15 (2.3)**	-0.10 (2.5)**	-0.16 (3.0)**	0.00 (–)	0.00 (–)	0.00 (–)
Penetration 1991	0.07 (1.2)	0.11 (3.1)**	0.07 (2.1)**	0.10 (1.8)*	0.13 (4.1)**	0.12 (4.6)**
Penetration 1992	0.32 (7.0)**	0.34 (13.8)**	0.33 (18.6)**	0.34 (7.8)**	0.36 (15.9)**	0.36 (28.4)**
Penetration 1993	0.53 (15.5)**	0.54 (29.9)**	0.55 (41.3)**	0.55 (16.6)**	0.55 (33.1)**	0.56 (58.2)**
Penetration 1994	0.73 (32.6)**	0.73 (53.6)**	0.74 (49.1)**	0.74 (34.3)**	0.73 (54.6)**	0.74 (52.6)**
Penetration 1995	0.90 (56.3)**	0.88 (62.8)**	0.90 (56.3)**	0.91 (58.7)**	0.89 (60.5)**	0.89 (53.9)**
Penetration 1996	0.98 (83.3)**	0.95 (61.5)**	1.00 (–)	0.98 (86.5)**	0.95 (58.5)**	1.00 (–)
Age fixed effects	no	no	yes	no	no	yes
Calendar year f.e.	no	yes	yes	no	yes	yes

b. The Netherlands; 1995–2008

	(1)	(2)	(3)
Engine immobilizer	-0.43 (21.8)**	-0.42 (19.4)**	-0.42 (20.5)**
Penetration 1990	0.26 (3.6)**	0.30 (4.7)**	0.25 (7.2)**
Penetration 1991	0.39 (8.2)**	0.43 (9.0)**	0.38 (13.1)**
Penetration 1992	0.54 (20.8)**	0.57 (19.5)**	0.52 (19.7)**
Penetration 1993	0.65 (24.8)**	0.67 (22.8)**	0.63 (20.4)**
Penetration 1994	0.73 (18.7)**	0.74 (18.6)**	0.71 (19.1)**
Penetration 1995	0.89 (23.3)**	0.90 (21.6)**	0.87 (35.6)**
Penetration 1996	0.99 (31.8)**	1.01 (27.5)**	1.00 (–)
Age fixed effects	no	no	yes
Calendar year fixed effects	no	yes	yes

Note: England and Wales (Netherlands) estimates based on 135 (210) observations; between parentheses absolute *t*-statistics based on robust standard errors; ** (*) indicates significance at a 5 (10)% level.

Table 3: **Parameter estimates of the effect of the engine immobilizer on the recovery rate; Mixed Proportional Hazard model; the Netherlands, 1995–2008**

	No immobilizer (1)	Immobilizer (2)	Both (3)	Both (4)
Probability				
Constant	1.67 (197.3)**	-0.20 (23.1)**	1.67 (197.2)**	1.67 (197.2)**
Engine immobilizer	–	–	-1.87 (192.5)**	-1.87 (152.5)**
Recovery rate				
Engine immobilizer	–	–	–	0.03 (1.3)
Diesel	-0.08 (8.1)**	-0.05 (3.8)**	-0.06 (7.8)**	-0.06 (7.8)**
Gas	-0.06 (3.9)**	0.00 (0.1)	-0.06 (4.2)**	-0.06 (4.2)**
Duration dependence				
1–2 days	0.38 (37.7)**	0.35 (13.9)**	0.37 (39.8)**	0.37 (39.8)**
3–7 days	-0.31 (29.4)**	-0.33 (12.9)**	-0.32 (32.9)**	-0.32 (32.9)**
8–31 days	-1.21 (113.8)**	-1.05 (43.1)**	-1.19 (122.4)**	-1.19 (122.4)**
$>$ 31 days	-2.47 (230.2)**	-1.73 (69.1)**	-2.29 (236.2)**	-2.29 (236.2)**
-Loglikelihood	341,500	129,891	785,599	785,599
Observations	104,852	51,709	156,561	156,561
Eventually recovered (%)				
No immobilizer	84	–	84	84
Immobilizer	–	45	45	45

Note: All estimates contain calendar fixed effects and age year fixed effects in the recovery rate; between parentheses absolute t-statistics; ** (*) indicates significance at a 5 (10)% level.

Table 4: **Parameter estimates of the effect of the engine immobilizer on the recovery rate; Mixed Proportional Hazard model; the Netherlands 1995–2008; separate makes**

	Probability		Recovery rate		Eventually recovered (%)	
	Constant	Engine immobilizer	Engine immobilizer	Observations	No immob.	100% immob.
BMW	-0.64 (15.8)**	-0.98 (18.5)**	-0.15 (1.2)	6,224	65	42
Ford	1.49 (45.9)**	-0.67 (13.3)**	0.18 (2.5)**	9,481	82	69
Mercedes-Benz	-0.29 (9.9)**	-0.45 (10.5)**	0.07 (0.6)	9,339	43	32
Opel	2.76 (148.3)**	-2.64 (79.1)**	-0.09 (1.7)*	56,847	94	53
Volkswagen	1.05 (59.3)**	-1.80 (70.3)**	0.14 (2.6)**	30,317	74	32

Note: All estimates contain the same parameters as in column (4) of Table 3; between parentheses absolute t-statistics based on robust standard errors; ** (*) indicates significance at a 5 (10)% level.

Table 5: **Parameter estimates of the effect of the engine immobilizer on casual and professional car theft; the Netherlands, 1995–2008**

	Effect immobilizer	Age/10	$Age^2/100$	Fixed effects age	Fixed effects calendar year
Casual theft					
1	-0.23 (11.0)**			yes	yes
2	-0.27 (10.2)**	0.07 (3.6)**			yes
3	-0.23 (10.7)**	-0.19 (6.6)**	0.19 (6.6)**		yes
Professional theft					
4	-0.20 (21.0)**			yes	yes
5	-0.22 (16.8)**	-0.09 (12.3)**			yes
6	-0.20 (19.8)**	-0.20 (12.1)**	0.09 (6.7)**		yes

Note: Estimates on 123 observations; between parentheses absolute t-statistics based on robust standard errors; ** (*) indicates significance at a 5 (10)% level.

Figure 1: **Passenger cars outfitted with an electronic engine immobilizer, US and the Netherlands, 1990-2008 (%)**

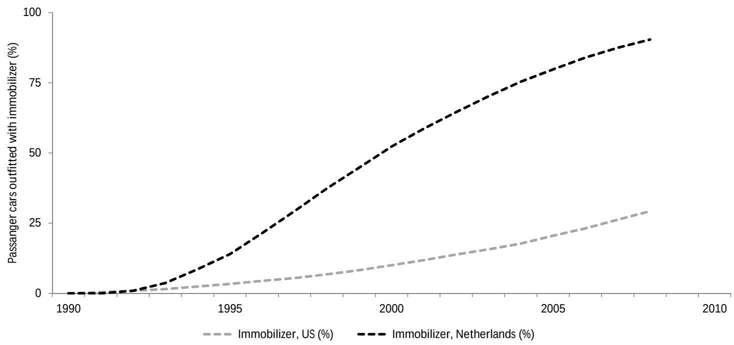


Figure 2: **Car theft (Netherlands) and motor vehicle theft (England and Wales), 1980-2009 (%)**

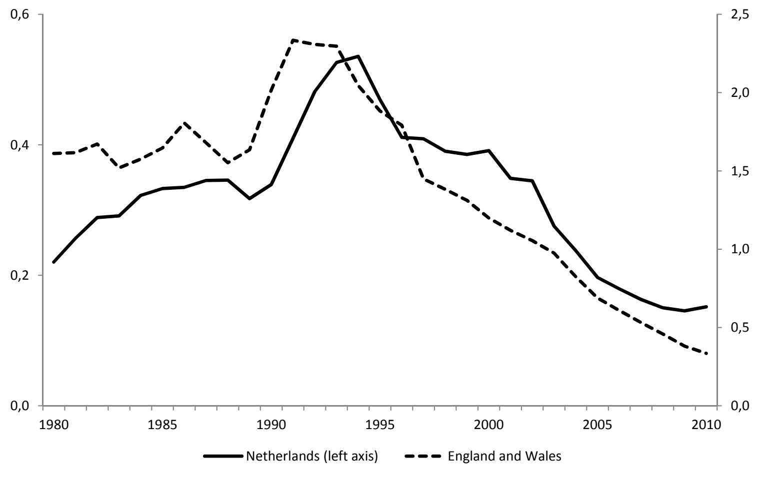
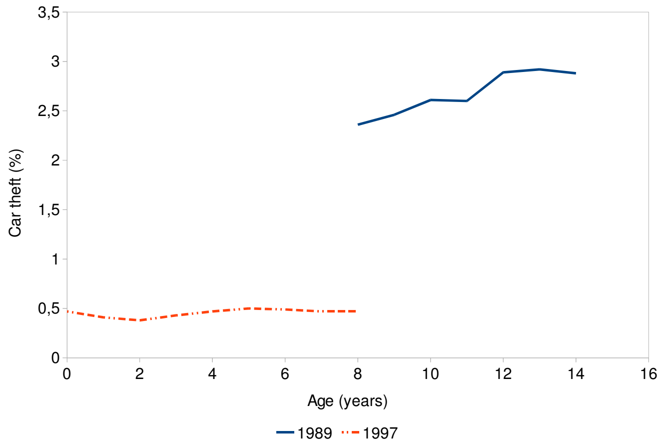


Figure 3: **Car theft by age and year of manufacture, 1989 and 1997 (%)**

a. England and Wales



b. The Netherlands

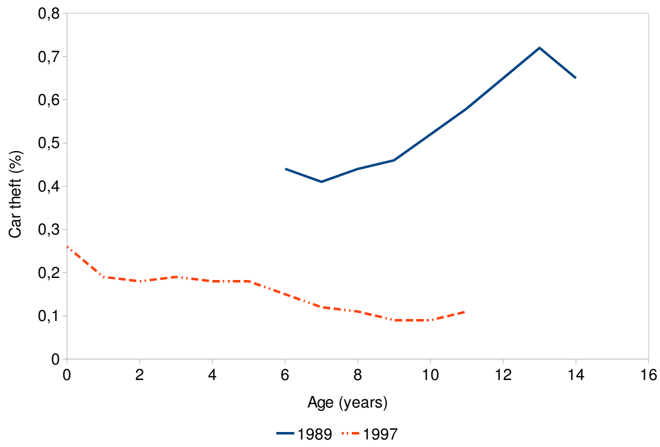
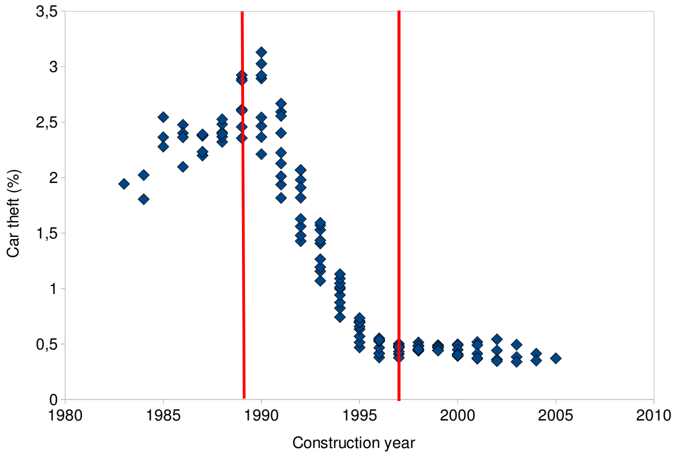
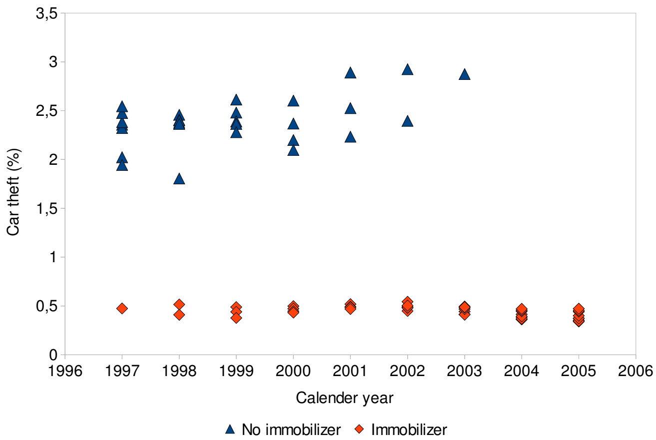


Figure 4: **Car theft by cohort, calendar year and age, England and Wales, 1997–2005 (%)**

a. By year of manufacture



b. By calendar year



c. By age

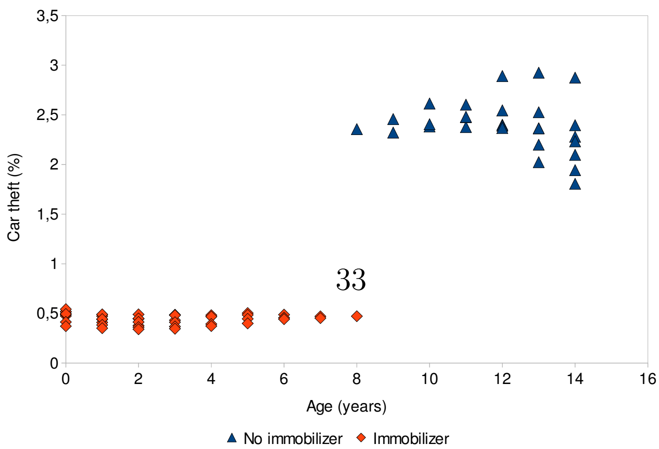
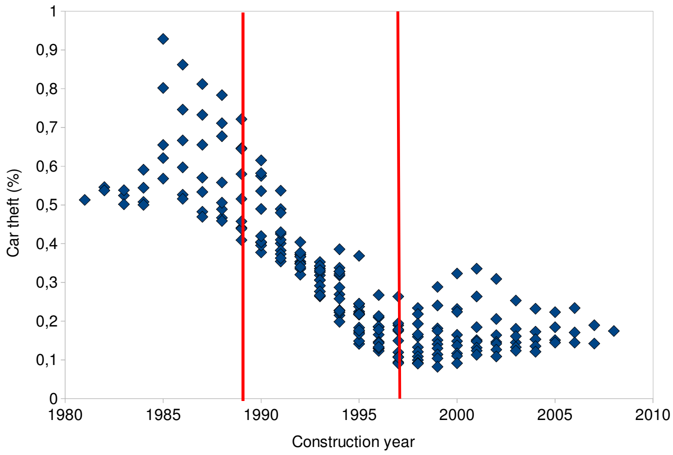
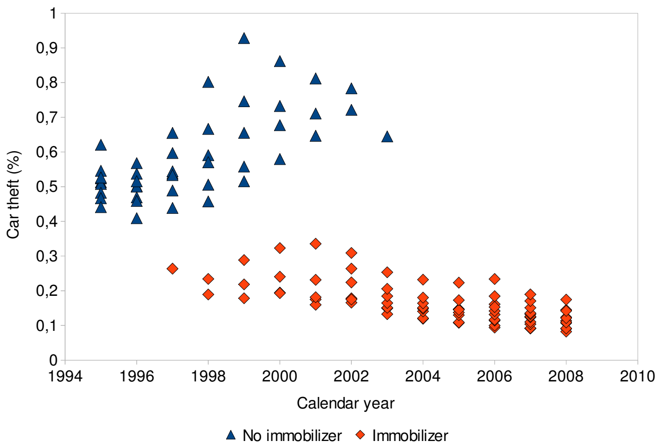


Figure 5: **Car theft by cohort, calendar year and age, the Netherlands, 1995–2008 (%)**

a. By year of manufacture



b. By calendar year



c. By age

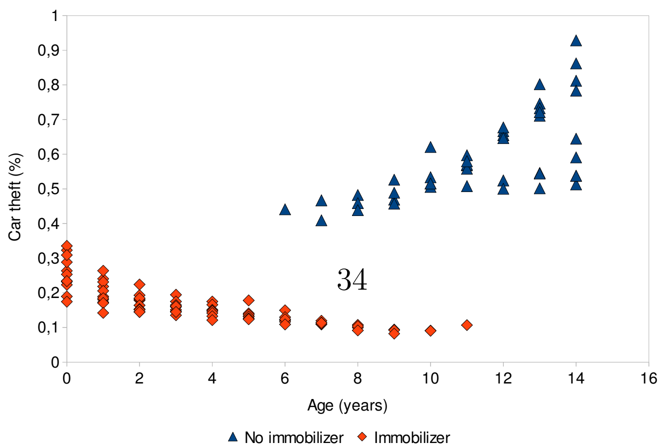


Figure 6: **Rate of car theft and rate of recovery within a week, the Netherlands, 1995-2008 (%)**

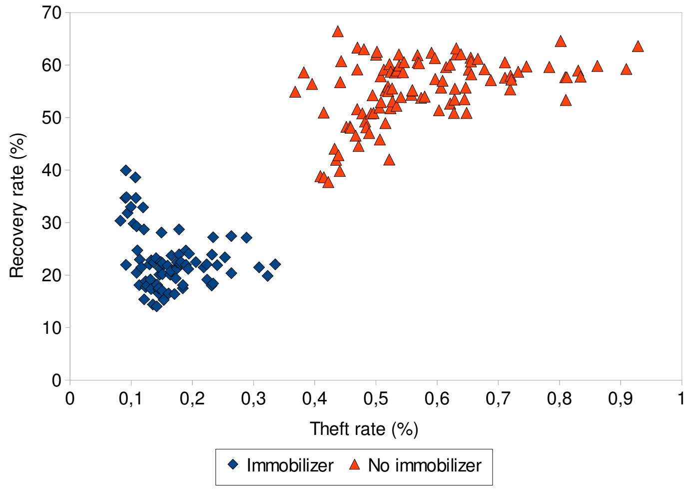
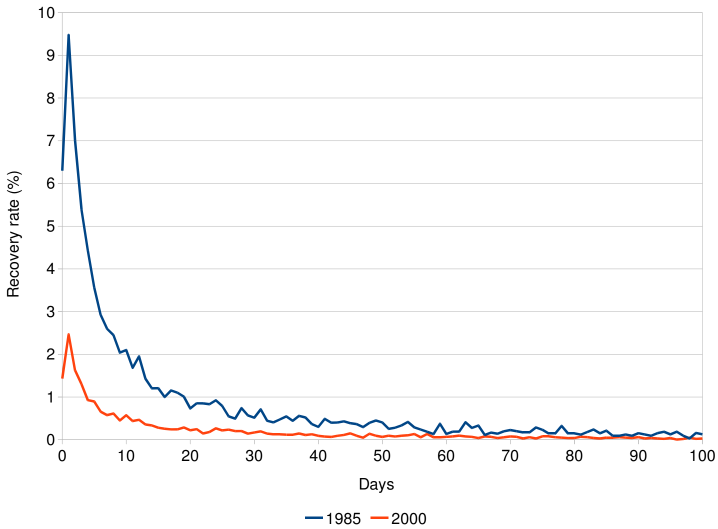


Figure 7: **Rate of recovery by duration, the Netherlands, year of manufacture 1985 and 2000**

a. Recovery rate (%)



b. Cumulative recovery rate (%)

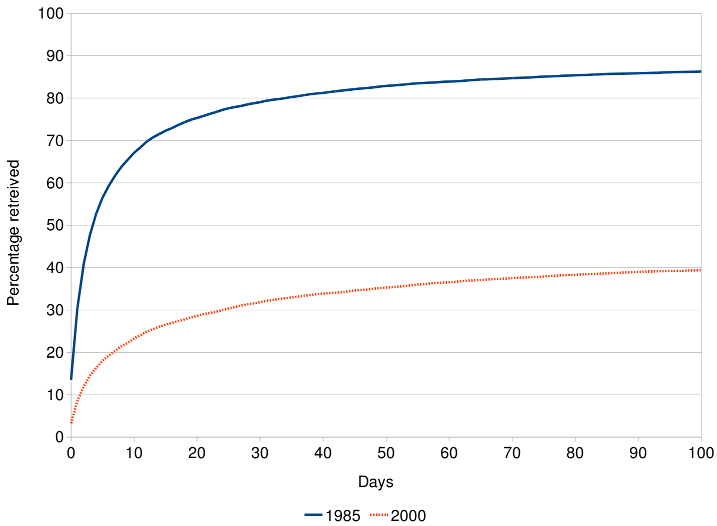
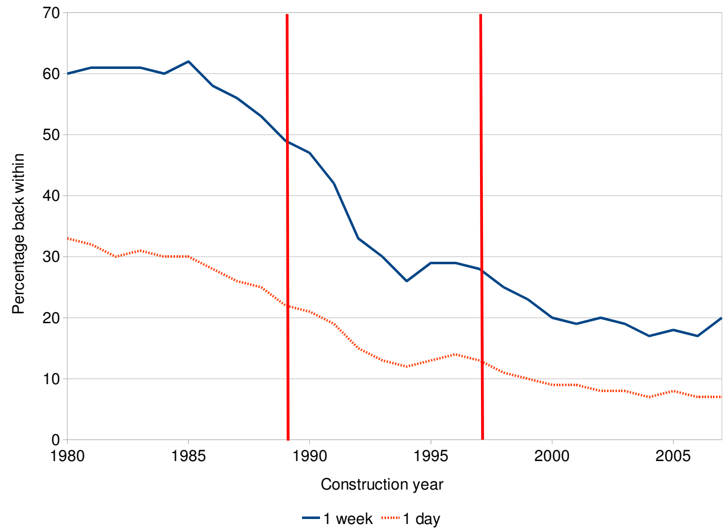


Figure 8: **Stolen cars recovered within 1 day and within 1 week, the Netherlands (%)**

a. By year of manufacture



b. By age; with and without engine immobilizer

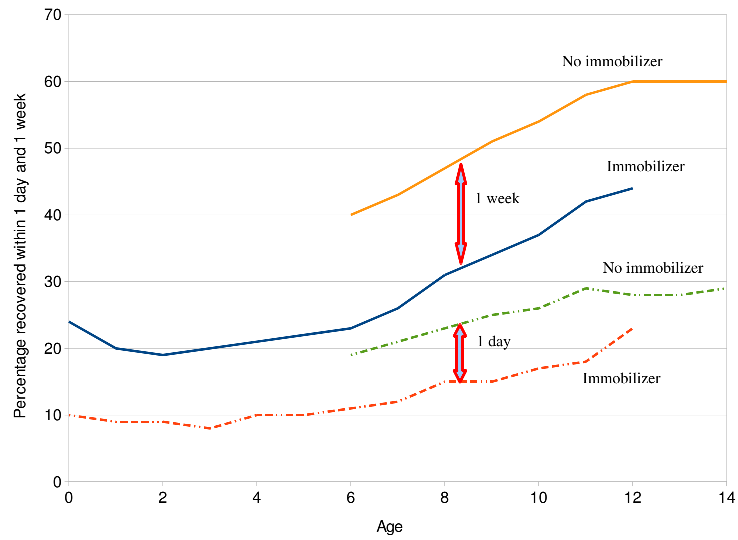


Figure 9: **Car theft and motorcycle theft, the Netherlands (%)**