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ABSTRACT

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

We provide evidence for a beneficial welfare impact of a crime policy that is targeted at strengthening victim precaution. 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. Based on detailed data at the level of car models, we find that uniform application of the security device reduced the probability of car theft by an estimated 50 percent on average in the Netherlands during 1995-2008, accounting for both the protective effect on cars with the device and the displacement effect on cars without the device. The costs per prevented theft equal some 1,500 Euro; a fraction of the social benefits of a prevented car theft.

JEL Classification: H11, H23 and K42

Keywords: car theft, crime, government regulation and victim precaution

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1 Introduction

Crime is the outcome of an interaction between a potential offender and his or her environment. The environment offers opportunities for crime, such as property that can be stolen, but also constraints on criminal behavior, such as watchful neighbors. Some factors in the offender's environment have received more attention in the literature than others. The interaction between the potential offender and the criminal justice system has been extensively studied; the interaction between potential offenders and potential victims has received much less attention (Felson and Clarke 2010; Cook and MacDonald 2011). In most of the study of crime, what potential victims do to prevent crime is either ignored or assumed to be exogenous.¹ The most notable exception is the literature on the use of guns as private deterrent, which is strongly tied to the debate in the US on gun control and right-to-carry laws.²

Similar to the limited attention to victim behavior, policies aimed at lowering crime by altering precautionary behavior are rarely discussed or evaluated – with the exception of gun control. The debate on crime prevention centers around public law enforcement on the one hand and rehabilitation of individuals with strong criminal inclinations on the other hand. The absence of debate about government interventions in victim behavior is surprising, given the strong interest in, for example, preventive health behavior in the public health literature and in preventive behavior within the context of natural hazard mitigation policy (Weinstein 1987). The empirical work that has been conducted in the area of victim-oriented crime prevention is mostly descriptive and lacks a research design that allows causal inference. In the absence of unbiased estimates of treatment effects, it is not clear how the benefits of policies in this area compare to the costs.³ Exceptions can mainly be found in the recent economics literature, including Cook and MacDonald (2011) and Vollaard and Van Ours (2011).

The classic economic argument for government intervention in precautionary behavior are externalities (Clotfelter 1977). Victims and property insurers may not take into account the costs of public crime control. 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). For instance, if precaution by one party reduces the crime risk for others, as in the case of some car security (Ayres and Levitt 1998), then this is likely to result in underinvestment in precaution. Another possible rationale for government intervention are systematic mistakes in the way people deal with the crime risk. For many people, criminal victimization is a rare event. For instance, on average in the US an household experiences burglary once every 40 years, any type of violent crime once every 60 years, and motor vehicle theft once every 170 years (Truman and Planty 2012). A growing

¹ An exception is the criminological literature under the umbrella of opportunity theory, in which the actions of potential victims are presented as one of the drivers of the supply of criminal opportunities (Cohen and Felson 1979; Felson and Clarke 1998). How potential victims deal with the crime risk is not worked out, however, with Van Dijk (2008) as a rare exception, and hard empirical evidence of how victim behavior affects the overall crime rate is scant (for a discussion, see Vollaard and Van Ours, 2011). Economists took some interest in victim behavior in the 1970s and the early 1980s (Clotfelter 1977; Ehrlich 1981; Cook 1986), but later contributions are rare. Exceptions are Shavell (1991), Hui-Wen and Png (1994) and Helsley and Strange (1999, 2005) on externalities of private precaution and Lacroix and Marceau (1995) and Baumann and Friehe (2012) on how private protection may attract the attention of potential offenders. We discuss a few other exceptions later in this paper.

² For recent work in this area, see Cook and Ludwig (2006), Acquisti and Tucker (2011) and McClellan and Tekin (2012). Related studies on guns and other violent means as private deterrent outside the US context are Grechenig and Kolmar (2011), Lenis, Ronconi and Schargrodsky (2011) and Leigh and Neill (2010).

³ Policies that have been studied within the context of car theft include publicity campaigns to raise awareness of the crime risk and what to do about it (Barthe 2006), the design of parking facilities (Clarke 2002), and mandatory application of security devices (Webb 1994). Later in this paper, we discuss work related to the electronic engine immobilizer.

body of evidence shows that many people fail to take appropriate precaution against losses from rare events. Precautionary measures tend to be only taken after experiencing the bad event. A rare event is not often experienced, and if it is, then the memory fades again. The result is that the average level of precaution is suboptimal given the losses experienced (Meyer 2012).

In this paper, we evaluate the crime-reducing effect and the welfare impact of mandatory application in new passenger cars of a simple, low-cost device to prevent car theft: the electronic engine immobilizer. The engine immobilizer has been the security device of choice for legislators. 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.⁴ 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 is expected to 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 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. Car theft is rare: the annual victimization rate in the Netherlands was 0.5 per 100 vehicles in 1995. Most people face a risk that is lower than the average while a small group faces a highly elevated risk (Maxfield and Clarke 2004). 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.

Using detailed data on car theft, passenger cars on the road and application of the engine immobilizer for the Netherlands for 1995-2008, 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 effective in reducing car theft. Uniform application of the device in cars reduced the overall rate of car theft by some 50 percent on average during 1995-2008, taking into account both the protective effect on cars with the device and the displacement effect on cars without the device. The costs per prevented theft equal some 1,500 Euro, which is a fraction of the social benefits of a prevented car theft. We do not find evidence for displacement towards other, related crimes such as motorcycle theft.

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: strengthening victim precaution. As discussed, most of what we currently know relates to crime policies that aim to punish or rehabilitate offenders, and the little we know about alternative policies such as the one discussed in this paper is often qualitative in nature and based on small-scale interventions. The crime-reducing effect that we find is relatively large compared to what we know about other

⁴ The legislative initiatives had an impact on other countries as well, particularly on small countries without a car manufacturing industry such as New Zealand.

crime policies, what indicates that victim-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 length are becoming increasingly unfavorable.

Second, we contribute to the evidence base on the causal effect of precautionary measures on 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). Previous work into the effect of the electronic engine immobilizer has mainly been based on broad comparisons of overall theft rates by age or year of manufacture-cohorts, without a research design that makes it plausible that the change in car security amounted to an exogenous shock (Brown 2004; Kriven and Ziersch 2007; Farrell et al. 2011b).⁵ Other factors such as changes to other types of car security and crime policies coinciding with the introduction of the immobilizer may well have biased estimates of the average effect on car theft, if such an estimate is at all presented.⁶ Moreover, cars with better security are on average younger – and we know the theft risk to be related to the age of a car (Maxfield and Clarke 2009). As a result, estimates based on simple comparisons of old cars without security and new cars with security are likely to be biased.

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 substantial during the first 10 years after the regulatory change. The overall effect on the theft rate remains clearly favorable, however, which is in line with previous findings (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. Section 3 describes the alternative ways in which offenders may respond to a greater use of the security device. In Section 4, we describe our data. In Section 5, we present our parameter estimates, including a variety of sensitivity tests. Based on our parameter estimates, we conduct an analysis of costs and benefits of the regulation in Section 6. Section 7 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 1995, many manufacturers selling cars within the EU had

⁵ Potter and Thomas (2001) provide a more detailed descriptive analysis at the level of car models for Australia, but do not attempt to estimate the average effect of the device on the rate of car theft.

⁶ Conclusions about the size of the effect on car theft in the two studies on the UK were also precluded by a lack of reliable data on the application of the electronic engine immobilizer. Brown (2004) relies on anecdotal evidence about the period around which application of the device in new cars became widespread. Farrell et al. (2011b) use data from the British Crime Survey (BCS). Given the unfamiliarity of the general public with the device, which is related to it quickly becoming a standard option, it is highly unlikely that the survey provides a reliable picture of the prevalence of this device. For instance, based on the BCS 2006/07, 46 percent of cars had an electronic engine immobilizer. The actual percentage should be at least 70 percent: that is roughly the percentage of cars on the road in 2006 with construction year 1998 or later.

already begun to change their manufacturing standards in anticipation of the new regulations (Brown 2004).

The decision to mandate application of the engine immobilizer may have been spurred by the tremendous increase in car theft during the first half of the 1990s, which was at least in part brought about by the fall of the Iron Curtain in 1989 (Bradsher 1999; Van Leiden and Ferwerda 2005). Because of the possible endogeneity of the policy change, a simple correlation between the overall trend in car theft and application of the electronic engine immobilizer is likely to be misleading. What makes identification of the effect of the device possible is that the overall trend in theft affected all cars, but the regulation only affected new cars. In addition, the regulation made the device a standard option in all new cars within a very short time span. It forced a difference between a sudden shock in application of the immobilizer and steady growth in other, unregulated security measures that may have affected car theft. Other 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 years before 1998. The regulation can be seen as a natural experiment as it made application of the security measure conditional on the year of manufacture of the car rather than on 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.

A comparison with the US shows how sudden a push the EU-regulation was for the application of the electronic engine immobilizer. Both in the US and Europe, the security device appeared on the market around 1990 (Brown 2004; Maxfield and Clarke 2009). In the first years, application of the device was mainly limited to premium makes and models. Soon, with the EU-regulation in the making, application rates of the device started to diverge sharply. Whereas the percentage of new passenger cars with an immobilizer only slowly expanded in the US, it experienced sharp growth from some 20 to a full 100 percent between 1994 and 1998 in the Netherlands. Figure 1 presents estimates of the percentage of all cars on the road with an electronic engine immobilizer installed for 1990-2010, for both countries. Overall penetration rates experienced much stronger growth in the Netherlands than in the US. Twenty years after the introduction of the engine immobilizer about a third of all cars on the road in the US have the device installed, compared to almost 90 percent in the Netherlands. There is no discrete jump in overall application rates in the Netherlands around 1995-1998 since the EU-regulation related to new cars only.

[FIGURE 1]

A comparison with the penetration of other security features in cars provides further indication of the shock in application of the electronic engine immobilizer. Farrell et al. (2011b) present data on the prevalence of central locking and car alarms in another EU-member state, the UK.⁷ The prevalence of central locking in all passenger cars went from 35 percent in 1991 to 85 percent in 2005. That amounts to less than half the growth rate of the electronic engine immobilizer for the Netherlands shown in figure 1. Since both the UK and the Netherlands were subject to the same EU regulation, and many car manufacturers sell similar models in both countries, the Dutch trend should give a good indication of what happened in the UK. Growth in the prevalence of car alarms in passenger cars was even lower than the growth in central locking. Even when compared to safety features that command strong interest from car buyers such as the driver airbag and the anti-lock braking system (ABS), the electronic engine immobilizer became a standard option more than twice as fast (Bovag/RAI 2006).

⁷ Related to footnote 6: in contrast to the electronic engine immobilizer, security measures such as a car alarm and central locking are likely to be familiar to the survey respondents.

3. The offenders' response to greater car security

Potential offenders have a number of ways to respond to the greater prevalence of the electronic engine immobilizer in cars. First, they may simply give up car theft, and not look into alternative criminal opportunities. Alternatively, potential offenders may try to overcome the immobilizer, shift their attention to cars without an immobilizer or to other, related criminal opportunities such as motorcycle theft. These responses are commonly referred to as tactical displacement, target displacement and crime type displacement. None of these types of displacement are a given. 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 is costly and takes time. Consequently, if displacement occurs, then it is often limited (Cook 1986, see Guerette and Bowers 2009 for a recent review of the evidence).

Reportedly, an immobilizer meeting the EU-regulations was close to impossible to overcome during the first years after its introduction (Der Spiegel 1997). To steal a car, thieves had to steal the key first (Levesley 2004; Kellner 2004). Apart from carjacking, which has remained very rare, to appropriate the car key, thieves commonly targeted car showrooms, jackets in restaurants, garment in changing rooms or the home of the owner (Kellner 2004). Alternatively, thieves could haul the car away on a flatbed truck. Clearly, these *modi operandi* involve more time, effort and risk than simply hot-wiring a car. Only some ten years after its introduction, car thieves found a way of disabling the immobilizer: taking over the engine management (De Miranda and Van der Mark 2012). Thieves were able to reprogram a car's electronic system and could start the engine without the original key. This *modus operandi* requires considerable preparation and technical knowledge, which is a hurdle to occasional offenders in particular. To conclude, given the difficulty of finding other, easy ways to steal a car, the immobilizer is likely to have severely hampered theft of cars fitted with the device.

Displacement of theft to older, less-protected cars may take place during the 25 odd years that it takes to replace (close to) all cars on the road. The scope for displacement depends on the motives of thieves. For instance, professional thieves looking for cars to sell are likely to be primarily interested in relatively new cars. Within a few years after the regulation started to have an effect on car security, easy-to-steal, young cars are no longer available for these offenders. In contrast, opportunities for non-professional theft such as joyriding are only slowly reduced through scrapping of old cars.

The externality on older cars is ambiguous, however, since the electronic engine immobilizer 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 at least two ways of inferring the likelihood of installation of the device in a specific car. First, only 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 further 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. Second, model changes are an easy visible cue. Older versions of the same car model may be known not to have the immobilizer installed. For instance, the Peugeot 205 was phased out in 1998 and replaced by the 206. The 205 never had the immobilizer as standard option, and may be an easily recognizable target for car thieves. 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 (1996-1998) that did not yet feature an immobilizer. We discuss the evidence for negative and positive externalities in Section 5.

Finally, displacement of theft to other crime types may blunt the effect of the greater application of the immobilizer on the overall crime rate. Given the costs associated with switching to other crimes, displacement to related crime types is most likely (Cook 1986). We obtained data on a similar type of crime, motorcycle theft, during 1995-2010 from the Netherlands Department of Motor Vehicles (RDW). The data show that the rate of motorcycle theft has been going down since at least 1995. This suggests that displacement, if present, was limited. We do not explore crime type displacement further in this paper.

4 Data and descriptive statistics

Cars on the road and stolen cars

The Netherlands Department of Motor Vehicles (RDW) provided us with the universe of stolen cars for calendar years 1995-2008. The car theft data include make, model, type and first year of registration. The first year of registration of a car is similar to the year of manufacture, although the exact production date is somewhat earlier because of the time it takes to transport the car and to make the car ready for sale. Data on the number of passenger cars on the road by make, model, type and first year of registration for calendar years 2002-2008 were also provided by RDW. The data relate to the stock of cars at the end of the calendar year. The year of manufacture goes back to 1985. Based on a survival analysis, we extrapolated the number of cars on the road by model and by year of manufacture for calendar years before 2002 (see Appendix A).

The theft data and the data on cars on the road do not match at the type level (for instance, Honda Civic 1.4i Sport). For this reason, we aggregated the data to the model level (Honda Civic). When going from the type to the model level, we accounted for all the different ways models are named in the data. In many cases, the commonly known model name is not used, but some model identifier from the car manufacturer. For instance, the Honda Civic is also known as EC9, ED2, ED3, EJ6, etcetera. Aggregating the data to the level of models is a labor intensive process. Consequently, we had to limit our data to a subset of models.

To obtain a representative sample of passenger cars, we selected models from different segments of the car market. We followed the segmentation of the car market that is usual in Europe: A (city car), B (economy), C (compact), D (mid-size) and E (executive). We excluded segments with a smaller than 5 percent share in the market in 1998, including sports cars (1.7 percent), large (luxury) cars (0.9 percent), SUVs (1.1 percent) and MPVs (4.5 percent). The segment A through E made up 91 percent of the Dutch passenger car market in 1998 (Bovag/RAI, 2006). Theft rates are relatively high for luxury and sports cars, but they represent too small a share of the market to have much of an effect on the average effect of the engine immobilizer on car theft.

We related the number of models per segment to the size of the market segments in 1998. We selected 2 models for the A segment (market share of 9 percent), 5 models for the B-segment (19 percent), 8 models for the C-segment (30 percent), 7 models for the D-segment (27 percent), and 2 models for the E-segment (6 percent).

To make the sample before and after introduction of the engine immobilizer as comparable as possible, we selected models that were sold both before and after the introduction of the immobilizer in a model. This constraint excluded several models, including those that had very few sales either before or after the introduction of the immobilizer such as the Fiat Panda/Seat Marbella and the Fiat Uno. We excluded a number of makes with a very small representation in the Dutch market, using 5,000 sales per year in the Netherlands in 1995 as the minimum (total

sales were 305,415 in 1995). This is equivalent to less than 1.5 percent of annual sales, which excludes European makes such as Saab and Lancia and some US makes such as Chevrolet, Chrysler and Mercury.

All models were updated every couple of years, some models were renamed. We excluded models for which the introduction of the engine immobilizer coincided with a major update of the model. This occurred in several cases, including the Opel Vectra A and B, Opel Omega A and B, Nissan Sunny/Almera, Audi 80/A4, Audi 100/A6, and Peugeot 205/206, rendering these models invalid for the analysis.

The models included in the analysis are: Suzuki Alto and Renault Twingo (A-segment), Opel Corsa, Honda Civic, Seat Ibiza, Renault Clio and Suzuki Swift (B-segment), Opel Astra, Volkswagen Golf, Toyota Corolla, Ford Escort, Peugeot 306/307, Citroën ZX, Volkswagen Jetta/Vento/Bora and Seat Toledo (C-segment), VW Passat, BMW 3-series, Peugeot 405/406/407, Nissan Primera, Mazda 626, Renault Laguna and Toyota Carina/Avensis (D-segment), Mercedes E and BMW 5-series (E-segment). We combined the Peugeot 306 and 307, since the 307 smoothly continued the prior 306. The same holds for the Volkswagen Jetta/Vento/Bora, Peugeot 405/406/407 and the Toyota Carina/Avensis.

Unit of analysis is a cohort of cars from a particular model of a certain age in a particular calendar year. To derive theft rates, for every model of a particular age in every calendar year we divide the number of stolen cars during that calendar year by the average of the number of cars of that model and that age on the road at the beginning and at the end of the year. The denominator approximates the number of cars at risk of being stolen during a year. We excluded theft rates for cars stolen in the year they were manufactured (age 0). For these cars, we could not derive the theft rate, because we do not know the number of cars at risk. The vehicle registration data only provides the year of manufacture, not the month and day. As a consequence, we do not know how long these cars have been on the road; this can vary between 0 and 12 months. We excluded observations for models from a year of manufacture with less than 1,000 cars on the road in a calendar year. This affected 170 observations, typically years in which a few cars were sold of a model that was discontinued the year before. For the same reason, we truncated age of a car at 14 years. Finally, we limited the time window around the introduction of the engine immobilizer as standard option to 20 years. We only included cars manufactured within this time window. In total, we have 3,597 observations (see Appendix B).

During 1995-1998, the years that the electronic engine immobilizer became a standard option, the average theft rate (weighted by the size of cohorts) in our sample is equal to 0.4 percent, which is equal to the national average. Moreover, the year-to-year trend in our sample of the overall theft rate during 1995-2008 is similar to the national trend. Obtaining a representative sample of car models is important, because the theft risk strongly varies between market segments. It could well be that the protective effect of the device differs depending on the theft risk or the types of offenders that target low-end and high-end cars (we explore heterogeneity in the effect in Section 5). In figure 2, we plot the average price of each model by December 1998 against the theft rate. To make the theft rate comparable across models, we selected cars up to three years of age before the electronic engine immobilizer became a standard option. The rate of theft of relatively new cars in the E-segment (prices of some 50,000 euro) is about four times higher than the rate of theft in the A-segment (prices of some 10,000 euro).

[FIGURE 2]

Application of the engine immobilizer

Our data on the time that the electronic engine immobilizer became a standard option in a car model were compiled by Allianz, a German insurance company (Allianz 1997). In most cases,

the data relate to the European Union, in some cases the data only relate to Germany. Although manufacturing standards for Germany and the Netherlands are generally similar (and about 40 percent of cars sold in the Netherlands are manufactured in Germany, see Bovag/RAI 2006), in these cases we double checked the date with car manuals from that period. For 10 out of the 24 models, the electronic engine immobilizer became a standard option not on January 1, but later in the year.⁸ For these models, the full impact of the immobilizer may only be felt in the second year after the device became a standard option.⁹ Figure 3 shows the percentage of cars which had the electronic engine immobilizer as standard option by year of manufacture. Cars in our sample had the device as standard option at the earliest in 1995 and at the latest in 1998. In between is a three-year transition period.

[FIGURE 3]

Knowing when the device became a standard option provides a good indication of its application. As discussed in the previous section, the EU-regulation impacted car security through the shock in uniform application of the device. The regulation targeted car manufacturers, not individual car buyers. Nonetheless, before the change in manufacturing standards, some car manufacturers offered the device as option to car buyers. In addition, car owners could retrofit the device. The rate of application of the device in cars that do not have it as standard option is low, however. The data from Allianz show that if the device was an option, typically this choice was only offered one year before it became standard. The Netherlands Crime Survey (VMR) suggests low rates of retrofitting of any type of car security. In the 2005 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. Moreover, the car owners that retrofit car security are much more likely to install a car alarm than a device like an engine immobilizer (Bovag/RAI 2006: 47, Table 9.6). Data from the used car market provide some idea of the rate at which the device was chosen as an option or was retrofitted. In cohorts that were manufactured before the immobilizer became a standard option, an immobilizer is noted to be present in at most 10 percent of cars that were for sale in mid-2012; often rates were much lower.¹⁰ Because of the non-zero application rates of the device before the change in manufacturing standards, our paper provides a lower bound estimate of the effect of the electronic engine immobilizer.

[FIGURE 4]

In figure 4, we show the rate of car theft by cohort, calendar year, and age for cars with and without the electronic engine immobilizer as standard option (the averages are weighted by the number of cars on the road for a model by year of manufacture and calendar year). From the top graph, it is clear that the theft rate by cohort is on a downward trend before the electronic engine immobilizer became a standard option. The downward trend is not necessarily the result of changing characteristics of cohorts. After all, cars manufactured in earlier years are on average older and have been exposed to theft for a longer time than cars manufactured later. The downward trend disappears once the electronic engine immobilizer is a standard option. The difference in theft rates between cars with and without the electronic engine immobilizer as standard option can also be seen in the two other graphs, which show theft rates by calendar year and age of the car. The theft rate is about 50 percent lower when the device is a standard option in a car.

⁸ These models are Toyota Corolla, Opel Astra, Opel Corsa, Nissan Primera, Renault Laguna, Honda Civic, Seat Toledo, Seat Ibiza, Citroën ZX, Volkswagen Passat.

⁹ Generally, car manufacturers did not follow a strategy of making the the device a standard option in the most expensive types of a model first. An exception is the Renault Laguna. Given the very short time frame within which all cars of this model had the device, the difference in timing should have little effect on our estimates.

¹⁰ Data were compiled for each car model from www.gaspedaal.nl, a website aggregating used cars for sale on a number of websites in the Netherlands.

Table 1 provides summary statistics for the variables used in the analysis.

[TABLE 1]

5 Empirical analysis

As a first step, we graphically analyze the effect of the electronic engine immobilizer. Based on the identification strategy outlined in Section 2, we specify a model that flexibly estimates the effect of the device on the rate of car theft. We estimate the following equation:

$$\text{Ln}(y_{t,a,m}) = \sum_{\tau=-7}^T [\beta_{\tau} W_{\tau}] + \alpha_t + \alpha_a + \alpha_m + \varepsilon_{t,a,m} \quad (1)$$

The dependent variable $y_{t,a,m}$ is the rate of car theft in calendar year t among age cohort a for car model m . Given the wide variation in the rate of theft across models, we take the natural logarithm of the theft rate. That allows us to compare percentage changes in the theft rate rather than absolute changes in the theft rate. The indicator variables W_{τ} track the year of manufacture-cohort τ which had the electronic engine immobilizer as standard option and the year of manufacture-cohorts preceding and following this change in manufacturing standards. The indicator variable W_1 equals 1 for the first year of manufacture-cohort with the immobilizer as standard option and is zero otherwise; W_2 equals 1 for the second year of manufacture-cohort with standard immobilizer and is zero otherwise, and so on. β_{τ} are the coefficients for each cohort that are to be estimated. The period before and after the immobilizer became a standard option spans 20 cohorts; 10 year of manufacture-cohorts before the change in manufacturing standards and 10 year of manufacture-cohorts after the change. The calendar year-fixed effects α_t control for events that could raise or lower theft rates in a given calendar year across the 24 models. The age-fixed effects α_a control for the relation between the theft rate and the age of a car. The car model-fixed effects α_m prevent estimation bias from unobserved factors that remained approximately stable over the study period and that caused theft rates to differ across models. $\varepsilon_{t,a,m}$ is an error term.

[FIGURE 5]

Figure 5, panel a, plots the estimated indicator coefficients β_{τ} from equation (1). The year of manufacture relative to the first cohort with standard electronic engine immobilizer is plotted on the horizontal axis. Time one corresponds to the year the electronic engine immobilizer became standard in a car model, which varies between 1995 and 1998. The coefficients are estimated relative to the first cohort with standard immobilizer, which has a value of zero.

The figure shows a difference of at least 50 percent in theft rates for cars with and without standard application of the security device. The average theft rate remains roughly flat for later cohorts with standard immobilizer, which suggests that on average the immobilizer remained equally effective up to ten years after it became a standard option.

The break between the two series is not fully discrete. First, the theft rate of the last cohort without standard immobilizer is somewhat lower than the theft rates of earlier cohorts. Second, the theft rate of the first cohort with standard immobilizer is higher than the theft rates of later cohorts. As discussed earlier, the latter phenomenon can be explained by the fact that, for several car models, it took more than one year before a complete cohort was uniformly fitted with the device. In other words: the full impact of the immobilizer can only be inferred from the second cohort after the change in manufacturing standards.

The relatively low theft rate for the last cohort without immobilizer can be explained in two ways. First, it could be that just before the immobilizer became a standard option, the application of other security measures experienced relatively strong growth. This would be problematic for our identification strategy, because we assume the shock in the application of the immobilizer to be distinct from the more gradual growth in the use of other security

measures. As discussed in Section 2, the available evidence supports this assumption, which makes this first explanation unlikely. A second explanation is that cars manufactured just before the immobilizer was uniformly applied have lower theft rates because they suffered less from displacement of theft than older cohorts. These cars looked most similar to cars with standard immobilizer (see Section 3). To examine this explanation more closely, next, we analyze displacement of theft to older cohorts.

To identify displacement of theft to older cohorts, we estimate the indicator variables for cohorts without a standard immobilizer both before and after cars with standard immobilizer came on the market. Before the change in manufacturing standards, displacement was not an issue, at least not within a specific car model. After the change, offenders had the choice between cars of a particular model with and without the immobilizer as standard option. If displacement is present, then the second set of coefficients should feature higher theft rates than the first set of coefficients. We limit our sample to those car models that were observed in calendar years before and after the immobilizer became a standard option. Only for these models can we identify how the theft rate for cars without the immobilizer as standard option changed as a result of the change in manufacturing standards. Since the device was made standard in 1995 for several models and the first calendar year in our data is 1995, this leaves us with 11 models. We estimate the following equation:

$$\ln(y_{t,a,m}) = \sum_{\tau=-T}^T [1(t < YR_IMMO_m) \beta_{\tau} W_{\tau}] + \sum_{\tau=-T}^T [1(t \geq YR_IMMO_m) \beta'_{\tau} W_{\tau}] + \alpha_t + \alpha_a + \alpha_m + \varepsilon_{t,a,m} \quad (2)$$

YR_IMMO_m denotes the year by which the electronic engine immobilizer became a standard option in car model m . In this subsample, this varies between 1996 and 1998. $1(t < YR_IMMO_m)$ represents an indicator function which has a value of one for those calendar years that the immobilizer was not yet a standard option in a car model and zero otherwise. Similarly, $1(t \geq YR_IMMO_m)$ has a value of one for those calendar years that the immobilizer was a standard option in a car model and zero otherwise. We estimate two sets of coefficients for cohorts without the device as standard option: β_{τ} before the change in manufacturing standards within a model and β'_{τ} after the change. These cohorts may have been exposed to displacement effects. Clearly, for cohorts with standard immobilizer we only have one set of coefficients. For these cohorts, the condition $t \geq YR_IMMO_m$ always holds.

Figure 5, panel b, presents the estimated coefficients β_{τ} and β'_{τ} . The baseline theft rates for cohorts without standard immobilizer, i.e. those estimated for the period before cohorts with standard immobilizer came on the market, show a gradual downward trend. This trend may be explained by the gradual introduction of more security features in cars, as discussed in Section 2.¹¹ The difference in the theft risk between the baseline coefficients of the cohorts without standard immobilizer and those of the cohorts with standard immobilizer is about 75 percent. This is the gross effect, not accounting for displacement of theft. Displacement is the difference in theft risk between cohorts without standard immobilizer in calendar years before and after the change in manufacturing standards. This difference is some 25 percent. In other words, during 1995-1998, the move towards uniform application of the immobilizer reduced the overall rate of car theft by 75 minus 25 equals 50 percent.

During the period after the change in manufacturing standards, the theft rate of the very last cohort of cars without standard immobilizer was relatively low. This is in line with what we found in Figure 5, panel a. Compared to earlier cohorts, this last cohort may not have suffered from displacement of theft to the same extent. By lack of a baseline estimate for this cohort (see footnote 11), we cannot draw hard conclusions about the nature of this externality, however.

¹¹ Because of data limitations, we cannot estimate the coefficient for the last cohort without standard immobilizer before the change in manufacturing standards. The observations are missing because we cannot derive theft rates for cars with age 0 (see Section 4).

Parametric evidence for an effect of the electronic engine immobilizer

Next, we analyze whether the average effect of having the electronic engine immobilizer installed meets the standards of statistical significance. We estimate the following equation:

$$\text{Ln}(y_{t,a,m}) = \beta \text{IMMO}_{t,a,m} + \alpha_t + \alpha_a + \alpha_m + \alpha_c + \varepsilon_{t,a,m} \quad (3)$$

$\text{IMMO}_{t,a,m}$ denotes the share of cars of model m with age a in calendar year t that has the electronic engine immobilizer as standard option. Parameter of interest is β , which denotes the percentage change in the rate of car theft resulting from having the immobilizer as standard option. Since cohorts without standard immobilizer show a downward trend in the theft rate by year of manufacture in Figure 5, we also include fixed effects for year of manufacture α_c (or cohort-fixed effects) in the estimation equation. Note that even if we introduce cohort-fixed effects we are able to identify the effect of the immobilizer because the immobilizer became standard for different models in different years. We assume a similar impact on the theft rate of the immobilizer across models. In the sensitivity analysis, we allow the effect to vary between segments of the car market.

The parameter estimates are presented in Table 2. The first column reports the results of the estimation equation (3), the baseline specification. We find a highly significant 72 percent reduction in the theft risk as a result of having the electronic engine immobilizer as standard option.

Given possible positive and negative externalities on the theft risk of other cars, the net effect on the theft rate may be different. As a next step, we allow for externalities. We include an indicator variable which is one for cohorts without a standard immobilizer during the time that cars with standard immobilizer were on the market and zero otherwise. In column (2), we find this displacement indicator to be positive, suggesting on average a 26 percent higher theft rate for older cohorts without standard immobilizer during the period of our analysis. Our estimate of the displacement parameter is not very precise, however. When taking into account this estimate of displacement, the net theft-reducing effect is 46 percent. Apparently, a little less than a third of the drop in the theft risk for cars with standard immobilizer was shifted to older cars. Clearly, over time, this displacement effect diminishes in importance because of the dwindling stock of old cars without standard immobilizer (see Figure 1).

To analyze how robust our results are to different specifications, we conduct two sensitivity tests. First, in our baseline specification, we use a 10-year period before and after the change in manufacturing standards. A long time window may introduce estimation bias through the presence of heterogeneity. Cars manufactured many years before or after the change in manufacturing standards are more likely to be different than cars manufactured just before and after the change. If these other characteristics affect the treatment and experimental group differently, then the estimated effect is likely to be biased. In the second column, we halve the time window around the change in manufacturing standards to 10 years rather than 20 years. We find very similar results, suggesting the absence of an estimation bias.

[FIGURE 6]

Given the difference in theft rates between market segments discussed in Section 4, the immobilizer may have had a different impact on different segments. Anecdotal evidence from police investigators suggests the deterrent effect to be largest for offenders looking for an easy-to-steal car for the purpose of joyriding or solving a temporary transportation problem after a night out relative to more professional offenders stealing cars for sale or for car parts (see also Brown, 2004). Inexpensive cars parked on a public street tend to be the target of the first group of offenders. To analyze heterogeneity in the theft-reducing effect, we allow the effect to differ between the five market segments. We fully interact the policy variable with dummy variables

for each segment. The results are reported in Column (4) of Table 2. As expected, we find the theft-reducing effect to be highest for the most inexpensive cars (city car and economy). The reduction in car theft is about twice as large in segments A and B compared to the other segments.¹² The difference between these two groups of market segments is statistically significant. In other words, those who had a relatively low theft risk to begin with saw that risk reduced to close to zero; cars with an elevated risk of theft experienced a much smaller protective effect. This relationship is shown in Figure 6. The theft-reducing effect of the electronic engine immobilizer is negatively related to the theft risk prior to the device becoming a standard option.

6 Benefits and costs of the regulation

The electronic engine immobilizer is an unobtrusive device that does not require anything else than taking the key out of the ignition. It does not pose additional effort on motorists. 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 no more than 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.

On average over the period 1995-2008, uniform application of the immobilizer reduced the rate of car theft by an estimated 46 percent – taking into account displacement of theft to older vehicles. Based on a 46 percent decline in the theft rate of 0.5 percent before the immobilizer became standard, and assuming the life cycle of a car to be 14.5 years, the costs per prevented car theft amount to some 1,500 Euro.

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 somewhat higher as motor vehicles other than cars tend to represent lower value. Other sources provide similar or higher estimates of the benefits. Using contingent valuation, Cohen et al. (2004) put the mean cost at 5,000 Euro; based on jury awards in the US, Roman (2009) puts the mean cost of motor vehicle theft at 12,000 Euro. Based on these estimates, we conclude that the social benefits of having an electronic engine immobilizer as standard option are several times higher than the costs.

7 Conclusions

This paper provides a first estimate of both the protective effect and the displacement effect of the electronic engine immobilizer on the nation-wide rate of car theft, based on detailed data for a representative sample of passenger cars in the Netherlands. The electronic engine immobilizer is a simple and low-cost anti-theft device whose application has been made mandatory in many parts of the world, including the European Union, Australia and Canada. We exploit the EU-regulation as source of exogenous variation in use of the device by year of manufacture of car models.

We find that uniform application of the precautionary measure in new cars led to a dramatic and prolonged reduction in car theft. The effectiveness of the device remained roughly equal in the ten years after it was made a standard option in cars. When taking into account displacement of theft to older cars, the device lowered the overall rate of car theft on average by about 50 percent during 1995-2008. We do not find evidence of displacement of car theft to a related crime type, motorcycle theft. Owners of relatively inexpensive cars benefitted most from having the electronic engine immobilizer installed. This is in line with anecdotal evidence

¹² The actual difference in effect may be somewhat smaller if endogeneity in application of the security device is greater for the premium segments than for the other segments, as discussed in Section 4.

that occasional offenders looking for easy-to-steal cars were more easily deterred than more professional offenders who tend to have less interest in the cheapest segments of the car market.

The size of the crime-reducing effect that we estimated may be conditional on the uniform, mandatory use of the device in new cars. For instance, opportunities for target displacement are likely to be closed off slower under optional rather than mandatory application. For this reason, the effect of the device may be different in countries that did not regulate its use, such as the US.

Finding a long-lived drop in the theft rate implies that the within-crime elasticity to other modi operandi (or 'tactical displacement') is low, at least within the first ten years after introduction of the engine immobilizer. Anecdotal evidence suggests that only a 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 their efforts on overcoming this one hurdle, which could make the protective effect of the device short-lived.

The costs per prevented theft are estimated at 1,500 Euro, which is a fraction of the average social benefits of a prevented car theft. 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 beneficial from a social welfare perspective. This result can only be explained by the presence of substantial positive externalities in car security or by a tendency of people not to act in their own best interest. Since we find little evidence for the presence of major positive externalities, the rationale for regulating this security device lies in the apparent difficulty people have in taking appropriate precautionary measures. The average car owner seems to be limited in his or her ability to anticipate on the losses of a rare event like car theft. The evidence presented in this paper suggests that government regulation can make people better off by helping them to commit to a strategy of precaution. This way, crime can be lowered substantially and for a prolonged period without the involvement of a single social worker, police officer or corrections officer. As such, strengthening victim precaution provides an interesting alternative to well-studied crime policies that are aimed at punishing or rehabilitating offenders.

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Table 1. **Summary statistics**

	Mean	Standard deviation	Min	Max
Rate of car theft (per 1,000 cars)	2.97	2.83	0.08	23.51
without electronic engine immobilizer as standard option	3.89	3.20	0.08	23.51
with electronic engine immobilizer as standard option*	1.87	1.78	0.10	18.72
Car price as at December 1998 (in 1998 euros)	18,725	8,447	8,500	49,000
Year of manufacture	1995	4.47	1985	2007
Age	6.82	3.69	1	14
Electronic engine immobilizer as standard option	0.43	0.49	0	1
Year electronic engine immobilizer became standard option	1996	1.12	1995	1998

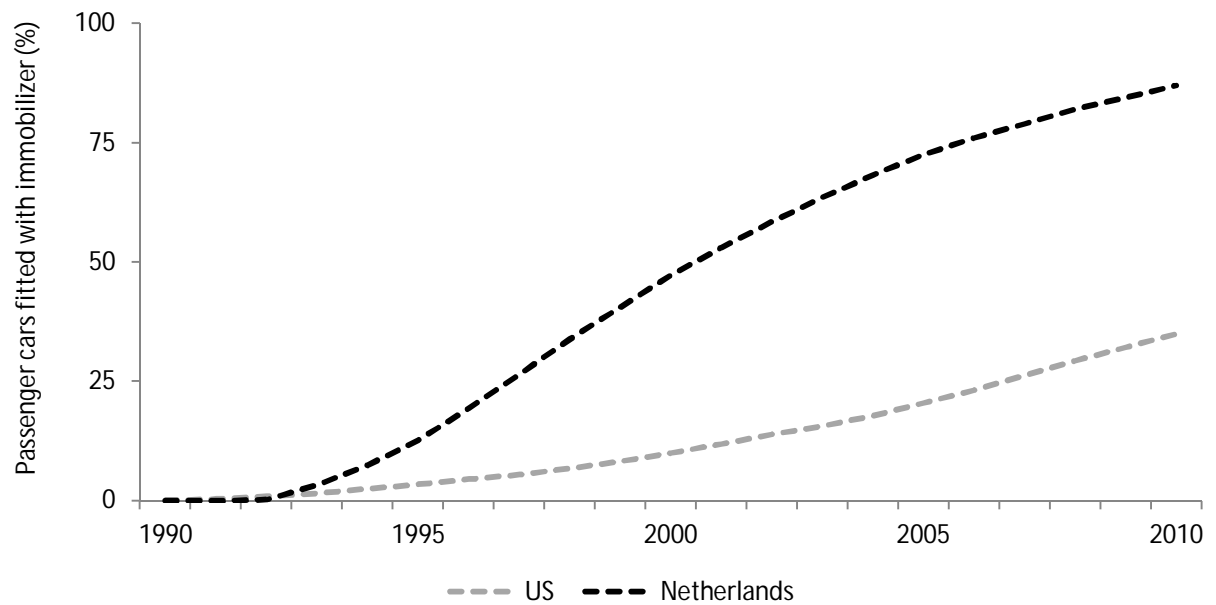
Note. Based on 3,597 observations. Yearly data for calendar years 1995-2008 for 24 car models up to 14 years of age, manufactured between up to 10 years before and up to 10 years after the electronic engine immobilizer became a standard option in a car model. Number of observations varies between models. Mean is weighted by number of cars in a cohort. To provide consistency with the estimates based on the natural logarithm of the theft rate presented in Table 2, 115 observations for which theft rate is zero are excluded. (*) Including cohorts that were only partly fitted with the electronic engine immobilizer as standard option.

Table 2. Estimated effect of the electronic engine immobilizer on car theft

Dependent variable: ln(rate of car theft)	(1)	(2)	(3)	(4)
Electronic engine immobilizer as standard option	-0.72 (0.12)***	-0.46 (0.14)***	-0.42 (0.14)***	
* segment a				-0.68 (0.18)***
* segment b				-0.75 (0.25)***
* segment c				-0.34 (0.19)*
* segment d				-0.31 (0.18)*
* segment e				-0.16 (0.20)
Cohorts without standard immobilizer (period after immobilizer became standard)		0.26 (0.13)*	0.23 (0.13)*	0.28 (0.13)**
Time window	20	20	10	20
Number of observations	3,597	3,597	2,465	3,597

Note. Based on annual data for 24 car models. All estimates contain fixed effects for calendar year, car model, age of car, and year of manufacture. Between parentheses standard errors clustered by car model. ***, ** and * indicate statistical significance at the 1, 5 and 10 percent level.

Figure 1. **Passenger cars fitted with an electronic engine immobilizer, US and the Netherlands, 1990-2010 (%)**



Source. Estimates for US based on data from Ward's Auto reported in Maxfield and Clarke (2009); estimates for the Netherlands based on data from SCM (Netherlands Institute for Certification of Vehicle Security Systems) and Netherlands Statistics.

Figure 2. **Theft rate by price of car**

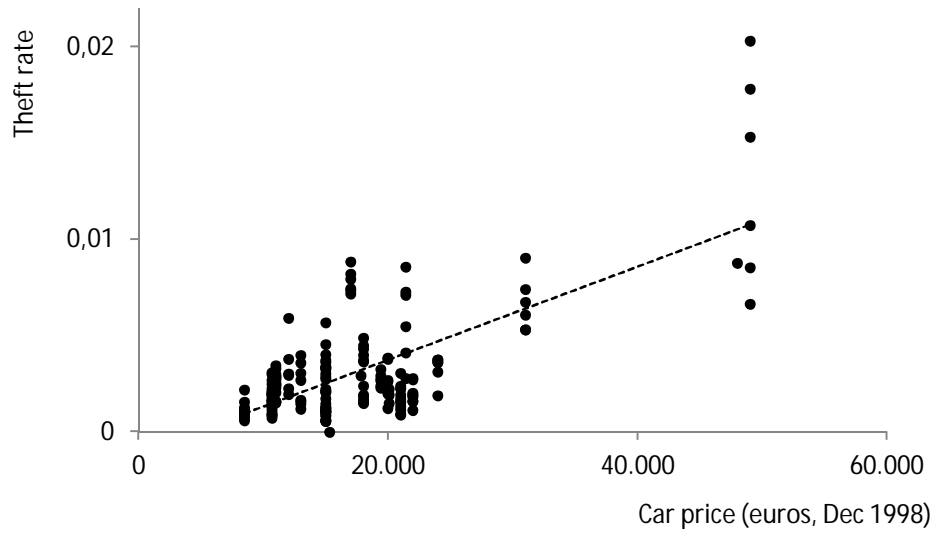
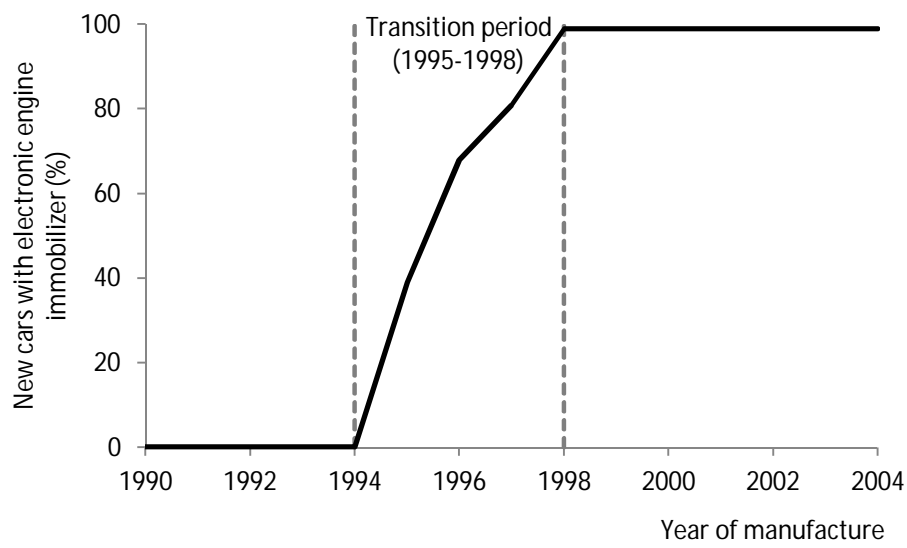


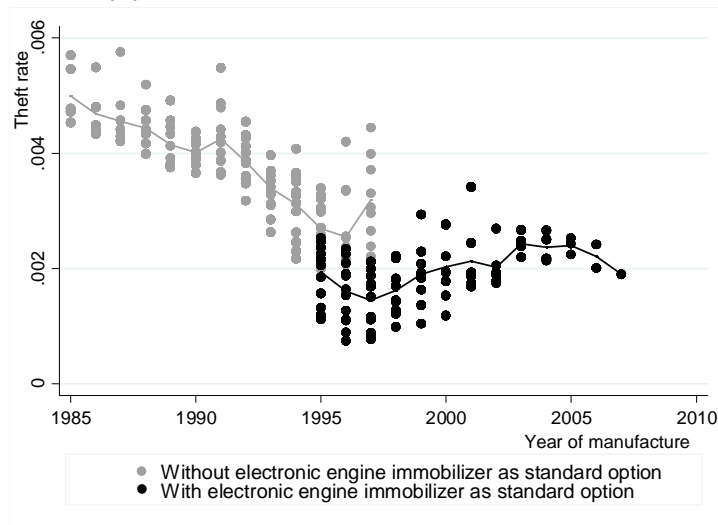
Figure 3. **Share of new cars with electronic engine immobilizer as standard option**



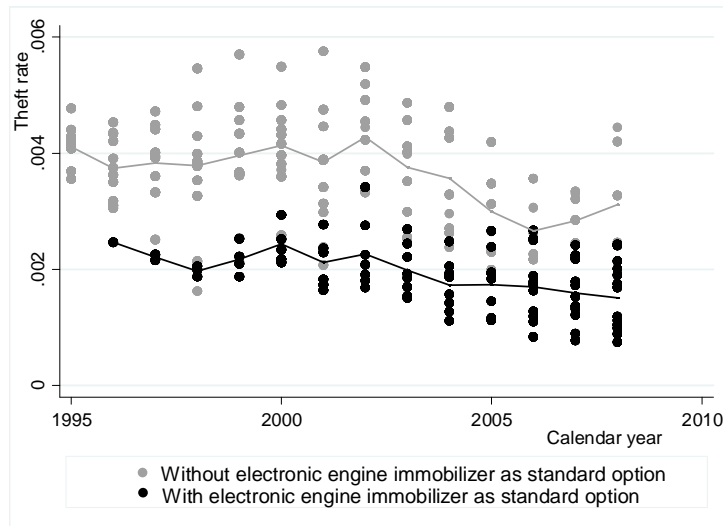
Source. Netherlands Department of Motor Vehicles (RDW), Allianz (1997).

Figure 4. Car theft by cohort, calendar year and age

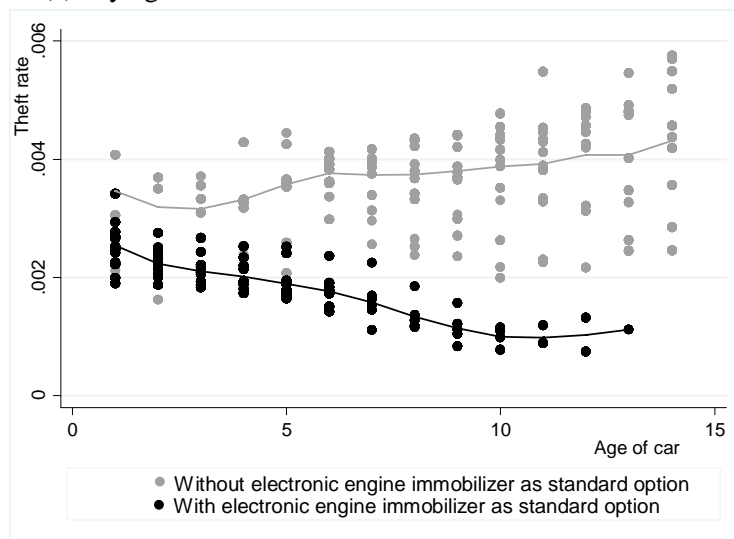
(a) By year of manufacture



(b) By calendar year

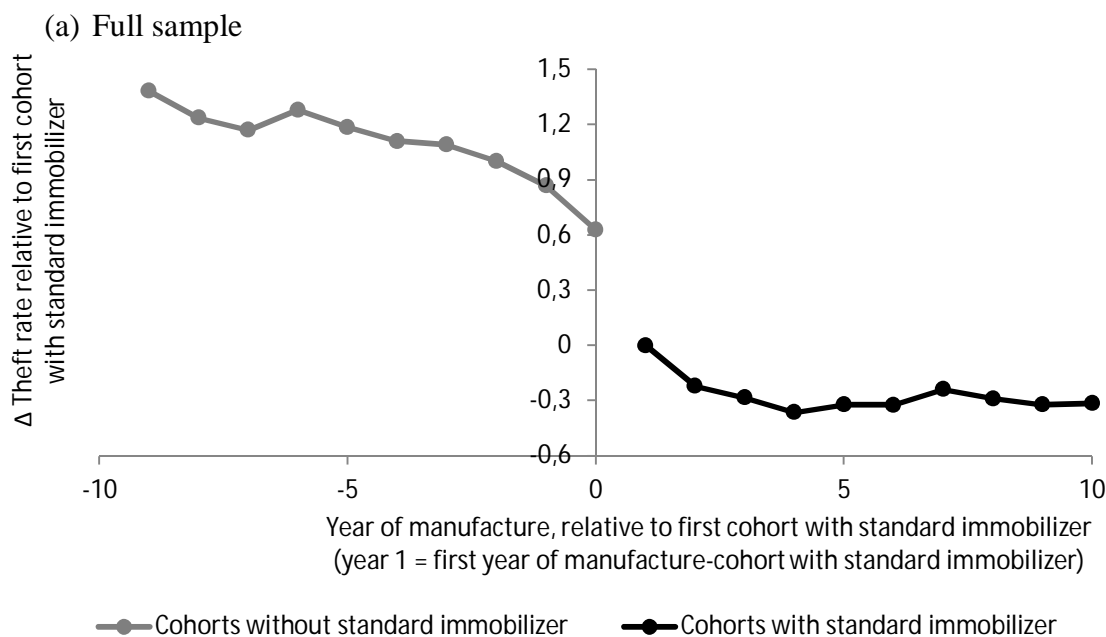


(c) By age



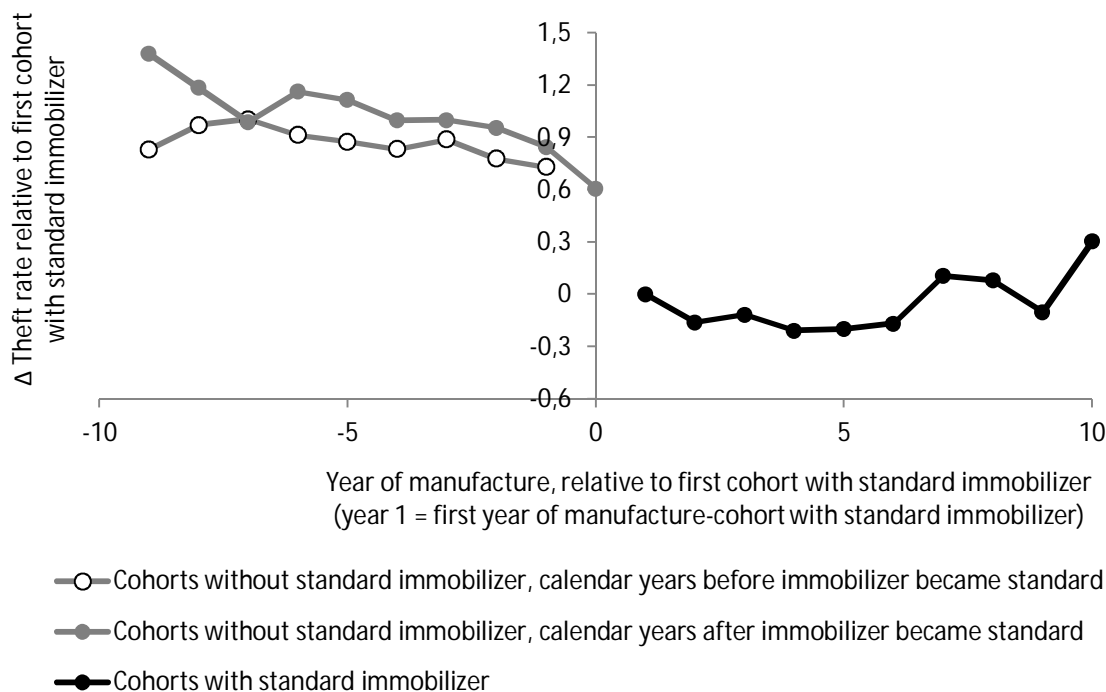
Note. Car theft rates are weighted by number of cars on the road. Excluding cohorts of car models that were only partly fitted with the electronic engine immobilizer as standard option.

Figure 5. Average rate of car theft, relative to first year of manufacture-cohort with electronic engine immobilizer as standard option, 1995-2008



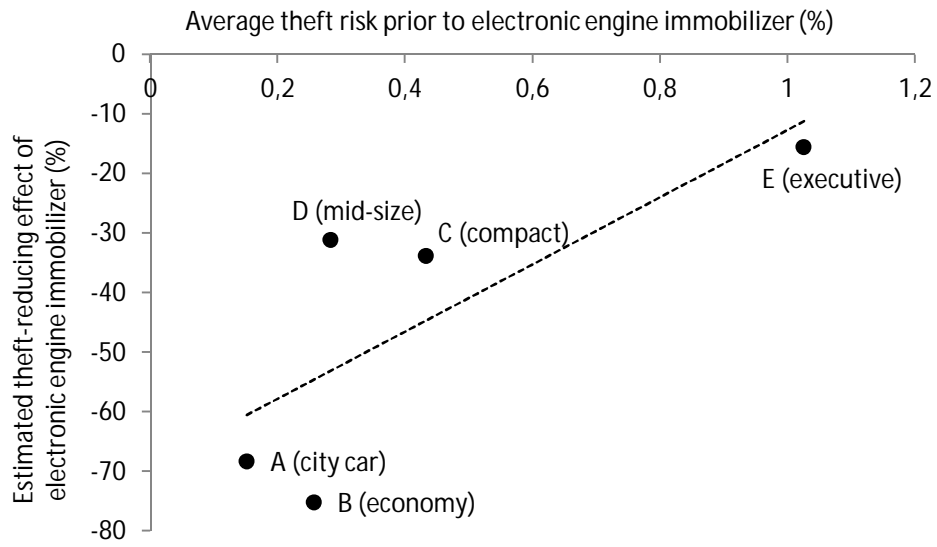
Note. Graph plots coefficients β_τ from estimation equation (1). Based on yearly data for 1995-2008 for 24 car models aged 1-14. Number of observations: 3,597.

(b) Sub-sample of cars observed before and after immobilizer became standard option



Note. Graph plots coefficients β_τ (open dots) and β'_τ (closed dots) from estimation equation (2). Based on yearly data for 1995-2008 for 11 car models aged 1-14. Number of observations: 1,588.

Figure 6. **Estimated theft-reducing effect by market segment**



Note. On the horizontal axis the average theft rate by market segment for cars without electronic engine immobilizer, up to three years of age.

Appendix A – Calculating missing values of the number of cars on the road

Our data contains information about the number of cars on the road for each age category and car model from 2002 to 2008 (as of December 31 of each year). Our analysis requires information about the number of cars on the road from (31 December) 1994 to 2008. The missing information was calculated as follows. First we calculated for each available calendar year age-specific and model-specific survival fractions s :

$$s_{tam} = C_{tam}/C_{t+1,a+1,m}$$

where C is the number of cars on the road, t is an index for calendar year, a an index for age and m an index for model. Then we regressed the survival fractions on age categories so that we have age and model-specific survivor fractions:

$$s_{tam} = \lambda_{am} a + v_{tam}$$

where v represents an error term. We then use these estimated survivor fractions to calculate missing numbers of cars on the road. For example:

$$C_{2001am} = \lambda_{am} C_{2002,a+1,m}$$

$$C_{2000am} = \lambda_{am} C_{2001,a+1,m}$$

etcetera.

Appendix B – Supplementary statistics at the level of car models

	Thefrate (per 1,000 cars)			Year of manufacture		Year immobilizer became standard	Number of observations
	Mean	Min	Max	Min	Max		
A-segment							
1 Renault Twingo	1.04	0.12	3.07	1993	2007	1998	113
2 Suzuki Alto	1.34	0.08	8.56	1987	2005	1997	169
B-segment							
3 Honda Civic	3.54	0.30	10.73	1985	2002	1995 ¹	164
4 Opel Corsa	3.62	0.19	14.94	1985	2004	1995 ²	180
5 Renault Clio	1.44	0.15	3.44	1991	2007	1998	140
6 Seat Ibiza	1.57	0.24	5.88	1986	2005	1996 ³	171
7 Suzuki Swift	0.98	0.20	2.69	1987	2006	1997	163
C-segment							
8 Citroën ZX	0.91	0.20	2.30	1991	1997	1995 ³	79
9 Ford Escort	4.99	0.33	14.63	1988	2000	1998	135
10 Opel Astra	1.35	0.31	4.40	1991	2004	1995 ³	135
11 Peugeot 306/307	7.38	0.61	23.02	1993	2005	1996	98
12 Seat Toledo	2.19	0.32	6.56	1992	2005	1996 ⁴	98
13 Toyota Corolla	0.90	0.10	2.26	1987	2006	1997 ³	169
14 VW Golf	5.55	0.79	12.23	1985	2004	1995	180
15 VW Jetta/Vento/Bora	3.58	0.36	10.08	1985	2003	1995	164
D-segment							
16 BMW 3	3.68	0.72	10.46	1985	2004	1995	180
17 Mazda 626	2.14	0.17	5.63	1985	2001	1995 ⁵	156
18 Nissan Primera	1.44	0.18	5.38	1990	2004	1995 ³	137
19 Peugeot 405/406/407	1.17	0.13	2.95	1987	2005	1996	168
20 Renault Laguna	1.00	0.14	2.52	1994	2004	1995 ⁶	95
21 Toyota Carina/Avensis	1.30	0.15	3.76	1987	2006	1997	164
22 VW Passat	2.73	0.26	7.15	1985	2004	1995 ³	180
E-segment							
23 BMW 5	5.28	0.56	14.66	1985	2004	1995	179
24 Mercedes E	7.98	1.27	23.51	1985	2004	1995	180
Total							3,597

Note. (1) First year 70% of cohort; (2) First year 25% of cohort; (3) First year 50% of cohort; (4) First year 40% of cohort; (5) First year 90% of cohort; (6) First year 20% of cohort; second year 50% of cohort.