MEASURING POSITIVE EXTERNALITIES FROM UNOBSERVABLE VICTIM PRECAUTION: AN EMPIRICAL ANALYSIS OF LOJACK*

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Lojack is a hidden radio-transmitter device used for retrieving stolen vehicles. Because there is no external indication that Lojack has been installed, it does not directly affect the likelihood that a protected car will be stolen. There may, however, be positive externalities due to general deterrence. We find that the availability of Lojack is associated with a sharp fall in auto theft. Rates of other crime do not change appreciably. At least historically, the marginal social benefit of an additional unit of Lojack has been fifteen times greater than the marginal social cost in high crime areas. Those who install Lojack, however, obtain less than 10 percent of the total social benefits, leading to underprovision by the market.

I. INTRODUCTION

The enormous resources devoted to the criminal justice system are well documented. Prison populations have more than tripled in the last two decades, with roughly 1.5 million Americans now behind bars. Total government spending on criminal justice in 1995 was almost $100 billion dollars. Often overlooked, however, is the fact that private expenditures on self-protection potentially dwarf public spending. Sources cited in Philipson and Posner [1996], for instance, estimate that private expenditures to reduce crime are $300 billion annually.[1] Laband and Sophocleus [1992] come to a similar conclusion. The opportunity cost associated with crime-related distortions to behavior (e.g., avoiding Central Park after dark or moving to the suburbs), while difficult to quantify, is also likely to be substantial.

Understanding the impact of private efforts taken to avoid criminal victimization is important not only because of their

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1. Victim precaution expenditures also appear to be growing at a rate faster than public spending. For example, Sherman [1995] cites a *Wall Street Journal* report that the security guard industry grew 11 percent in 1994, more than twice the rate of police expenditures in recent years.

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magnitude, but also because of the potential externalities associated with such actions. Many forms of victim precaution, such as highly visible car alarms or home-security systems, may serve primarily to redistribute crime across victims rather than to reduce crime. Consequently, those who engage in observable self-protection may impose a cost on those who do not.[2] In contrast, other forms of precaution such as silent alarms and passive disabling devices in automobiles may provide positive rather than negative externalities. Criminals cannot identify who has engaged in unobservable precaution, providing benefits to all potential victims.

The first formal treatment of externalities associated with victim precaution dates to Clotfelter [1978]. Subsequent theoretical work includes Friedman [1984], Cook [1986], Shavell [1991], De Meza and Gould [1992], Harel [1994], Hui-Wen and Png [1994], and Ben-Shahar and Harel [1995]. Empirical analysis of victim precaution, however, is almost nonexistent, with the exception of gun ownership and right-to-carry laws which have recently become the subject of heated debate [Black and Nagin 1997; Duggan 1996; Lott and Mustard 1997].[3] These studies, however, cannot differentiate between direct benefits to gun owners and externalities.

In this paper we provide the first thorough empirical examination of the externalities associated with self-protective efforts, focusing our attention on the Lojack car retrieval system. With Lojack, a small radio transmitter is hidden in one of many possible locations within a car. When the car is reported stolen, the police remotely activate the transmitter, allowing specially equipped police cars and helicopters to track the precise location and movement of the stolen vehicle. From an economic perspective, what makes Lojack most interesting is that there is no

2. Shavell [1991] notes that observable self-protection may also have a general deterrent effect. For instance, if there are fixed costs to engaging in criminal activities or search costs in finding suitable victims, then increases in observable self-protection may deter criminals and consequently may provide positive externalities. At least in the auto theft case, where there are a large number of available targets that are close substitutes, the magnitude of this deterrent effect is likely to be outweighed by the negative externality associated with crime displacement.

3. Crime-shifting in response to changes in the level of public law enforcement is somewhat better documented. For instance, Mayhew et al. [1976] find that the installation of surveillance cameras in selected London subway stations did not increase crime in other stations. Wilson [1983] reports that increased evening police patrols in New York City subways led to a rise in daytime subway robberies. Eck [1993] and Hesseling [1994] review the existing literature.

indication anywhere on a Lojack-equipped vehicle that Lojack is installed.[4] Thus, Lojack is a prototypical example of the positive externality-generating unobservable self-protection.[5] An individual car owner's decision to install Lojack only trivially affects the likelihood of his or her own vehicle being stolen since thieves base their theft decisions on mean Lojack installation rates. Thus, to the extent that Lojack has any impact on lowering auto theft rates, these reductions are purely an externality from the perspective of the car owner installing Lojack. The only internalized benefits of Lojack are higher retrieval rates and lower theft damages once a vehicle is stolen.

There are various reasons why the presence of Lojack makes auto theft riskier and less profitable, leading to a reduction in the number of such crimes. First and foremost, Lojack disrupts the operation of "chop-shops" where stolen vehicles are disassembled for resale of parts. In the absence of Lojack, identifying chop-shops requires time-consuming, resource-intensive sting operations. With Lojack, police following the radio signal are led directly to the chop-shop. In Los Angeles alone Lojack has resulted in the breakup of 53 chop-shops. Second, data collected in California suggest that the arrest rate for stolen vehicles equipped with Lojack is three times greater than for cars without Lojack (30 percent versus 10 percent). Since most thieves are repeat offenders [Visher 1986; DiIulio and Piehl 1991], arrests that lead to incarceration may also provide social benefits via reductions in victimizations while the criminal is behind bars.[6]

Empirically, we find strong support for the argument that Lojack reduces auto theft. According to our estimates, one auto theft is eliminated annually for every three Lojacks installed in

4. Lojack executives report that law enforcement agencies condition their acceptance of the Lojack technology on the product being unidentified. Insurance boards make insurance premium discounts conditional on a vehicle owner not privately identifying the presence of Lojack (for example, by a decal). Lojack owners may or may not individually benefit from concealing the presence of Lojack in their cars. Signaling the presence of Lojack may reduce the likelihood that a vehicle is stolen, but will also increase the chances that a criminal will search for and successfully disable Lojack, reducing the likelihood that the stolen car is recovered. Even if a Lojack owner wanted to signal the presence of Lojack, it may be difficult to do so in a credible manner.

5. Ben-Shahar and Harel [1995] also note the unobservability of Lojack and use it to illustrate their theoretical arguments.

6. Other possible benefits of Lojack include the elimination of the need for high-speed chases in Lojack-equipped vehicles. In 1993, 238 fatal accidents resulted from high-speed chases with police in pursuit according to data from the Fatal Accident Reporting System. Also, to the extent that the availability of a stolen vehicle facilitates the commission of other crimes, Lojack may reduce the rate of such crimes.

high-crime central cities. There is little evidence that the reductions in central city auto thefts are simply being displaced either geographically or to other categories of crime. Auto theft rates also fall in the remainder of the state (much of which is typically also covered by Lojack, but at a lower penetration rate). There is little systematic change in the rates at which other crimes are committed in these cities. One form of substitution that is observed, however, is toward older vehicles, which are less likely to have Lojack.

An important issue is whether the negative association that we observe between Lojack and auto theft truly reflects a causal relationship. For instance, if cities grant regulatory approval to Lojack when they decide that it is time to get tough on auto theft, it may be that the observed reduction in auto theft is due not to Lojack, but rather to other actions the city takes coincident with the arrival of Lojack. We address this concern in a number of ways. First, if cities adopting Lojack shift police resources away from other crimes to fight auto theft, then one would expect to observe both an increase in the arrest rate for auto theft and a rise in those other crimes from which resources have been diverted.[7] Neither of these predictions are borne out in the data. Second, in an attempt to address the possibility of selection bias in the set of cities that grant regulatory approval to Lojack, we instrument for our measures of Lojack using the number of years that have elapsed since Lojack began the regulatory process in a state.[8] The resulting instrumental variables estimates are larger than the ordinary least squares estimates, implying that Lojack is more likely to be approved in cities where the auto theft problem is expected to worsen. Finally, we analyze whether the arrival of Lojack precedes or follows the declines in auto theft. Given lags of two to seven years in gaining regulatory approval for Lojack in a particular market, if Lojack systematically targets cities that are getting tough on auto theft, one would expect to observe falling auto theft rates immediately prior to the introduction of Lojack. Once again, such a pattern is not apparent.

Nor can our results be easily explained by the omission (due to lack of available data) of other measures of victim precaution

7. As will be discussed later, increased arrests do not appear to be the primary channel through which Lojack reduces auto theft.

8. It is also possible that there is sample selection in the set of cities that Lojack attempts to enter, which would not be addressed by this instrument. As discussed in Section III, the direction of this bias is uncertain.

such as expenditures on antitheft devices, the locking of car doors, or not parking in dangerous neighborhoods. The presence of Lojack reduces the incentives for these other forms of victim precaution, both for car owners with Lojack, who suffer less harm when their vehicle is stolen, and for other car owners, who face lower theft rates as a consequence of Lojack's positive externality. Thus, the omission of these factors is likely to lead our estimates to understate the true effect of Lojack.

Our calculations suggest that an individual-Lojack owner who does not have theft insurance will benefit from installing Lojack in high crime areas due to the increased recovery rate of and lessened damage to Lojack-equipped stolen vehicles. For vehicle owners who have theft insurance, the internalized benefit of Lojack is much smaller since most of the costs associated with vehicle theft are borne by the insurer. In either case, the direct benefit to the Lojack-owner/insurer represents less than 10 percent of the social benefits of Lojack installation since almost all of the benefit results from the positive externality of reduced auto theft. Consequently, Lojack is likely to be dramatically undersupplied by the free market, suggesting a role for public policy. One form of government intervention currently in place is state-mandated insurance discounts; the current levels of such discounts, however, are far below the socially optimal levels.

The remainder of the paper is organized as follows. Section II provides background on Lojack and the data used in the paper. Section III contains the empirical estimates of the impact of Lojack. The fourth section discusses the results and considers numerous extensions. Section V presents a rough accounting of the private and social costs and benefits of Lojack. The final section offers a brief set of conclusions.

II. Background on Lojack and Data Sources

As noted above, Lojack is a radio-transmitter device hidden inside a car in order to allow fast and near-certain recovery of the vehicle if stolen. Virtually all Lojack systems are installed in new cars at the time of purchase. Installation involves a one-time fee of roughly $600. There are no additional maintenance costs or annual fees. According to statistics collected by the Lojack company, 95 percent of stolen vehicles equipped with Lojack are recovered, compared with roughly 60 percent of vehicles that do not have Lojack.[9]

The Lojack company has followed the strategy of entering markets sequentially. Approval for entry into a market by Lojack requires the cooperation of the state police organization, the state Attorney General, and local police departments. Time elapsed in waiting for approval into markets has ranged historically from fourteen weeks to almost a decade. A full list of markets covered by Lojack as of December 1994 and dates of entry into those markets is presented in Table I.[10] Lojack was first introduced in Massachusetts in 1986, and Massachusetts remains Lojack's strongest market today.[11] Lojack was subsequently introduced in South Florida in 1988 and in three additional markets in 1990. As of December 1994, Lojack served twelve markets. Lojack is the only widely available product for the remote tracking of stolen vehicles currently on the market.

The percentage of cars equipped with Lojack differs greatly across markets. Because installation is almost exclusively in new cars, initial penetration into markets tends to be slow (new car sales in a given year represent less than 10 percent of total cars registered). While the installed base increases over time, the fraction of cars equipped with Lojack generally remains small. After five years in a market, Lojack's typical coverage rate is less than two percent of registered vehicles.[12]

9. All data on vehicle recovery rates, chop-shops eliminated, and arrest rates for cars equipped with Lojack are from the internal reports generated monthly by Bob Montoya, Lojack's law enforcement liaison in California, in cooperation with various California police departments. Data on Lojack installations, dates of entry into markets, and types of vehicles protected are drawn from internal Lojack records. Other Lojack information cited in the paper is based on discussions with Lojack executives.

10. The latest UCR crime data available at the time of this analysis covered 1994, so markets entered after 1994 (Connecticut, Orange County, and San Diego County) are not included as having Lojack coverage in our analysis.

11. Two factors contributing to Lojack's success in Massachusetts are traditionally high rates of auto theft (in 1985, the year before Lojack became available there, Boston ranked first among large cities in stolen vehicles per capita) and substantial insurance discounts to cars with Lojack. Installation of Lojack provides a mandatory 20 percent discount on the comprehensive portion of Massachusetts auto insurance. Lojack in conjunction with selected antitheft devices increases that discount to 35 percent. Insurance discounts in other states are typically capped at 20 percent and are often at the discretion of individual insurance companies.

12. Confidentiality agreements with Lojack prohibit us from revealing penetration rates into individual markets. Estimates of the percent of total cars equipped are derived from data provided by Lojack on the percent of new car registrations equipped with Lojack and authors' calculations of new car sales as a function of total registrations, factoring in typical rates of removal of cars from the road.

TABLE I
MARKETS SERVED BY LOJACK AS OF DECEMBER 1994

Market	Cities > 250,000 covered	Date of entry
Massachusetts	Boston	July 1986
South Florida	Miami	December 1988
New Jersey	Newark	March 1990
Los Angeles County	Los Angeles Long Beach	July 1990
Illinois	Chicago	November 1990
Georgia	Atlanta	August 1992
Virginia	Norfolk Virginia Beach	August 1993
Michigan[a]	Detroit	February 1994
New York	New York City	June 1994
Rhode Island	None	June 1994
Tampa/St. Petersburg	Tampa	July 1994
District of Columbia	Washington, DC	September 1994

a. Lojack was available in parts of Michigan beginning in April 1990, but service in Detroit did not begin until 1994.

When entering a market, the coverage range of Lojack varies. In some cases, an entire state is covered; in other instances, only an extended metropolitan area. On average, in states where Lojack is available, roughly 60 percent of the population is in coverage range. While no estimates of the geographic breakdown of Lojack installations within a market are available, installation rates are probably highest in the areas with the highest auto theft rates, which are invariably large cities. Auto theft rates per capita in cities with populations over 250,000 are three times higher than in cities with populations under 250,000 and more than ten times higher than in rural areas. For that reason, the primary focus of our analysis is on cities with a population greater than 250,000, although we also provide estimates for the remainder of the state as well. As of December 1994, Lojack was available in 13 of the 57 U. S. cities with population greater than 250,000.

Data on auto theft rates per capita, as well as for other crime rates, arrest rates, and number of police officers, are available annually on a city-level basis from the FBI's *Uniform Crime Reports*. UCR data include only those crimes reported to the police. Reported auto theft figures are considered more reliable than data for most other crimes because insurance companies require that auto thefts be reported to police to be eligible for reimbursement.[13]

In addition to the theft data, a number of economic and demographic variables are used as control variables in the analysis. These measures (unlike the theft data) are generally not available on a yearly basis at the city-level, necessitating a number of data compromises. Unemployment rates are available annually at the SMSA level; these values are used as proxies for city-level unemployment. State per capita income is measured on an annual basis at the state level, as are data on the age distribution of the population. The percent of a city's residents who are black is linearly interpolated between decennial census years. Year dummies and city-fixed effects are also included as control variables.

Summary statistics are presented in Table II, both for all central cities with populations greater than 250,000 in 1981 and for the subset of those cities served by Lojack by December 1994. It is important to note that cities served by Lojack differ systematically from the other cities in the sample. Lojack cities tend to be larger and have not only higher auto theft rates, but also more crime generally. Consequently, in our empirical analysis we focus exclusively on specifications that include city-fixed effects so that our parameter identification comes from within-city changes over time rather than from cross-city comparisons.

III. Empirical Estimates of the Impact of Lojack

Figure I presents per capita auto theft rates over the period 1981–1994 for the six cities with population over 250,000 in markets Lojack entered before or during 1990.[14] Mean auto theft rates per capita for all non-Lojack U. S. cities with population over 250,000 are also shown. The vertical line in each picture represents the year in which Lojack became available in the market. Boston has experienced a 50 percent decline in auto theft rates

13. Victimization data from the National Crime Victimization Survey shows that 75 percent of all auto theft attempts (including 92 percent of all completed thefts) are reported to the police, compared with only 53 percent of burglaries, 51 percent of robberies, and 27 percent of larcenies [Bureau of Justice Statistics 1994].

14. For the purposes of the figure, Los Angeles and Long Beach, which share an SMSA, are combined. These cities are entered separately in the regressions.

The regression results that follow are not sensitive to using 1981 as the starting point for our sample. Using a later beginning date has almost no effect on the Lojack coefficients or standard errors, but somewhat increases the precision with which other parameters are estimated.

TABLE II
SUMMARY STATISTICS

Variable	Mean	Standard deviation	Minimum	Maximum
All cities in sample:				
Lojack share (% of all vehicles)	.05	.33	0	4.95
Years of Lojack	.17	.85	0	9
City population	764,268	1,045,791	250,720	7,375,097
Auto theft per capita	.012	.008	.002	.054
Robbery, burglary, larceny per capita	.078	.021	.033	.156
Assault, rape, murder per capita	.008	.004	.001	.025
SMSA unemp.	6.3	2.1	2.2	15.9
State per capita real income ($1994)	19,911	2,821	13,720	31,228
% Black	26.0	18.7	1.2	80.7
% Aged 0–17	26.3	2.0	19.7	31.7
% Aged 18–24	11.5	1.3	8.4	15.1
% Aged 25–44	31.4	2.1	26.1	36.4
Sworn officers per capita (×1000)	2.47	.96	1.32	7.81
Cities with Lojack coverage by 12/94				
Lojack share (% of all vehicles)	.21	.67	0	4.95
Years of Lojack	.83	1.71	0	9
City population	1,402,239	1,959,315	257,617	7,375,097
Auto theft per capita	.018	.011	.002	.05
Robbery, burglary, larceny per capita	.0881	.025	.044	.156
Asault, rape, murder per capita	.011	.006	.001t	
SMSA unemp.	6.5	2.1	2.7	15.9
State per capita real income ($1994)	20,843	3,370	13,932	31,228
% Black	37.5	21.0	10.4	80.7
% Aged 0–17	24.9	2.2	19.7	31.7
% Aged 18–24	11.5	1.5	8.4	15.1
% Aged 25–44	32.0	2.3	26.1	36.4
Sworn officers per capita (×1000)	3.20	1.33	1.40	7.81

Data cover the period 1981–1994 for the 57 U. cities with a population greater than 250,000 in 1981. For the thirteen cities with Lojack coverage, data presented are for the entire period 1981–1994, not just for the years with Lojack. Lojack data were provided by the Lojack company. Crime, police, and city population data are from the FBI's *Uniform Crime Reports*. Demographic data are from the U. S. Bureau of the Census and the *Statistical Abstract*. Unemployment data are from *Employment and Earnings*. State per capita income is in 1994 dollars, deflated using the CPI.

since the introduction of Lojack, going from nearly twice the rate for large cities to only slightly higher than average. There is, however, some evidence of a declining trend before the arrival of Lojack. Newark (−35.0 percent) and Los Angeles/Long Beach

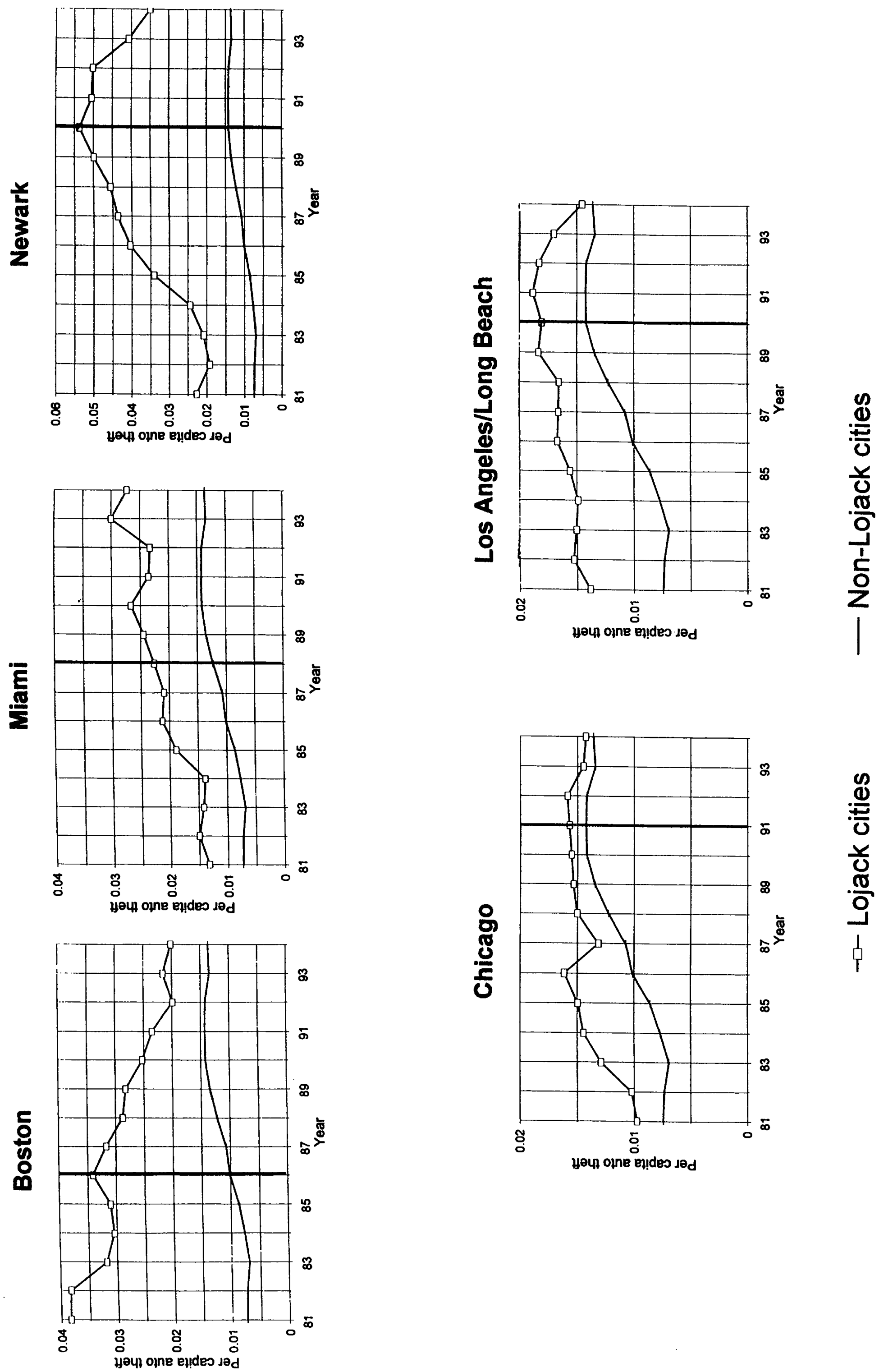

FIGURE I
Auto Theft Patterns in Cities Adopting Lojack before 1991

(−19.6 percent) have also seen substantial declines since the introduction of Lojack. In both cases, the post-Lojack declines represent a break from past trends. Auto theft rates continued to rise in Miami (11.4 percent) after the introduction of Lojack, although preliminary data released by the FBI (not included in the figure or subsequent analysis) show a 15 percent decline in auto theft in 1995, leaving present auto theft rates in Miami below those at the time of Lojack's introduction. There is little apparent impact of Lojack in Chicago where Lojack market shares are extremely low—less than one-twentieth as large as Boston. The low penetration rates in Chicago appear to be attributable to the fact that until 1996 Illinois law prohibited insurance companies from giving discounts for Lojack.

Figure II combines the information for these six cities into one figure. Because the level of auto theft varies across cities, the figure is expressed in terms of changes in auto theft, using five years prior to the entry of Lojack as a baseline. Since Lojack enters cities at different times, the horizontal axis is years pre- or post-Lojack entry; e.g., year 0 is 1986 for Boston and 1990 for Los Angeles. For comparison, Figure II also reports a simple average of changes in auto theft rates for all non-Lojack cities for the relevant years.[15] In the years preceding Lojack's arrival, the cities that will be served by Lojack experience slightly greater increases in auto theft. Directly coinciding with the introduction of Lojack, that trend reverses. In the four years after the introduction of Lojack, auto thefts per capita decline by .0051, or 17.4 percent. There is little apparent change in non-Lojack cities.

While it is true that the cities Lojack enters tend to have both higher than average levels of auto theft and faster rates of increase in advance of entry, the subsequent declines in auto theft do not appear to simply reflect mean reversion. The cities targeted by Lojack were perennially high auto theft cities. In 1973, for instance, almost two decades before Lojack entered most of these markets, per capita auto theft rates were 64 percent higher than average for big cities. There is evidence, however, that short-run *changes* in auto theft are partially offset in ensuing years. In our

15. For instance, year $t - 1$ in Figure II corresponds to 1985, 1988, 1989, 1989, and 1990 for the five Lojack cities. Thus, the value of the non-Lojack cities is the average change in auto theft in those years for the 44 large U. S. cities that do not adopt Lojack in our sample period. Note that the 1989 value would carry twice the weight of the other years because there are two relevant observations in that year.

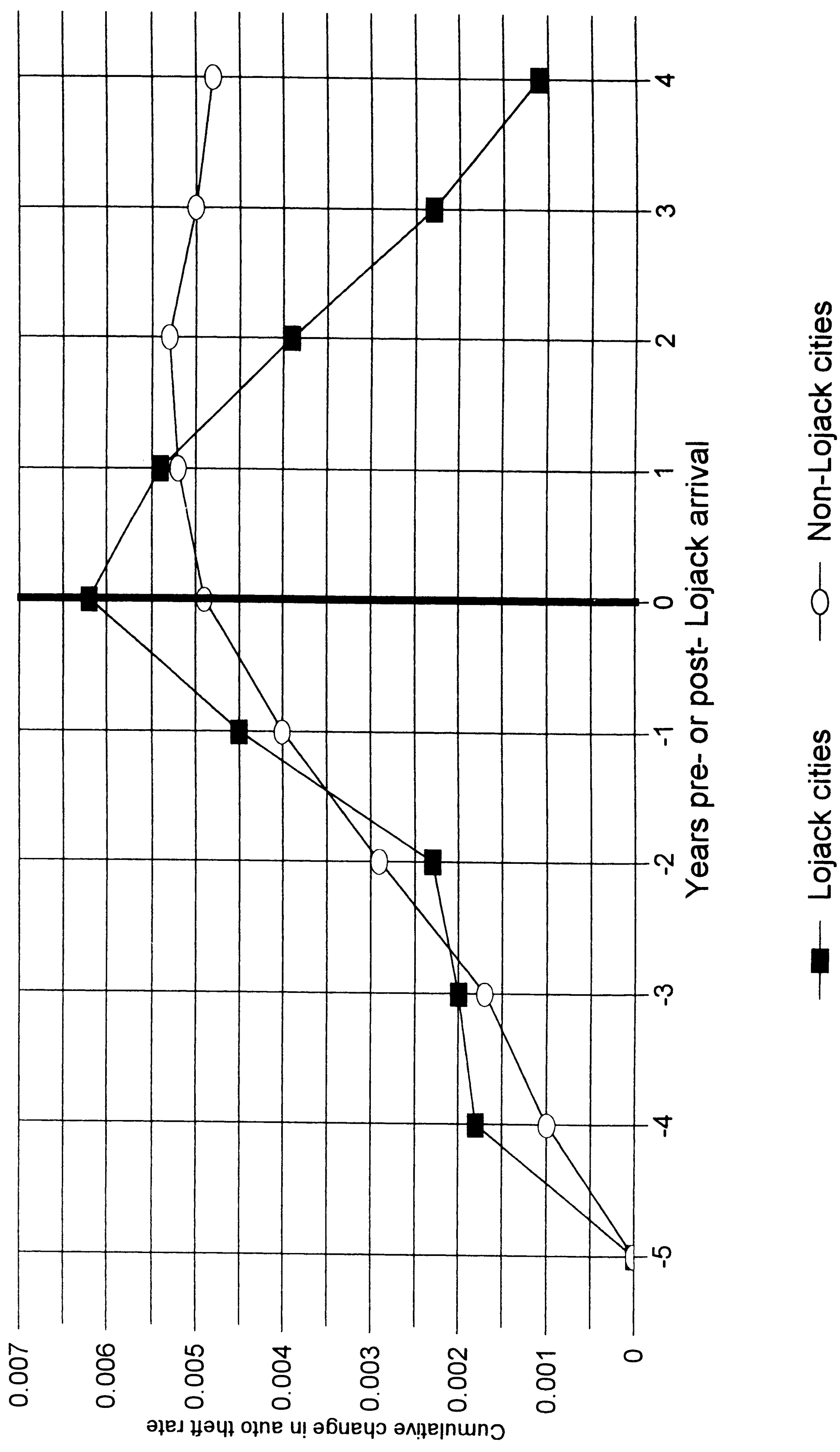

FIGURE II
Auto Theft and Lojack Availability
Lojack Cities versus non-Lojack Cities

data, roughly one-sixth of recent changes in auto theft per capitaare undone in the subsequent two years.[16] This effect, however, explains only a small fraction of the decline in auto theft rates after the introduction of Lojack since rates of growth in auto theft are not very different before Lojack arrives. Also, given the long regulatory delays often encountered by Lojack in entering a market, it is difficult to tell a compelling story that Lojack entry is driven by short-term fluctuations in auto theft rates.

In the analysis that follows, we employ two alternative measures of Lojack's market presence. The first measure is simply the number of years that Lojack has been available in a market. Since Lojack is installed almost exclusively in new vehicles, its market share grows steadily over time. This simple proxy has the advantages of being straightforward to interpret and also allows for the possibility that criminals learn about Lojack over time in a manner not based solely on the number of Lojacks installed. The disadvantage of this measure is that it sacrifices much of the variation in the data since penetration rates vary widely across markets. Consequently, we also consider the fraction of total car registrations equipped with Lojack in a given market and year as a proxy for Lojack's presence. This estimate is derived from Lojack's internal data on installation rates in new cars and authors' estimates of the hazard rates for autos being removed from the road.[17] There are two major drawbacks of this measure. First, due to data limitations, it can only be defined for the market as a whole, rather than, just for the central city. Since auto theft rates are higher in large cities, it is likely that Lojack's penetra-

16. This estimate of mean reversion is obtained by regressing the change in a city's auto theft rate between years t and $t + 2$ on the change in that city's auto theft rate between years $t - 2$ and t, including year dummies in the specification. Cities that adopt Lojack are excluded from the regression. The coefficient of interest is $-.159$ with a standard error equal to .065. If city-fixed effects are included in the regression, the coefficient rises to $-.250$ (standard error equal to .060).

17. Our estimates of the hazard rates for removal of cars from the road are based on data for passenger cars in use published in compact disc form by the Polk Company under the title *National Vehicle Population Profile.* Based on a census of currently registered passenger vehicles and light trucks, this data source provides information on the number of cars on the road annually by model year. The authors' calculations using these data show that roughly 3 percent of vehicles are removed from the road annually in the first five years of operation, with that hazard growing to 8 percent between years six and ten, and approximately 15 percent thereafter. Our estimates ignore the fact that some vehicles will move away from the Lojack coverage area, leading our estimated market shares to overstate the true Lojack presence.

tion rates are greater in these cities than in outlying areas, and thus are measured with error. In order to interpret the coefficients, one must make an assumption about the relative installation rates in central cities and outlying areas. A second problem with this measure is that market share may be endogenously determined. Cities where auto theft is expected to be high and increasing will tend to have higher installation rates. This may lead the estimates to understate the true magnitude of the impact of Lojack.

The form of the equations estimated in the basic specifications is as follows:

$$(1) \quad \ln (AUTO\_THEFT)_{it} = \beta LOJACK_{it} + X'_{it}\Gamma + \lambda_t + \theta_i + \epsilon_{it},$$

where I indexes cities and t corresponds to years. $AUTO\_THEFT$ is the auto theft rate per capita, $LOJACK$ is one of the two Lojack proxies described earlier, and X is a vector of controls for SMSA unemployment rates, the state age distribution, and the number of city police per capita.[18] Chiricos [1987] and Freeman [1996] report that property crime is negatively related to labor market conditions. Blumstein et al. [1986] find that the prevalence of criminal involvement drops off sharply after the teenage years. Levitt [1997] and Marvell and Moody [1996] find that increased numbers of police reduce crime. λ_t are year indicators and θ_i are city-fixed effects. Because the dependent variable is logged, β is roughly interpreted as the percent change in auto theft rates associated with a unit change in the Lojack proxy.

If the timing of regulatory approval of Lojack by cities is endogenous (e.g., cities approve Lojack at the same time other steps are taken to reduce auto theft), then the OLS estimates of equation (1) will be inconsistent. Consequently, in some specifications we instrument for the Lojack variables using the number of years that have elapsed since Lojack initiated the often lengthy regulatory approval process. Included in the construction of this variable are the three cities (Baltimore, Philadelphia, and Pittsburgh) where Lojack had begun the regulatory process, but had not yet been granted approval by the end of our sample. This variable is highly correlated with our two measures of Lojack

18. There is no strong theoretical justification for our choice of a log-linear functional form. The primary rationale for this specification is the ease of interpretation of the coefficients. The findings with the dependent variables in levels are completely consistent with the results reported using the log-linear specification.

presence,[19] but does not exploit any of the potentially endogenous variation in the timing of regulatory approval.[20]

Estimation results are presented in Table III. Columns (1) and (2) include the number of years that Lojack has been available as a regressor; columns (3) and (4) use the Lojack market share. Odd numbered columns are OLS estimates with White-standard errors in parentheses. Even columns are 2SLS estimates using years since Lojack initiated the regulatory approval process as an instrument for the Lojack variables. The full set of demographic and economic controls are included in Table III, along with year dummies and city-fixed effects. The bottom row of Table III also provides the corresponding coefficient on the Lojack variable from specifications where only year dummies and city-fixed effects are included as controls.

In all specifications the coefficient on the Lojack variable is

19. The first-stage regression results are as follows (White-standard errors are in parentheses):

$$LOJ\_YEARS = .418{*}YEARS\_APPLY + YEAR\ DUMMIES + CITY\text{-}FIXED\ EFFECTS \quad N = 796 \quad \text{Adj. } R^2 = .703$$

$$LOJ\_SHARE = .142{*}YEARS\_APPLY + \text{YEAR DUMMIES} + CITY\text{-}FIXED\ EFFECTS \quad N = 796 \quad \text{Adj. } R^2 = .545.$$

Each additional year elapsed since the regulatory approval process began is associated with an additional .418 years of Lojack availability and an extra .142 percentage points of market share. For simplicity in displaying the results, the specification above omits demographic and socioeconomic covariates. When the covariates described below are included, the coefficients on years elapsed since initiating the regulatory approval process are virtually unchanged: .408 (standard error = .043) for *LOJ_YEARS* and .138 (standard error = .022) for *LOJ_SHARE*. The only covariate that is a statistically significant predictor of Lojack in both first-stage regressions is real income per capita, which is negatively related to Lojack.

20. One may also worry about possible sample selection in the set of cities where Lojack chooses to initiate the regulatory approval process. It is probably in Lojack's interests to enter markets where auto theft is high and is expected to remain high (to sustain consumer demand), which suggests that any bias should work against finding that Lojack reduces auto theft. The contrary possibility that Lojack would try to enter markets in which it expected auto theft to fall—in order to demonstrate to other markets Lojack's effectiveness—is belied by Lojack's belief that it is primarily selling a stolen vehicle retrieval service that reduces the expected damages if a vehicle is stolen. (The corporation has never attempted to measure how increased market penetration affects the auto theft rate.)

In an attempt to control for sample selection in the cities Lojack enters, we estimated a logit predicting Lojack adoption by the year 1994 as a function of lagged auto theft rates, city population, per capita sworn officers, and state per capita income. We then limited our sample to those cities with above average propensity scores for Lojack adoption. The coefficient estimates obtained were slightly larger than those in Table III, suggesting that sample selection in the set of cities entered is unlikely to explain our findings.

TABLE III
IMPACT OF LOJACK ON CITY AUTO THEFT RATES

Variable	(1)	(2)	(3)	(4)
Years of Lojack availability	−.109	−.157	—	—
	(.013)	(.021)		
Lojack share	—	—	−.242	−.463
			(.031)	(.065)
Unemployment rate	.019	.026	.017	.028
	(.009)	(.010)	(.009)	(.010)
State real per capita income (×1000)	.022	.028	.016	.022
	(.014)	(.015)	(.014)	(.016)
% Black	−.005	−.005	−.002	.001
	(.008)	(.008)	(.009)	(.009)
% Aged 0–17	.106	.115	.102	.118
	(.030)	(.026)	(.030)	(.027)
% Aged 18–24	.003	−.005	−.004	−.027
	(.039)	(.039)	(.039)	(.041)
% Aged 25–44	.028	.059	.008	.056
	(.039)	(.038)	(.039)	(.039)
ln (sworn officers/per capita)	.044	.060	−.001	−.009
	(.130)	(.133)	(.131)	(.137)
Instrument w/years since Lojack began regulatory process?	No	Yes	No	Yes
Adjusted R^2	.883	—	.882	—
Coefficient on Lojack excluding covariates from the specification	−.086	−.113	−.200	−.333
	(.012)	(.018)	(.028)	(.053)

Dependent variable is ln(reported auto thefts per capita). Data cover the period 1981–1994 and include all 57 U. S. central cities with a population greater than 250,000 in 1981. Lojack share is the estimated percent of total vehicles registered that have Lojack installed in the market. Number of observations is equal to 751 in all columns as a result of occasional missing data. In columns (2) and (4) the number of years elapsed since Lojack began the regulatory approval process is used as an instrument for the Lojack variables. All columns include year dummies and city-fixed effects in addition to the variables shown. Unemployment is the annual SMSA unemployment rate. % Black is linearly interpolated between decennial census years. Age categories refer to state age distributions; the omitted category is percent of the population over age 45. White standard errors are in parentheses. The bottom row of the table presents the coefficient on the Lojack variable in specifications that include only year dummies and city-fixed effects as covariates.

negative and highly statistically significant. In column (1) each additional year of Lojack availability in a market is associated with roughly a 10 percent decline in auto theft. The 2SLS estimate in column (2) are even larger. Column (3) shows that each additional percentage point of Lojack in the market is associated with a greater than 20 percent reduction in auto theft in central cities. This coefficient is deceptively large, however, since Lojack is disproportionately installed in central cities. Assuming that Lojack penetration rates are three times higher in cities than in the overall market, each percentage point of Lojack installation translates into a 7 percent decline in auto theft. 2SLS estimates column (4) are once again larger than OLS estimates.[21]

Increases in the unemployment rate are associated with rising auto theft rates as expected. Each percentage point increase in unemployment raises auto theft by about 2 percent. There is also some evidence that high incomes are associated with higher auto theft rates, presumably due to an increase in the pool of attractive automobiles available to be stolen. The coefficient on percent black is substantively small and statistically insignificant. The age category variables generally have the expected positive sign relative to the omitted category (over age 44), but are statistically significant only for the 0–17 age range. The coefficient on sworn officers, as is typically the case in correlational analyses [Cameron 1988], is small and sometimes carries a counterintuitive sign. The generally weak performance of the control variables is not surprising given the inclusion of year dummies and city-fixed effects. After removing year and city means, there is relatively little variation remaining in the controls, especially for the race and age variables. Coefficients on the Lojack variables from specifications that include only year dummies and city-fixed effects as controls are presented in the bottom row of Table III. The estimated impact of Lojack is somewhat smaller, but still highly statistically significant.

IV. Discussion and Extensions

Given the large estimated impact of Lojack, it is worth considering whether the magnitude of the effect is plausible. As noted above, a one percentage point increase in the Lojack share of the entire market is likely to be associated with a much greater increase in the share of vehicles protected by Lojack in the central city. Even so, it does not seem likely that changes in the aggregate likelihood of arrest for auto theft can account for the large effects: if arrests are three times as likely with Lojack-equipped cars (30 percent versus 10 percent), a 3 percent Lojack market share would increase the likelihood of arrest only 6 percent (i.e., from 0.10 to 0.106). Levitt [1998] estimates the elasticity of auto theft

21. As a further check on the potential endogeneity of the timing of Lojack adoption in a city, we ran specifications identical to those in Table III, but adding in leads of the Lojack variables to test whether the declines in auto theft precede the arrival of Lojack. There is no evidence of systematic patterns in auto theft rates in the three years preceding the arrival of Lojack. The signs on the leads of the Lojack variables flipped across specifications and were not statistically significant.

with respect to the auto theft arrest rate to be roughly −0.10, which implies that the increase in aggregate arrest rates can explain only a small fraction of the overall Lojack-related decline. Empirically, when we replicate the specifications in Table III using the auto theft arrest rate (defined as the number of auto theft arrests divided by the number of reported auto thefts) as the dependent variable, we obtain small, negative, and statistically insignificant coefficients on Lojack. These estimates are consistent with the argument that changes in the arrest rate are not the primary channel through which Lojack reduces auto theft.

However, if there is a subset of professional auto thieves who steal large numbers of vehicles with virtually no likelihood of being caught in the absence of Lojack, then the introduction of Lojack may have a dramatic impact on their activities. For example, a professional thief stealing 100 cars a year who has only a three-tenths of 1 percent chance of arrest per theft without Lojack, but a 10 percent chance of arrest when Lojack is installed, sees the annual chance of arrest increase from 26 percent to 45 percent. The incapacitation effect from this heightened chance of arrest is also substantial: prisoners surveyed in DiIulio and Piehl [1991] self-report committing a mean of 141 nondrug, serious crimes in the year prior to imprisonment. Sources cited in Clarke and Harris [1992] estimate that roughly 60 percent of vehicles are stolen with the intention of stripping, VIN-switching, or exporting. If much of this activity is done by professional thieves, a large fraction of our results can plausibly be explained through this channel.

The most important effect of Lojack, however, may not be its direct impact on the auto thief, but rather the disruption it creates for chop-shop operations. Without Lojack, it is extremely difficult to break such auto theft rings without expensive, time-consuming stings. By leading police directly to the site where cars are stripped, Lojack makes the detection of chop-shops routine.[22] The Lojack company reports that their product has led police to 53 chop-shops in the Los Angeles area, the only area for which complete data are available. Given the large number of vehicles processed by a typical auto theft ring, a small Lojack presence

22. One anecdote emphasizes this point in a particularly telling way. The FBI had been conducting a year-long sting operation and was finally on the verge of shutting down an auto theft ring that it had under observation. As FBI agents engaged in the stakeout watched, a single local police cruiser, following a Lojack signal, stumbled onto the chop-shop in question, leading to multiple arrests and the dissolution of the auto theft ring.

translates into a high likelihood that at least one Lojack-equipped vehicle will be encountered. For instance, assuming a 3 percent Lojack market share, if 50 cars are stripped annually, the likelihood that at least one of these cars has Lojack is 78 percent. If 100 cars are stripped, this value rises to 95 percent. As evidence that the threat Lojack poses to auto theft rings is real, in cities where Lojack has a presence, professional auto thieves drive stolen vehicles for no more than a few miles before temporarily abandoning them. They return to the spot later; if the stolen car is still there, they presume it does not have Lojack and only then proceed to the chop-shop.[23] Thus, even if Lojack does not lead to the dismantling of a given auto theft ring, it greatly increases the time costs and inconvenience of conducting such an operation.

One indirect piece of evidence supporting the argument that Lojack's primary impact is on professional thieves and chop-shops comes from allowing for nonlinearities in the impact of Lojack's market share. Figure III presents a plot of the curve traced out in a specification identical to that of column (3) of Table III, except that squared and cubic values of Lojack's market share are also included in the regression.[24] Over the range in which most of the available data lie (i.e., 0–2 percent Lojack penetration), the function is concave, implying sharply decreasing marginal returns to Lojack installation. The decline associated with the first percentage point of Lojack market share is two and a half times larger than that of the second percentage point, and seven times that of the third percentage point. While there is some hint of an upturn in the high penetration ranges, only Massachusetts has experienced such penetration levels, making inference based on this portion of the curve suspect. One interpretation of these sharply declining marginal returns is that those who are most affected by Lojack's presence, namely professional car thieves and chop-shops, alter their practices in response to relatively low concentrations of Lojack. Having changed their behavior (e.g., temporarily abandoning stolen vehicles in parking lots, substituting toward other crimes, or moving out of central cities), there is little crime-reduction benefit from higher concentrations of Lo-

23. The police, however, have responded to this practice by staking out some stolen Lojack-equipped vehicles rather than immediately recovering them. If the thief returns, he or she is trailed by undercover police.

24. The squared and cubic terms are jointly, but not individually, statistically significant at the .05 level (F-statistic = 3.25 with degrees of freedom equal to 2 in the numerator and 672 in the denominator). In regressions using years of Lojack in place of Lojack's share, the nonlinear terms are not statistically significant.

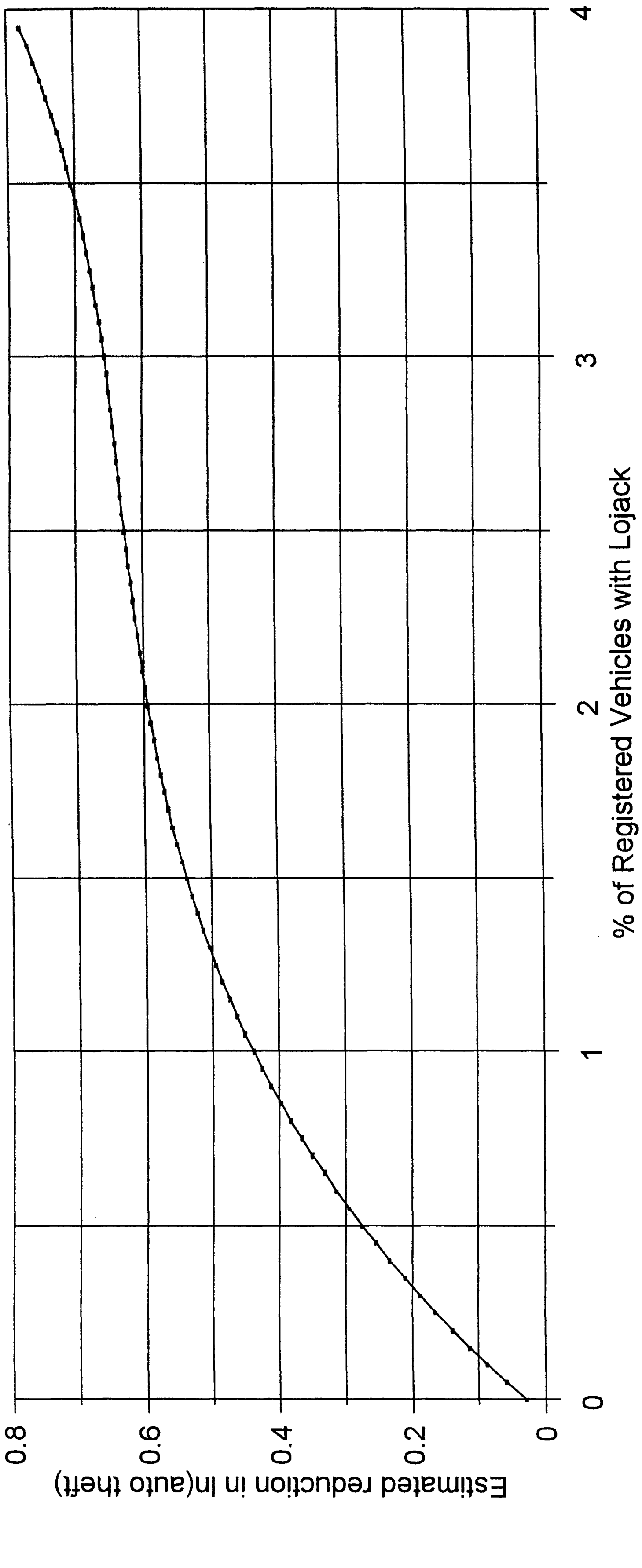

FIGURE III

Estimated Auto Theft Decline with Lojack Allowing for Nonlinearities jack. In contrast, one would expect the crime-reducing impact of Lojack market share on joyriders to be roughly linear (and, as argued above, of second-order importance).

A. Displacement

Assuming that the observed decline in central city auto theft is real, it is important to explore whether this reflects a true reduction in crime or is simply a displacement. It is possible that crime shifts either geographically or toward other criminal acts such as burglary or robbery.[25]

The first possibility we explore is that crime shifts geographically, falling in central cities and rising in other parts of the state. Table IV explores this hypothesis by replacing per capita *city* auto theft rates with the corresponding variable for the remainder of the state, excluding any cities with Lojack coverage and population over 250,000. Because the dependent variable in Table IV is defined at the state level, the covariates in the table are also state-level variables. Otherwise, the specifications in Table IV mirror those in Table III. Each year of Lojack availability is associated with 3–6 percent declines in rest-of-state auto theft rates, or roughly one-third that observed in central cities. The effect of Lojack market share is also negative and substantially smaller than that observed in central cities. The smaller magnitudes outside of central cities is consistent with Lojack installations being disproportionately concentrated in large cities where the auto theft threat is greatest, and with the fact that only 50 percent of the outlying areas in these states are actually covered by Lojack.

A more skeptical interpretation of Table IV is that the decline in auto theft outside of the central cities is evidence not of the effectiveness of Lojack (which is likely to be installed in relatively few cars), but rather of a spurious correlation between Lojack and declining auto theft rates that may also be tainting the central city estimates. Incorporating this perspective, a potential lower bound on the true effect of Lojack in central cities may be obtained by subtracting the estimates of Table IV from those of Table III, which would reduce the magnitudes of the coefficients by roughly 30 percent.

An alternative form of displacement is across crime catego-

25. Cornish and Clarke [1987] and Clarke and Harris [1992] survey studies that examine both types of displacement in auto theft.

TABLE IV
IMPACT OF LOJACK ON OUTLYING AREA AUTO THEFT RATES

Variable	(1)	(2)	(3)	(4)
Years of Lojack availability	−.041	−.058	—	—
	(.011)	(.019)		
Lojack share	—	—	−.056	−.173
			(.019)	(.059)
Unemployment rate	.000	.004	−.004	.006
	(.007)	(.009)	(.007)	(.009)
State real per capita income (×1000)	.004	.	−.002	.001
	(.016)	(.015)	(.015)	(.015)
% Black	−.0004	−.0005	−.0002	−.0004
	(.0003)	(.0003)	(.0003)	(.0003)
% Aged 0–17	.128	.134	.118	.126
	(.022)	(.026)	(.022)	(.026)
% Aged 18–24	.089	.086	.089	.076
	(.035)	(.036)	(.036)	(.038)
% Aged 25–44	.070	.083	.052	.082
	(.034)	(.034)	(.035)	(.035)
ln (police/per capita)	.136	.131	.123	.068
	(.113)	(.119)	(.112)	(.126)
Instrument w/yrs. since Lojack began regulatory process?	No	Yes	No	Yes
Adjusted R^2	.874	—	.907	—
Coefficient on Lojack excluding covariates from the specification	−.027	−.032	−.045	−.092
	(.009)	(.012)	(.019)	(.035)

Dependent variable is ln(reported auto theft per capita) for all areas in the state *except* central cities with population greater than 250,000 that are covered by Lojack by the year 1994. Data cover the period 1981–1994. Only states with at least one city with a population greater than 250,000 are included in the sample. Lojack share is the estimated percent of total vehicles registered that have Lojack installed in the market covered within this state. In columns (2) and (4) the number of years since Lojack began the regulatory approval process is used as an instrument for the Lojack proxy. Number of observations is equal to 403 in all columns. All columns include year dummies and state-fixed effects in addition to the variables shown. Unemployment, % Black, police, and age categories refer to the entire state, not just the outlying areas. White-standard errors are in parentheses. The bottom row of the table reports the Lojack coefficient from a specification with only year dummies and state-fixed effects as controls.

ries rather than across geographic areas. The economic model of crime [Becker 1968] predicts that rising punishments or reduced rewards for one crime will lead criminals to increase their involvement in substitutable crimes. If reductions in auto theft are accompanied by increases in burglaries and robberies—crimes that entail a much greater likelihood of injury to the victim than auto theft—then Lojack may be socially costly. On the other hand, there are numerous scenarios in which Lojack leads to reductions in other crimes. For instance, if stealing a car facilitates the commission of other crimes and Lojack impedes the acquisition of a vehicle, then fewer crimes of all kinds may occur. Similarly, if some criminals do not attribute the increased ability of police to fight auto theft to a specific technological advance, then a "halo deterrence" effect can emerge, with criminals mistakenly perceiving a general increase in police capabilities and consequently reducing all criminal activities. Finally, if Lojack allows the apprehension of professional criminals who are both generalists [Beck 1989] and otherwise difficult to catch, there may be incapacitation effects as well.

Table V presents estimated impacts of Lojack on crimes other than auto theft. These crimes are divided into two categories: "substitutable" and "nonsubstitutable." Substitutable crimes (burglary, larceny, robbery) are those whose primary motivation is financial; nonsubstitutable crimes (murder, rape, aggravated assault) are those where financial gain is generally not the primary motive. The specifications in Table V are identical to those of Table III, except that the dependent variable has changed.[26] The regressions suggest that Lojack has only a small impact on crimes other than auto theft. While the Lojack coefficients are consistently negative, the estimates are statistically different from zero at the .05 level in only one of eight cases. Even the largest coefficients are only about one-fourth of the magnitude of the estimates for auto theft, increasing our confidence that the observed decline in auto theft reflects real effects of Lojack. If the fall in other crimes was commensurate with that of auto theft, it would call into question the causal role of Lojack. While theory would predict a greater shift toward financially motivated crimes, there is little evidence of a differential effect of Lojack across substitutable and nonsubstitutable crimes.[27]

Another form of auto theft displacement is away from newer, expensive vehicles that are more likely to have Lojack toward older, cheaper models. While we do not have detailed Lojack penetration rates by make, aggregate data on Lojack installations shows that Mercedes and BMWs are, respectively, four times and two times as likely as the typical car to have Lojack. The fact that Lojack is installed almost exclusively in new vehicles allows us to test the degree of substitution toward older models by auto

26. Specifications utilizing two-stage least squares, omitted from Table V, are consistent with those presented.

27. Replicating the specifications in Table V, but replacing city nonauto theft crime rates with the equivalent crime rates from the rest of the state yielded an even mix of positive and negative coefficients on the Lojack variable, none of which were statistically significant.

TABLE V
IMPACT OF LOJACK ON CRIMES OTHER THAN AUTO THEFT

Variable	Substitutable crimes (robbery, burglary, larceny) (1)	(2)	Nonsubstitutable crimes (assault, rape, murder) (3)	(4)
Years of Lojack availability	−.015	—	−.005	—
	(.009)		(.006)	
Lojack share	—	−.059	—	−.015
		(.015)		(.016)
Unemployment rate	.024	025	−.022	−.022
	(.005)	(.004)	(.006)	(.006)
State real per capita income (×1000)	−.019	−.019	.003	.003
	(.009)	(.009)	(.010)	(.010)
% Black	−.005	−.004	−.001	−.001
	(.004)	(.004)	(.006)	(.006)
% Aged 0–17	−.065	−.064	−.015	−.016
	(.013)	(.013)	(.018)	(.018)
% Aged 18–24	−.037	−.041	−.019	−.020
	(.022)	(.022)	(.029)	(.029)
% Aged 25–44	.099	.102	−.012	−.012
	(.024)	(.024)	(.023)	(.022)
ln(sworn police per capita)	.077	.070	.398	.396
	(.064)	(.063)	(.090)	(.090)
Adjusted R^2	.819	.839	.928	.936
Coefficient on Lojack excluding covariates	.005	−.016	−.016	−.040
	(.006)	(.011)	(.005)	(.008)

Dependent variable is the natural log of the crime categories named. Substitutable crimes are those that are presumed to be close substitutes for auto theft, i.e., robbery, burglary, and larceny. Nonsubstitutable crimes are murder, rape, and aggravated assault. In both cases, the sum of the reported crime rates within the various crime categories is used. Data cover the period 1981–1994 and include all 57 U. S. central cities with a population greater than 250,000 in 1981. Number of observations varies between 742 and 767 based on the number of missing observations. All columns include year dummies and city-fixed effects in addition to the variables shown. Lojack share is the estimated percent of total vehicles registered that have Lojack installed in the market. Unemployment is the annual SMSA unemployment rate. % Black is linearly interpolated between decennial census years. Age categories refer to state age distributions; the omitted category is percent of the population over age 45. White-standard errors are in parentheses. The bottom row of the table presents estimates of the Lojack coefficient from specifications including only year dummies and city-fixed effects as covariates.

thieves. Annual data on the breakdown of motor vehicle thefts by city and model year were provided to us by the National Insurance Crime Bureau (NICB). The NICB database includes information on roughly 30 percent of vehicles stolen annually. The sample of vehicles included in the NICB figures are those for which member insurance companies voluntarily provided data. Consequently, these data are not representative of all auto thefts since many vehicles (particularly older ones) do not carry comprehensive auto insurance. These data are available only back to 1989.

Table VI presents simple tabulations of the raw data breaking down auto theft by vehicle age for the years 1989 and 1994 for the cities in our sample without Lojack and the cities that adopted Lojack by 1990 (the same cities included in Figures I and II).[28] Vehicles are assigned to one of three age categories: less than four years, four to six years, and more than six years old. Columns 1 and 2 compare non-Lojack and Lojack cities in 1989, at which time the percent of cars equipped with Lojack (denoted in the table by the number in brackets), even among new cars, was extremely low. The proportion of stolen vehicles in each category is nearly identical in non-Lojack and Lojack cities. Roughly 44 percent of the cars stolen in 1989 had been on the road for three years or less. Columns 3 and 4 present the same comparison for 1994. The fraction of new cars stolen declines sharply between 1989 and 1994 in both sets of cities due to a decline in the relative number of new cars on the road in the latter period.[29] The fall in the fraction of new vehicles stolen in Lojack cities, however, is almost five percentage points greater. This finding is consistent with the pattern of Lojack penetration: new vehicles are four times as likely to be equipped with Lojack as vehicles that are four to six years old. Vehicles older than this are very unlikely to have Lojack. A two-tailed test of the equality of means for the 1994 fraction of stolen vehicles less than four years old in Lojack and non-Lojack cities rejects equality at the .10 level. Regression estimates of the impact of Lojack market share on the fraction of stolen vehicles less than four years old (not shown in tabular form) confirm the patterns in Table VI. Using data for the period 1989–1994, we ran a range of specifications (with and without year dummies, city-fixed effects, demographic covariates, and instrumenting using years elapsed since Lojack initiated the regulatory approval process). In ten of twelve cases the coefficient on Lojack market share was negative and statistically significant. In the other two cases, the point estimate was positive, but statistically insignificant.

28. Miami is excluded from this analysis because of wild inconsistencies between NICB and UCR data. The NICB data, which matched closely with UCR data for all other cities, implied three times as many auto thefts in Miami as did the UCR data. When Miami is included in the following analysis, similar trends are observed, but the magnitude of the effect is diminished.

29. According to *National Vehicle Population Profile,* published on compact disc by the Polk company, in 1989 30.6 percent of cars on the road had been built in the last three years. By 1994 this fraction had fallen to 17.7 percent.

TABLE VI
FRACTION OF STOLEN VEHICLES BY VEHICLE AGE NON-LOJACK VERSUS LOJACK CITIES

	1989		1994	
Vehicle age	Non-Lojack cities	Cities with Lojack by 1990	Non-Lojack cities	Cities with Lojack by 1990
Three or fewer years	44.3	44.6	28.5	23.9
	(1.4)	(1.3)	(1.4)	(2.3)
	[0.0]	[0.63]	[0.0]	[5.60]
Four to six years	29.5	28.7	26.9	28.3
	(0.7)	(1.5)	(0.6)	(1.0)
	[0.0]	[0.0]	[0.0]	[1.66]
Seven or more years	26.2	26.8	44.6	47.8
	(1.4)	(1.2)	(1.6)	(2.8)
	[0.0]	[0.0]	[0.0]	[0.02]
Total	100.0	100.0	100.0	100.0

Data on ages of stolen vehicles were provided by the National Insurance Crime Bureau (NICB) and represent roughly 30 percent of the stolen vehicles. Cities with Lojack coverage by 1990 are Boston, Newark, Los Angeles, Long Beach, and Chicago. Data for Miami are not included due to apparent inconsistencies between the *Uniform Crime Report* data used throughout the paper and NICB data used in computing this table. Breakdowns by vehicle age are not available prior to 1989. Numbers reported in the table are the means across cities in the percentage of all vehicles stolen in the named year that fall within a given age category. The standard error of the mean is reported in parentheses. The mean Lojack market share among cars of a given age category is reported in brackets.

B. Robustness

Table VII presents a range of additional specifications as a means of assessing the sensitivity of our results to alternative sets of assumptions. The four columns in Table VII correspond to city auto theft rates, outlying auto theft rates, substitutable crimes in cities, and nonsubstitutable crimes in cities. Rows in Table VII represent different specifications. Each cell entry, therefore, is the regression coefficient on years of Lojack availability from a separate regression. The pattern of estimates using Lojack's market share, rather than years of Lojack, is similar in all instances. The regressions include the full set of covariates from earlier tables. Full regression results are available on request from the authors.

The first row of Table VII simply replicates results from Tables III–V to provide a baseline for evaluating the alternative specifications. The second row of Table VII adds region-year interactions to the basic specification to control for any region-specific shifts in crime. Adding region-year interactions has little effect on the auto theft point estimates. The coefficients on other

TABLE VII
SENSITIVITY OF LOJACK COEFFICIENTS TO ALTERNATIVE SPECIFICATIONS

	Coefficient on years of Lojack for:			
Specification	Central city auto theft	Rest of state auto theft	Substitutable crimes	Nonsubstitutable crimes (from earlier tables)
Baseline (from earlier tables)	−.109	−.041	−.015	−.005
	(.013)	(.011)	(.009)	(.006)
Region-year interactions	−.100	−.044	.013	−.009
	(.013)	(.014)	(.007)	(.008)
City-trends	−.065	−.073	−.022	−.031
	(.017)	(.032)	(.009)	(.014)
Only cities with population greater than 500,000	−.149	−.042	−.030	.008
	(.012)	(.014)	(.009)	(.008)
Only cities with above average auto theft in 1985	−.077	−.049	−.003	.013
	(.021)	(.014)	(.011)	(.008)
Include once- and twice-lagged dependent variable as regressor	−.031	−.024	−.004	−.001
	(.009)	(.013)	(.004)	(.005)
Instrument for police per capita using mayoral and gubernatorial elections	−.158	−.049	−.020	−.012
	(.026)	(.029)	(.014)	(.021)
Excluding Boston from sample	−.077	−.037	.008	−.003
	(.015)	(.020)	(.009)	(.009)
Excluding Newark from sample	−.112	−.038	−.018	−.001
	(.014)	(.011)	(.008)	(.007)

All table entries are coefficients on years of Lojack availability in a market from separate regressions. The dependent variable in each case corresponds to that listed in the column heading. In all cases, the full set of covariates listed in previous tables is employed in addition to the listed changes in specification. The first row of values represents baseline estimates from previous tables for comparison purposes.

crimes remain statistically insignificant. The third row adds city-specific trends to take into account that cities may systematically differ not only in the level of crime (which city-fixed effects control for), but also in the rate of change. Including trends reduces the estimated impact of Lojack on city auto theft, but makes the estimates more negative for the other three crime classifications. Auto theft falls more in outlying areas than in central cities in this specification, the only instance where this is the case among all the estimates presented in this paper.

Rows 4 and 5 limit the sample such that the group of control cities more closely matches the characteristics of cities that actually adopted Lojack, which tend to be larger and have higher rates of auto theft. Restricting the sample to the 28 cities with greater than 500,000 in population, or those with above average auto theft in 1985 (the year before Lojack was first introduced) does not substantively change the conclusions. Although the coefficient in row 6, which allows for an autoregressive component in motor vehicle theft, is smaller than those in the other rows, it is important to recognize that it is not directly comparable. When lagged dependent variables are included in the specification, the Lojack variable captures only the direct effect of Lojack on auto theft, missing the dynamic feedback effects operating through the lags of the dependent variable.[30] When the full impact of Lojack is calculated over a five-year period, the implied decrease in auto theft due to Lojack in row 6 is roughly two-thirds as large as the magnitude in the base specification.

In the seventh row we instrument for the police variable using the timing of mayoral and gubernatorial election years. Levitt [1997] demonstrates that police hiring is disproportionately concentrated in election years, and argues that the exclusion of elections from the second-stage regression seems plausible. Instrumenting for police once again leads to more negative Lojack coefficients on auto theft. The elasticity of crime with respect to police, which is small and positive in most of the OLS specifications, ranges between −.20 and −.58 in the instrumented regressions. While large standard errors make the police coefficients statistically insignificant, the magnitude of the estimates is similar to those obtained in Levitt [1997].

The final two rows of Table VII are estimates of the basic specification eliminating, respectively, Boston and Newark, the two cities that have experienced the greatest auto theft declines after Lojack's introduction. Dropping those cities has only a small impact on the point estimates.

V. Analyzing the Private and Social Costs and Benefits of Lojack

The preceding analysis suggests that increases in Lojack market penetration are associated with large declines in city auto theft rates and smaller percentage declines in outlying area auto theft rates, with little apparent impact on other types of crime. In this section the social welfare implications of Lojack are exam-

30. The coefficient on once- and twice-lagged auto theft in column 1 of Row 6 are .708 (standard error equal to .137) and −.005 (standard error equal to −.112), respectively.

ined, paying special attention to differentiating between direct benefits to those who install Lojack (or their insurers) and externalities associated with auto theft reductions. Our cost-benefit analysis is admittedly incomplete. Omitted from our calculations is any consideration of criminals' welfare, increases in the price of used auto parts, or diversion of auto theft across state lines, all of which will exaggerate the apparent social benefit of Lojack. On the other hand, we also ignore the reduction in expenditure on other forms of victim precaution (as well as the reduction in negative externalities associated with observable victim precaution), and the fact that substitution toward older, cheaper vehicles will reduce the average loss per theft, both of which lead us to understate the benefits of Lojack.

As our benchmark for determining social benefits, we use the characteristics of the six large cities that Lojack has served for at least five years, evaluated at the city mean in the fifth year of coverage. In all cases we base our estimates on the coefficients from the uninstrumented regression using Lojack's market share (i.e., column (3) of Table III). These estimates imply smaller effects than the 2SLS estimates or the coefficients on years of Lojack availability and thus provide more conservative conclusions with respect to the social benefits of Lojack. We begin by analyzing the direct benefits to Lojack owners and their insurers and then proceed to calculate the externalities associated with Lojack's general deterrence effect.

Three factors are critical in determining the direct benefits of Lojack to those car owners who install it: the value of the vehicle, the auto theft rate, and the presence or absence of comprehensive auto insurance. While the first two factors have an obvious and direct impact on the calculations, the role of comprehensive auto insurance is less straightforward. The comprehensive portion of auto insurance covers theft, vandalism, and fire damage.[31] Car owners are not required to carry such coverage if they own their vehicles outright, but it is commonly required for vehicles that are financed. Standard deductibles range from \$100 to \$500. If a car owner does not choose to have comprehensive insurance, all of the direct benefits of higher Lojack retrieval rates accrue to the car owner. However, if a car owner has comprehensive insurance, Lojack provides little direct financial benefit except for insurance

31. Much of the information that follows regarding comprehensive insurance is drawn from the Insurance News Network's web page and links available on the internet at http:\\www.insure.com.

premium discounts since recovered vehicles will typically sustain damage greater than the deductible. Thus, with comprehensive insurance, it is the insurer rather than the insured who reaps the direct benefits of Lojack.

We examine first the case of a car owner who does not have comprehensive insurance coverage. The mean loss per stolen vehicle for cars not equipped with Lojack, based on self-reported losses in the National Crime Victimization Survey, is roughly $4000 per vehicle [Cohen 1988]. According to company estimates, vehicles equipped with Lojack sustain slightly less than $1000 worth of damage on average.[32] The mean auto theft rate per capita in the baseline cities is 0.025.[33] With roughly one vehicle per every two people, this implies a theft rate per vehicle of 0.05 annually. Assuming that Lojack cars are stolen at the same rate as non-Lojack cars, uninsured Lojack-installed vehicle owners receive an expected benefit of $150 per vehicle per year in reduced auto theft losses from Lojack installation. This figure will, of course, depend crucially on the value of the car being protected from theft loss. Given that Lojack entails a one-time $600 fee, whether Lojack is worth installing for a given car owner depends also on the discount rate, the length of time that the vehicle will be owned, and the increment to resale value associated with having Lojack. As a benchmark, amortizing the initial cost over a ten-year period at 10 percent interest rate yields a yearly Lojack cost of approximately $97.[34]

With comprehensive insurance coverage, the Lojack owner

32. This estimate of the mean loss for Lojack vehicles appears to be reasonable. Approximately 60 percent of non-Lojack-equipped stolen vehicles are recovered according to the National Insurance Crime Bureau. Cohen's estimates of the loss per vehicle does not separately distinguish losses to vehicles recovered and those not found. Assuming an average of $750 in damages for the typical recovered vehicle, this implies a $9000 loss for vehicles that are never recovered. Because Lojack-equipped vehicles are found more quickly, they tend to sustain less damage. Assuming a value of $500 in losses for vehicles recovered by Lojack and applying a $9000 value to the 5 percent of Lojack-equipped vehicles that are never recovered, yields an average loss of $925 with Lojack.

33. This value is roughly 60 percent above the average for large cities in the sample during the 1990s since Lojack tends to enter high auto theft cities. It is twice as high as the overall sample average due both to the cities Lojack chooses and to large increases in auto theft during the 1980s. As a consequence, the scenario outlined here provides larger estimates of the benefits of Lojack than would be obtained using the sample mean as the benchmark.

34. The consumer's price is likely to overstate the true marginal social cost for two reasons. First, some fraction of that price accrues as profit to Lojack shareholders. Second, that price is likely to reflect an average rather than a marginal cost and thus also reflects the fixed costs of establishing Lojack in a market and providing the physical equipment required to make the system operational.

weighs the cost of installation against the value of the available insurance discounts.[35] The real value of these discounts varies widely as a consequence of differences in comprehensive insurance premiums and state regulations concerning discounts. The mean annual comprehensive insurance premium for automobiles in the United States is roughly $100, although this number varies dramatically by geographic location and vehicle type. In high-theft urban areas, comprehensive insurance is much more expensive. For instance, these costs are almost ten times higher in sections of the Bronx and three times higher on average in Miami. Insurance premium discounts for Lojack also vary widely. In Massachusetts, for instance, state law mandates a 20–35 percent reduction in comprehensive insurance premiums for vehicles with Lojack installed, depending on what antitheft devices are also present in the vehicle. In most other states, insurance discounts are capped at 20 percent. In some states, discounts are at the discretion of the insurer rather than mandatory. Back-of-the envelope calculations suggest that insurance discounts are well below the cost of Lojack installation for most vehicle owners. Even in Boston, which offers the most generous discounts, the dollar value of such discounts is likely to be only $70 per year for the typical car. In Miami and Los Angeles the discount for Lojack is typically no more than 10 percent, yielding an average benefit of $30. These estimates suggest that insurance companies capture most of the benefit of Lojack, calculated as $150 per vehicle per year above.

Given these results, it is not surprising that insurance companies have been very supportive of Lojack. It is common for insurers to donate the funds necessary for equipping police cruisers with Lojack detection devices. In Massachusetts insurers lobbied the state insurance board to increase the comprehensive insurance deduction for Lojack from a maximum of 20 percent to 35 percent. In South America insurance companies have even gone a step farther, purchasing Lojack directly and installing it into customer vehicles free of charge. Half of all Lojack units installed in Colombia were purchased by insurance companies. It is surprising, however, that in areas of the United States where discounts are discretionary, competition has not led insurers to offer larger discounts.

35. The damage sustained by a recovered stolen vehicle almost always exceeds the deductible on most comprehensive insurance policies. We ignore the psychic benefits of vehicle recovery via Lojack, which may also be substantial.

While higher retrieval rates provide direct benefits to those who install Lojack, installing an individual Lojack will have no practical impact on the likelihood that the protected car will be stolen. The impact of aggregate Lojack installations on a city's auto theft rates is consequently purely external to a car owner's individual decision whether to purchase Lojack.[36] Assuming that Lojack installation rates are three times greater in cities than in the market as a whole, a one percentage point increase in Lojack for the market as a whole corresponds to a three percentage point increase in Lojack installation in the central city. Using a baseline auto theft rate of 0.05 per vehicle per year and a regression coefficient of $-.24$, that three percentage point increase in Lojack is associated with roughly a one percentage point decrease ($.05 * -.24$) in the auto theft risk. Put another way, one auto theft is eliminated each year for every three Lojacks.[37] Using a loss per stolen vehicle of $4000 from Cohen [1988], each Lojack yields an annual externality of over $1300. Note that this externality is almost ten times the magnitude of the direct benefit to the owner/insurer from Lojack installation.

Combining the direct benefits of Lojack with the externality associated with reduced auto theft yields an estimated social benefit from each marginal unit of Lojack of roughly $1500 per year. In comparison, an upper bound on the social cost of a marginal unit of Lojack is the consumer's one-time outlay of $600, which discounted over the life of a vehicle, equates to roughly $97 per year. The marginal social benefit of Lojack, at least historically, appears to be fifteen times greater than the marginal social cost.

VI. Conclusions

Lojack is a real-world example of an unobservable victim precaution measure that yields positive externalities. Increases in the fraction of Lojack-equipped vehicles are associated with substantial declines in auto theft, without any evidence of in-

36. Large insurers are able to internalize a fraction of the auto theft reduction externality consistent with their market share, making the failure of insurers to offer greater premium discounts to those installing Lojack even more puzzling.

37. If there are decreasing returns as in Figure III, the reduction in auto theft will be sensitive to the amount of Lojack that is present. The estimate we use here (from the linear specification) corresponds roughly to the marginal effect assuming a starting Lojack concentration of 0.5 percent in Figure III. At higher (lower) starting concentrations, the marginal benefit would be reduced (increased).

creases in other crime categories. From the perspective of the car owner who installs Lojack, this auto theft decline is a pure externality. Because Lojack is unobservable, auto theft rates are affected by thieves' perceptions about the mean Lojack installation rate, which are only imperceptibly affected by a given car owner's choice. Combining this externality with the direct benefit of an increased likelihood of successful vehicle recovery for those with Lojack, the estimated marginal social benefit of Lojack installation has been roughly fifteen times greater than the marginal social cost. Lojack appears to be one of the most cost-effective crime reduction approaches documented in the literature, providing a greater return than increased police, prisons, jobs programs, or early educational interventions [Donohue and Siegelman 1996]. The car owner who installs Lojack internalizes only 10 percent of the total social benefit, however, implying that Lojack will be undersupplied by the free market. The current system of insurance premium discounts is far less generous than the apparent social optimum.

An important consideration is the extent to which the estimates of this paper can be generalized. Lojack tends to enter markets with high auto theft rates. Extrapolating to other markets with lower initial levels of crime, we would predict smaller, but not categorically different benefit-cost ratios. It is more difficult to extrapolate from our results to a determination of the optimal level of Lojack penetration within markets. If criminals did not engage in behavior designed to offset Lojack, it would appear that auto theft could be all but eradicated with Lojack penetration rates of 10–20 percent. It is clear, however, that Lojack affects criminal behavior, even at low penetration rates.[38] The apparent presence of decreasing marginal returns to Lojack in Figure III is consistent with the argument that low levels of Lojack penetration are sufficient to provide a costly disruption of operations for professional thieves. From the perspective of social welfare, expansion of the geographical coverage of Lojack at relatively low levels of vehicle installation is likely to be preferable to large increases in Lojack penetration rates in existing markets.

The magnitude of the externalities associated with Lojack points to the importance of conducting parallel research on other

38. One would also expect that thieves would engage in heightened technology development designed to thwart Lojack.

types of self-protection which, unlike Lojack, are observable to criminals and therefore carry negative externalities. In the extreme case of perfect substitutability across targets, such self-protection actions may represent pure deadweight loss.

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