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

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Measuring Positive Externalities from Unobservable Victim Precaution: An Empirical Analysis of Lojack

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Abstract

Private expenditures on crime reduction have potentially important externalities. Observable measures such as barbed-wire fences and deadbolt locks may shift crime to those who are unprotected, imposing a negative externality. Unobservable actions, on the other hand, provide positive externalities since criminals cannot determine a priori who is protected. Focusing on one specific form of victim precaution, Lojack, we provide the first thorough empirical analysis of the magnitude of such externalities. Because vehicles equipped with Lojack are not identifiable to criminals, any decrease in crime rates associated with Lojack is an externality from the perspective of the Lojack purchaser. We find that Lojack has large crime-reducing effects. Each one-percentage point increase in the Lojack installation rate in a market is associated with a 20 percent decline in auto theft rates in large cities and a 5 percent decline in the rest of the state. Rates of other crimes do not change appreciably. Our estimates suggest that the marginal social benefit of an additional unit of Lojack is 15 times greater than the marginal social cost. Those who install Lojack in their cars, however, obtain less ten percent of the total social benefits of Lojack, causing Lojack to be dramatically undersupplied by the free market. Current insurance subsidies for the installation of Lojack appear to be well below the socially optimal level.

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The growth in resources devoted to the criminal justice system in recent years is well documented. Prison populations have more than tripled in the last two decades, with roughly 1.5 million Americans now behind bars at any one time. Total government spending on criminal justice in 1995 is almost $100 billion dollars. Often overlooked, however, is the fact that private expenditures on self-protection dwarf public spending.[1] Sources cited in Philipson and Posner (1986), for instance, estimates that private expenditures to reduce crime are $300 billion annually. Laband and Sophocleus (1992) come to a similar conclusion. The opportunity cost associated with crime-related changes in behavior (e.g. avoiding Central Park after dark or moving to the suburbs), while difficult to measure, are also likely to be substantial.

Understanding the impact of private efforts taken to avoid criminal victimization are important not only because of their 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. Those who engage in observable self-protection impose a cost on those who do not. In contrast, other forms of precaution such as silent alarms and passive disabling devices in automobiles may provide positive rather than negative externalities. Criminals, unable to observe whether any particular potential victim has engaged in observable precaution, must rely in part on perceptions about the mean level of such precautions in the community.

The first formal treatment of externalities associated with victim precaution dates to

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[1] Victim precaution expenditures also appear to be growing at a faster rate 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.

Clotfelter (1976). 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 non-existent.[2] Some studies of gun ownership and right-to-carry laws (Kleck 1988, Duggan 1996, Lott and Mustard 1996) find a reduction in crime, but 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 radio transmitter is hidden inside a vehicle. When a car is reported stolen, the police remotely activate the transmitter, allowing the stolen vehicle's location and movements to be tracked. 95 percent of stolen vehicles equipped with Lojack are recovered, compared to roughly 60 percent of stolen vehicles as a whole. We estimate the mean loss per auto theft to be under $1,000 for cars with Lojack versus roughly $4,000 for non-Lojack cars (Cohen 1988).

From an economic perspective, what makes Lojack most interesting is that there is no indication anywhere on a Lojack-equipped vehicle that Lojack is installed.[3] To the extent that

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[2] Crime-shifting in response to changes in the level of public law enforcement is somewhat better documented. Mayhew et al. (1976) finds 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.

[3] Lojack executives report that law enforcement agencies condition their acceptance of the Lojack technology on the product being unidentified and some states, such as Massachusetts, prohibit identifying the presence of Lojack (for example, by a decal) by law. 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

Lojack has any impact in reducing auto-theft rates, such reductions are purely an externality from the perspective of the car owner installing Lojack. Because Lojack is unobservable, auto theft rates are affected by thieves' perceptions of the mean Lojack installation rates, which are only trivially affected by a given car owner's choice. Installing Lojack thus will not prevent a car from being stolen, but rather will only aid in the retrieval of the vehicle once stolen.

There are many reasons to believe that the presence of Lojack will make auto theft riskier and less profitable, leading to a reduction in the number of such crimes. First, Lojack disrupts the operation of "chop-shops" where stolen vehicles are dissembled for resale of parts.[4] Police following a Lojack signal can be lead directly to the chop-shop. Second, data collected in California suggest that the likelihood that a stolen vehicle leads to at least one arrest is two to three times greater when it is equipped with Lojack. Since most thieves are repeat offenders (Visher 1986, DiIulio and Piehl 1993), arrests that lead to incarceration may also provide social benefits via reductions in victimizations while the criminal is behind bars.

As the arguments of the preceding paragraph would suggest, the presence of Lojack in a market is associated with substantial declines in auto theft rates. According to our estimates, each additional percentage point of vehicles equipped with Lojack is associated with a 20 percent decline in auto theft rates. Moreover, there is no evidence that crime is being redistributed to outlying areas in the state (many of which are also covered by Lojack, but at a lower penetration

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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.

[4] The National Insurance Crime Bureau reports that the total value of a car stripped for parts is two to four times greater than the price that can be obtained in the market for intact stolen vehicles. Thirty-one percent of stolen vehicles that are recovered have been stripped.

rate): auto theft also falls roughly 5 percent with each one percentage point increase in Lojack installations in the market. Nor is there evidence that the rates of other crimes increase in response to Lojack as a result of criminals substituting away from auto theft.

There are two potential sources of endogeneity between Lojack's market share and crime rates which are addressed in the analysis. First, vehicle owners are more likely to install Lojack the higher is the perceived current and future threat of auto theft. Thus, Lojack market shares may be greater in areas where auto theft is increasing. To eliminate this source of endogeneity, we instrument for Lojack's market share using the number of years that Lojack has been available in a particular market. Because Lojack is installed almost exclusively in new vehicles, its market share of registered vehicles increases over time, providing a good first-stage fit. As would be expected given this source of endogeneity, the instrumental-variables estimates are greater in magnitude than the OLS estimates. A second endogeneity story is that Lojack is more likely to obtain regulatory approval in areas that are getting serious about reducing auto theft. Thus, auto theft rates may tend to fall with the arrival of Lojack without the relationship being causal. To test this hypothesis, we instrument for the Lojack market share using the number of years since Lojack first began to seek regulatory approval in a market, thus avoiding any sample selection induced by the regulatory process.[5] Counter to the predictions of this line of argument,

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[5] A third possible source of endogeneity is sample selection in the set of cities that Lojack attempts to enter. However, 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 subside -- 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 effects the auto theft rate).

the IV estimates are once again greater in magnitude than the OLS estimates.

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 ten 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 I presents a brief overview of the theory concerning the private provision of victim precaution. 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 provides a rough accounting of the private and social costs and benefits of Lojack.

I: Theory of Victim Precaution

The theoretical aspects of victim precaution are well understood as a result of previous work examining the topic (Clotfelter 1978, Friedman 1984, Cook 1986, Shavell 1991, De Meza and Gould 1992, Hui-Wen and Png 1994, and Ben-Shahar and Harel 1995). In this section, we motivate our empirical analysis with a very simple theoretical model, focusing on the distinction between observable and unobservable victim precaution; readers interested in a more thorough treatment are directed to the works cited above.

Observable victim precaution

Assume first that all private actions taken by potential victims are observable to criminals. Examples of such actions include deadbolt locks, fences, and security alarms accompanied by signs and warnings.[6]

To the extent that such self-protection devices are successful, the costs associated with victimizing a protected person rises, making him or her a less attractive target. These measures, however, carry a negative externality: some of the crime is displaced onto those who do not invest in self protection and consequently appear relatively more attractive to criminals. In mathematical terms, let V_i represent the victimization costs of potential victim i where

$$V_i = V_i(P_i, P_j, \ldots, P_N) \tag{1}$$

P_i is the level of precaution taken by individual i. It is assumed that:

$$\frac{\partial V_i}{\partial P_i}<0,\ \frac{\partial V_i}{\partial P_j}>0,\ \frac{\partial^2 V_i}{\partial P_i^2}<0,\ and\ \frac{\partial^2 V_i}{\partial P_j^2}>0. \tag{2}$$

Observable victim precaution efforts reduce own-victimization, but increase the victimization of

[6] The potential for false claims about protective actions, e.g. posting a "Beware of Dog" sign when no dog is present, raises another set of interesting questions that are beyond the scope of this paper.

others.[7] The observability of self-protective actions is critical in making the derivative of V_i with respect to P_j negative, because criminals observing j's precaution are more likely to steal from i. The second-order conditions ensure interior solutions.

Victim precaution effort entails a cost C which can be monetary or non-monetary (e.g. lifestyle changes), where

$$C_i = C_i(P_i) \tag{3}$$

with

$$\frac{\partial C_i}{\partial P_i} > 0 \;\; and \;\; \frac{\partial C_i^2}{\partial^2 P_i} > 0. \tag{4}$$

An individual optimizes his or her personal level of self-protection by choosing P_i such that

$$\frac{\partial V_i}{\partial P_i} + \frac{\partial C_i}{\partial P_i} = 0 \tag{5}$$

i.e., the marginal private benefit of the last unit of self-protection exactly offsets the cost.

From the perspective of social welfare, however, the level of self-protection chosen is too

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[7] Shavell (1991) notes that observable self-protection may also have a general deterrent effect. If, for instance, 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, the magnitude of this deterrent effect is likely to be outweighed by the negative externality associated with crime displacement.

high.[8] Assuming that there are N identical potential victims, social welfare W is given by

$$W = -\sum_{i=1}^{N} V_i(P_i,P_j,...,P_N) - \sum_{i=1}^{N} C_i(P_i) \tag{6}$$

Optimizing social welfare with respect to P_i yields the first-order condition

$$\frac{\partial V_i}{\partial P_i} + (N-1)\frac{\partial V_j}{\partial P_i} + \frac{\partial C_i}{\partial P_i} = 0 \tag{7}$$

Since increases in person i's self-protection increases person j's victimization, the individually optimal level of self-protection exceeds the social optimum.

Unobservable victim precaution

The social welfare implications of self-protection change markedly when such actions are not observable to criminals. Examples of such actions include Lojack and carrying concealed weapons. Since the criminal cannot observe the protection level of a potential victim, conclusions about the likely payoffs to crime must be based on the criminal's estimates of self-protection in the population as a whole or by type of victim (e.g. criminals may think that women are less likely to carry guns than men). As a consequence, unobservable self-protection efforts exert a positive rather than negative externality on other victims.

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[8] The social welfare function optimized here excludes the welfare of the criminal. Including the criminal's utility exacerbates the externalities discussed here.

For a simple, stylized treatment, we assume that self-protection only reduces the likelihood of victimization. However, it is certainly the case with Lojack (where retrieval rates of stolen vehicles are much higher when the system is installed and damages per retrieved vehicle are lower) that self-protection may also reduce the costs when one is a victim of crime.

In the simplest case, assume that victimization costs are no longer based on own self-protection, but rather only on the population mean. Therefore, victimization costs in equation 1 above are replaced by

$$V_i(\bar{P}) = V_i(\frac{1}{N}\sum_{i=1}^{N} P_i) \qquad \textbf{(8)}$$

where $\bar{P}$ is the population mean of self-protection. An optimizing individual sets

$$\frac{1}{N}\frac{\partial V_i}{\partial P_i} + \frac{\partial C_i}{\partial P_i} = 0 \qquad \textbf{(9)}$$

Comparing equations 5 and 9, when self-protection is not observable, less self-protection effort is exerted since the full deterrence benefits are not internalized. As N becomes arbitrarily large, the amount of observable self-protection chosen by individuals goes to zero -- because an individual's choice of self-protection only trivially increases the mean level of protection.[9]

On the other hand, the social welfare maximizing level of self-protection:

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[9]When unobservable self-protection reduces the expected loss per crime, individuals may continue to demand positive, but still socially sub-optimal, amounts.

$$\frac{\partial V_i}{\partial P_i} + \frac{\partial C_i}{\partial P_i} = 0 \qquad (10)$$

is not only greater than the level provided by the individual (comparing equations 9 and 10), but also is greater than the social welfare maximizing amount of victim precaution when such precaution is observable (comparing equations 7 and 10). Unobservability increases the socially optimal amount of self-protection, but reduces the amount that individuals demand.

Thus, there is a clear under provision of unobservable victim precaution. Furthermore, when both observable and unobservable actions are available, individuals will inefficiently overinvest in the observable actions. Similarly, if there is a means of making unobservable actions observable, even at some cost to the individual, then there will be too much effort devoted to such signaling.[10]

Section II: Background on Lojack and Data Sources

Lojack is a radio transmitter-based motor vehicle retrieval system. A small transmitter is hidden in one of 25 possible locations within a car. When the vehicle 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. The Lojack company reports that 95 percent of stolen cars and trucks equipped with Lojack are recovered, compared to 60

[10]In the absence of market interventions, it is uncertain whether a prohibition on making actions observable (e.g. punishment for posting signs advising that a warning system is installed) raises or lowers social welfare. Total protection falls with such a prohibition, but all potential victims benefit from the protection that is undertaken.

percent of stolen cars overall. Over 95 percent of 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.

Nowhere on the vehicle is there any indication that the car is equipped with Lojack.[11] Thus, Lojack is a prototypical example of the positive externality-generating unobservable self-protection.[12] In addition to the general deterrence effect identified in the preceding section, Lojack also offers other potential sources of positive externalities. First, stolen Lojack-equipped vehicles lead to successful arrests in over 20 percent of cases, compared to 10 percent for non-Lojack cars. Since many criminals are frequent offenders (Visher 1986, DiIulio and Piehl 1992), an arrest and conviction that leads to incarceration of a criminal is likely to reduce the overall crime rate due to incapacitation effects. Second, Lojack aids in breaking up "chop-shop" operations; police tracking Lojack signals are sometimes led directly to the location where cars are stripped. Finally, because Lojack does not require visual contact, it eliminates the need for high-speed chases. In 1993, 238 fatal accidents resulted from high-speed chases with police in pursuit according to data from the Fatal Accident Reporting System.

Approval for entry into a market by Lojack requires the cooperation of the state police

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[11] In some markets, Lojack is bundled with an observable alarm. The alarm is generic in appearance, however, and thus does not provide a strong signal of Lojack's presence. The criminal may be able to make finer distinctions about the likelihood a particular car is equipped with Lojack. For instance, Lojack is almost exclusively installed in new cars. When Lojack enters a market, it is very unlikely that older cars will be equipped with Lojack, leading car thieves to divert their efforts away from new models. The empirical results that follow suggest that any diversion is small relative to the general deterrence effect.

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

organization, the state Attorney General, and local police departments. Time elapsed in waiting for approval into markets ranges historically from 14 weeks to 7 ½ years. A full list of markets covered by Lojack as of December 1994 and dates of entry into those markets is presented in Table 1.[13] Lojack was first introduced in Massachusetts in 1986, and Massachusetts remains Lojack's strongest market today.[14] Lojack was subsequently introduced to South Florida in 1988 and three additional markets in 1990. As of December 1994, Lojack served 12 markets. Lojack is the only product for the remote tracking of stolen vehicles currently on the market.[15]

The percentage of cars equipped with Lojack differs tremendously 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 ten 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

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

[14] 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 anti-theft 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.

[15]Satellite tracking services are of little use for tracking stolen cars because they are not effective if the line-of-sight is broken (say, by a garage roof) and because the observable satellite equipment is easily disabled.

percent of registered vehicles.[16]

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. 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 population greater than 250,000, although we do also provide some 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 100,000.

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 includes 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.[17]

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[16] 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.

[17]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 to only 53 percent of burglaries, 51 percent of robberies, and 27 percent of larcenies (Bureau of Justice Statistics 1994).

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 is data on the age distribution of the population. The percent of a city's residents that 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 2, 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, have a greater fraction of black residents, and have not only higher auto theft rates, but 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.

Section III: Empirical Estimates of the Impact of Lojack

Figure 1 presents per capita auto theft rates over the period 1980-1994 for the 6 cities with population over 250,000 in markets Lojack entered before or during 1990.[18] Mean auto

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[18] 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.

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, in Figure 1a, has experienced a 50 percent decline in auto theft rates 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 (-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. There is little apparent impact of Lojack in Chicago where Lojack market shares are extremely low -- less than one-tenth as large as Boston. The low penetration rates in Chicago are at least partly attributable to the fact that Illinois law prohibits insurance companies from giving Lojack discounts.

Figure 2 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 six years prior to the entry of Lojack as a baseline. Since Lojack enters cities at different times, the horizontal access is years pre- or post-Lojack entry, e.g. year 0 is 1986 for Boston and 1990 for Los Angeles. For the non-Lojack city control group, a simple average of changes in auto theft rates for all non-Lojack cities for the relevant years is presented. In the years preceding Lojack's arrival, the cities that will be served by Lojack experience 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 higher than average auto theft rates at the time 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. The fact that auto theft rates continued to grow at a faster rate in these cities just prior to the arrival of Lojack contradicts a simple mean reversion argument. 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 use estimates as our measure of Lojack penetration the fraction of total car registrations in a market equipped with Lojack in a given year. 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.[19] One shortcoming of this measure is that it is 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 penetration rates are greater in these cities than in outlying areas, and thus is measured with error. A second problem with this measure is that market share may be endogenously determined. Cities where the auto theft is expected to be

[19] Our estimates of the hazard rates for removal of cars from the road are based on data for passenger cars in use published by the Polk Company. 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.

high and increasing will tend to have higher installation rates.[20] Our solution to both of those problems is to instrument for Lojack's market share using the number of years that Lojack has been available in a given market. Since Lojack is installed almost exclusively in new cars, its market share tends to increase over time, providing a good first stage fit.[21] The fact that years of Lojack enters in the first stage in the expected manner, combined with the fact that it is unlikely to be systematically correlated with the residuals of the auto theft regression when Lojack market share is an included regressor, makes it a plausible instrument.

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

$$\ln(AUTO\_THEFT)_{it} = \beta LOJ\_SHARE_{it} + X_{it}^{\prime}\Gamma + \lambda_t + \theta_i + \epsilon_{it} \tag{11}$$

where i indexes cities and t corresponds to years. *AUTO_THEFT* is the auto theft rate per capita,

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[20] One may also worry about possible sample selection in the set of cities where Lojack operates. In selecting cities, Lojack would like to find markets where auto theft is high and expected to increase. This selection will tend to work against finding a negative relationship between Lojack and auto theft. A second selection story relates to the regulatory process; if only the cities that are serious about fighting auto theft approve Lojack, then this could introduce a spurious negative correlation between Lojack and auto theft rates. We deal with this potential source of sample selection in Table 6, where the number of years since Lojack initiated the regulatory approval process is used as an instrument for the Lojack market share.

[21] The first stage regression yields (White-standard errors in parentheses):

$$LOJ\_SHARE = \underset{(.034)}{.367} * LOJ\_YEARS + YEAR\ DUMMIES + CITY\text{-}FIXED\ EFFECTS$$

N=796 Adj-R^2=.844

Each additional year of Lojack availability increases the market share by .367 percentage points. For simplicity in displaying the results, the specification above omits demographic and socio-economic covariates. When the covariates described below are included, the coefficient on years of Lojack is virtually unchanged: .371 (standard error=.034). The only covariates that are statistically significant predictors of Lojack are %Black, which is positively related to Lojack market share, and ln(sworn police per capita), which is negatively related to Lojack market share.

LOJ_SHARE is the Lojack market share among all registered vehicles, and *X* is a vector of controls for SMSA unemployment rates, the state age distribution, and the number of city police per capita. 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 (1995) and Marvell and Moody (1995) 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 one-percentage point change in the Lojack market share.

Estimation results are presented in Table 3. Odd numbered columns include only year dummies and city-fixed effects as controls; even columns use the full set of covariates. The first three columns are estimated using OLS, with White-standard errors reported in the table. The last three columns use 2SLS, instrumenting for the Lojack market share using the years that Lojack has been available in the market. In the simplest specification (column 1), each percentage point of Lojack is associated with roughly a 20 percent decline in auto theft and is highly statistically significant. Adding covariates increases the estimated magnitude of the impact, as does instrumenting for the Lojack share in columns 4 and 5. It is important to remember, however, that Lojack-equipped vehicles are concentrated in central cities. Assuming that Lojack installation rates within a given market are proportional to auto theft rates, a one percentage point increase in Lojack for the market as a whole corresponds to a 3 percentage point increase in Lojack installation in the central city, causing the estimates to appear exaggeratedly large.

Columns 3 and 6 of Table 3 semi-parametrically explore non-linearities in the effect of Lojack, adding Lojack's market penetration squared and cubed to the specification. Figure 2 presents a plot of the curve traced out by the coefficients in Column 3. Over the range in which most of the available data lie (i.e. 0-2 percent Lojack penetration), the function is concave, implying decreasing marginal returns to Lojack installation. Beyond that point, the marginal reduction is roughly linear in Lojack market share, with some hint of an upturn in the high penetration ranges. Only Massachusetts, however, has experienced such penetration levels, making inference based on this portion of the curve suspect.

Returning to Table 3, 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 two percent. The other controls, however, do not substantially improve our ability to predict auto theft rates. 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 counter-intuitive sign. While the generally poor performance of the control variables is disappointing, it is perhaps to be expected given the inclusion of year dummies and city-fixed effects. After removing year and city means, there is very little variation remaining in the controls, especially for the race and age variables. The lack of explanatory power in these controls is revealed by the fact that the R^2 values are virtually unaffected by their inclusion.

<u>Disrupting Recidivists and Chop-Shops</u>

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 (perhaps 3-5 times as large) 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: an additional three percentage points of Lojack equipped vehicles will increase the likelihood of arrest only 6% (i.e. from 0.10 to 0.106) if arrests are three times as likely with Lojack equipped cars. If, however, 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. A professional thief who has only a three-tenths of one-percent chance of arrest per theft without Lojack, but is no better at avoiding arrest than the average car thief when Lojack is installed, sees his or her effective per theft arrest rate increase almost four-fold (from .3% to 1.19%). For a professional stealing 100 cars a year, this represents a significant change, raising the annual chance of arrest from 30% to 71.6%. 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 non-drug, serious crimes in the year prior to imprisonment.

However, the most important effect of Lojack 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. The Lojack company reports that their product has lead police to 53 chop-shops in the Los Angeles area, the only area for which complete data is available. Given the large number of vehicles processed by a large auto theft ring, a small Lojack presence translates into a high likelihood that at least one Lojack-equipped vehicle will be encountered. For instance, assuming a 2 percent Lojack market share, if 100 cars are stripped annually, the likelihood that at least one of these cars has Lojack is 87 percent. If 200 cars are stripped, this value rises to over 98 percent. As evidence that the threat Lojack poses to auto theft rings is real, in cities where Lojack has a presence, professional auto thieves now 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."[22] 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.

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 simply a displacement. It is possible that crime shifts either geographically or away from auto theft towards other criminal acts such as burglary or robbery.[23] These two possibilities are examined in turn.

The first possibility is that crime shifts geographically, falling in central cities and rising

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[22] 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.

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

in other parts of the state.[24] Table 4 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 4 is defined at the state level, the covariates in the table are also state-level variables. Lojack is associated with declines in rest-of-state auto theft rates of roughly 4-10 percent for each percentage point of Lojack installation in the market. The fact that these estimates are smaller than those for central cities is consistent with Lojack installations being disproportionately concentrated in large cities where the auto theft threat is greatest.

An alternative form of crime shifting is across crime categories 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

[24] It is also possible that auto theft shifts across state lines. Testing such a claim, however, does not appear to be feasible.

professional criminals who are both generalists (Beck 1989) and otherwise difficult to catch, there may be appreciable incapacitation effects as well.

Table 5 presents estimated impacts of Lojack on crimes other than auto theft. These crimes are divided into two categories: "substitutable" and "non-substitutable." Substitutable crimes (burglary, larceny, robbery) are those whose primary motivation is financial; non-substitutable crimes (murder, rape, aggravated assault) are those where financial gain is generally not the primary motive. The specifications in Table 5 are identical to those of Table 3, except that the dependent variable has changed. The regressions suggest that Lojack has only a small impact on crimes other than auto theft. While the Lojack coefficients are negative in seven of the eight specifications, suggesting that Lojack is associated with reductions in other crimes, the estimates are statistically different from zero at the .05 level in only three cases. Even the largest coefficients are only about one-fifth of the magnitude of the estimates for auto theft. While theory would predict a greater shift towards financially motivated crimes, there is little evidence of a differential effect of Lojack across substitutable and non-substitutable crimes.[25]

Robustness

Table 6 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 6 correspond to city auto theft rates, outlying auto theft rates, substitutable crimes in cities, and non-substitutable crimes in cities. Rows in Table 6 represent different specifications. Each cell

[25]Replicating the specifications in Table 5, but replacing city non-auto 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.

entry in Table 6, therefore, is the regression coefficient on Lojack market share from a separate regression. In all cases the regressions include the full set of covariates from earlier tables. Except where noted, years of Lojack availability is used as an instrument for Lojack market share. Full regression results are available on request from the authors.

The first row of Table 6 simply replicates results from Tables 3-5 to provide a baseline for evaluating the alternative specifications. The second row of Table 6 adds region-year interactions to the basic specification to control for any region-specific shifts in crime. Adding region-year interactions leads to point estimates on auto theft that are more negative, but less precise. The coefficients on other 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 slightly 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.

The fifth and sixth rows of Table 6 instrument for two potential sources of endogeneity in the basic specification. If there is sample selection in the regulatory approval process, then it is possible that Lojack is more likely to be approved in areas where police are becoming more serious about combating auto theft. To purge this form of endogeneity, we instrument for Lojack's market share using the number of years that have elapsed since Lojack initiated the regulatory approval process in a state rather than our standard instrument, the number of years that Lojack has actually been available to consumers in the market. Contrary to what would be expected if the sample selection story were true, the coefficients on auto theft again become more negative. In the next row, we instrument not only for Lojack's market share (using years Lojack has been available), but also for the police variable. The instrument employed is the timing of mayoral and gubernatorial election years. Levitt (1995) 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 -.21 and -.71 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 (1995).

The final two specifications of Table 6 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 a surprisingly small impact on the point estimates, although the standard errors increase appreciably when Boston is eliminated since Boston provides far more variation in Lojack market shares than does any other city.

Section IV: 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 examined, paying special attention to differentiating between direct benefits to those who install Lojack (or their insurers) and externalities. 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 regressions including only year and city controls. These estimates are smaller than the 2SLS estimates and specifications with a broader set of covariates and thus provide more conservative estimates of 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.

Direct Benefits to Lojack owners and their insurers

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.[26] Car owners are not required to carry such coverage. 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. If, however, a car owner has comprehensive insurance, Lojack provides little direct benefit except for insurance premium discounts since recovered vehicles will typically sustain damage greater than the deductible. Thus, with

[26] 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.

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. According to Lojack company estimates, 95 percent of Lojack-equipped cars are recovered. Mean auto theft loss per stolen vehicle is estimated to be slightly under $1,000 when Lojack is installed, including losses when the vehicle is never recovered. The average loss for cars not equipped with Lojack is estimated to be $4,000 per vehicle (Cohen 1988).[27] The mean auto theft rate per capita in the baseline cities is 0.025. 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 depend crucially on the value of the car being protected from theft loss. The expected benefits are likely to be greater in early years both because the car is worth more and because recent model cars are more likely to be stolen. 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

[27] The Cohen (1988) numbers appear consistent with the Lojack claims. Approximately 60 percent of non-Lojack equipped stolen vehicles are recovered according to the National Insurance Crime Bureau. Assuming an average of $750 in damages for the typical recovered vehicle, this implies a $9,000 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 $9,000 value to Lojack-equipped vehicles that are not recovered, yields an average loss of $925 with Lojack.

period at a ten percent interest rate yields a yearly Lojack cost of approximately $97.

With comprehensive insurance coverage, the Lojack owner weighs the $600 cost of installation against the value of the available insurance discounts.[28] The real value of these discounts vary 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 anti-theft devices are installed. 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. Other states, such as Illinois, prohibit insurers from giving discounts for Lojack. 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. In Miami and Los Angeles, the discount for Lojack is typically no more than 10%, 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.

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[28] The damage sustained to a recovered stolen vehicle almost always exceeds the $100-500 deductible on most comprehensive insurance policies.

Externalities to Lojack via a reduction in auto theft rates

While higher retrieval rates provide direct benefits to those who install Lojack, reductions in auto theft rates are pure externalities from the perspective of an individual installing Lojack because installing an individual Lojack will have no practical impact on the likelihood that the protected car will be stolen. However, each percentage point increase in the number of vehicles in a market with Lojack installed is associated with roughly a 20 percent reduction in auto theft in the central city. Assuming that Lojack installation rates within a given market are proportional to auto theft rates, a one percentage point increase in Lojack for the market as a whole corresponds to a 3 percentage point increase in Lojack installation in the central city.[29] Using a baseline auto theft rate of 0.05 per vehicle per year, that 3 percentage point increase in Lojack is associated with a 1 percentage point decrease in the auto theft risk, i.e. one auto theft is eliminated each year for every 3 Lojacks. Using a loss per stolen vehicle of $4,000 from Cohen (1988), each Lojack yields an annual externality of over $1,300. 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 $1,500 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 consumer's price is likely to overstate the true marginal social cost for

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[29] This assumption is consistent with our estimates that the decline in outlying auto theft rates is roughly one-third as great as that for central cities.

two reasons. First, some fraction of that price accrues as profit to Lojack shareholders. Secondly, 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. Even ignoring these factors, the marginal social benefit of Lojack appears to be roughly 15 times greater than the marginal social cost.

Section V: Conclusions

Lojack is a real-world example of an unobservable victim precaution measure that yields positive externalities. A one percentage point increase in the fraction of vehicles with Lojack installed is associated with a 20 percent decline in auto theft in big cities and a 5 percent decline in outlying areas, without any evidence of increases in other crime categories. From the perspective of the car owner who installs Lojack, this auto theft decline is a pure externality since Lojack provides no specific deterrence. 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 is roughly 15 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 somewhat 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.[30] The apparent presence of decreasing marginal returns to Lojack in Figure 3 is consistent with the argument that low levels of Lojack penetration are sufficient to provide a costly disruption of operations for professional thieves. Within the next five years, the number of markets with high Lojack penetration will have increased markedly, allowing a direct test of the marginal benefits of higher Lojack market coverage.

The magnitude of the externalities associated with Lojack point to the importance of conducting parallel research on other 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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[30] One would also expect that thieves would engage in heightened technology development designed to thwart Lojack.

Figure 1

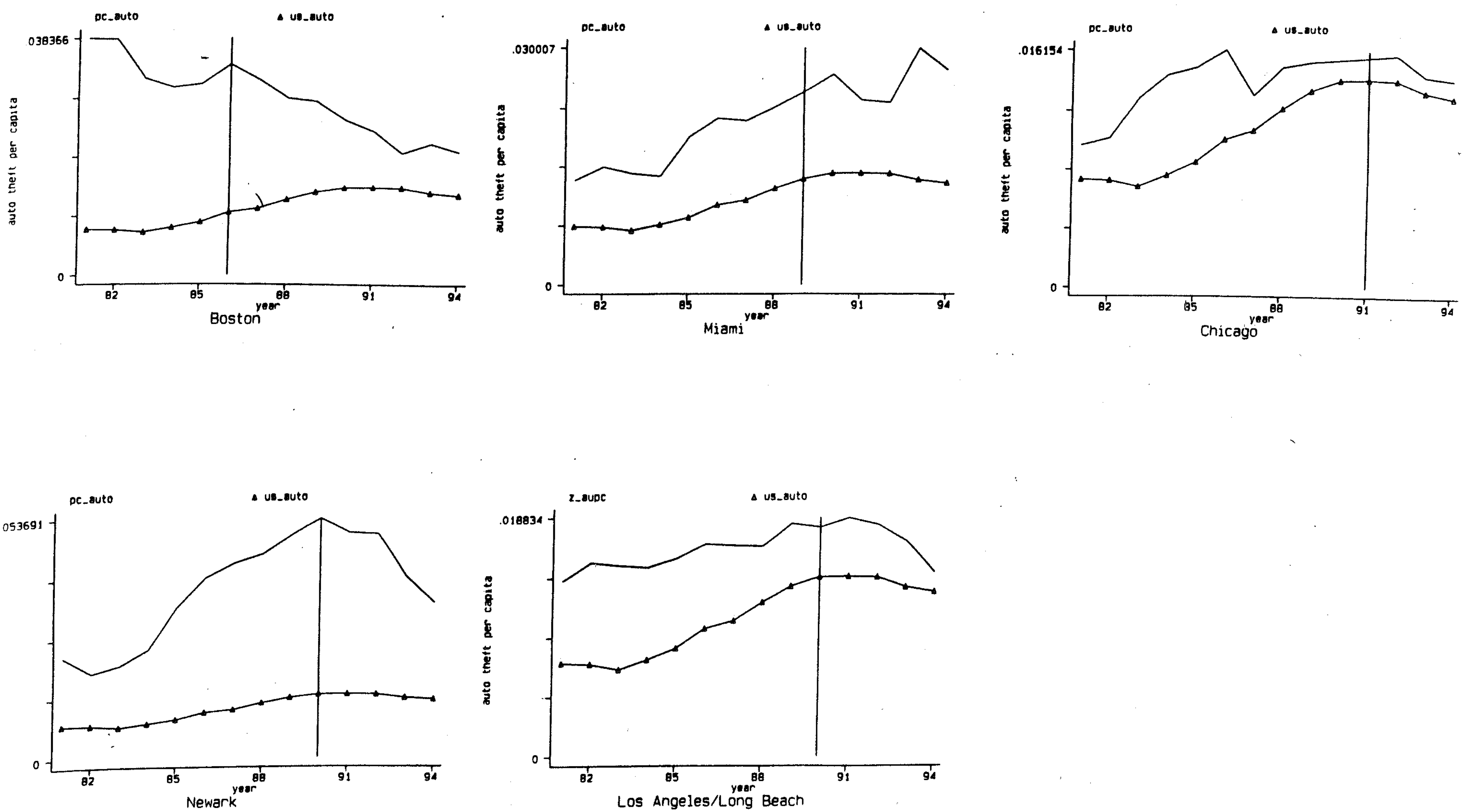
pc_auto
▲ us_auto
auto theft per capita
.038366
0
82
85
88
91
94
year
Boston
.030007
Miami
.016154
Chicago
053691
Newark
z_aupc
.018834
Los Angeles/Long Beach

Figure 2

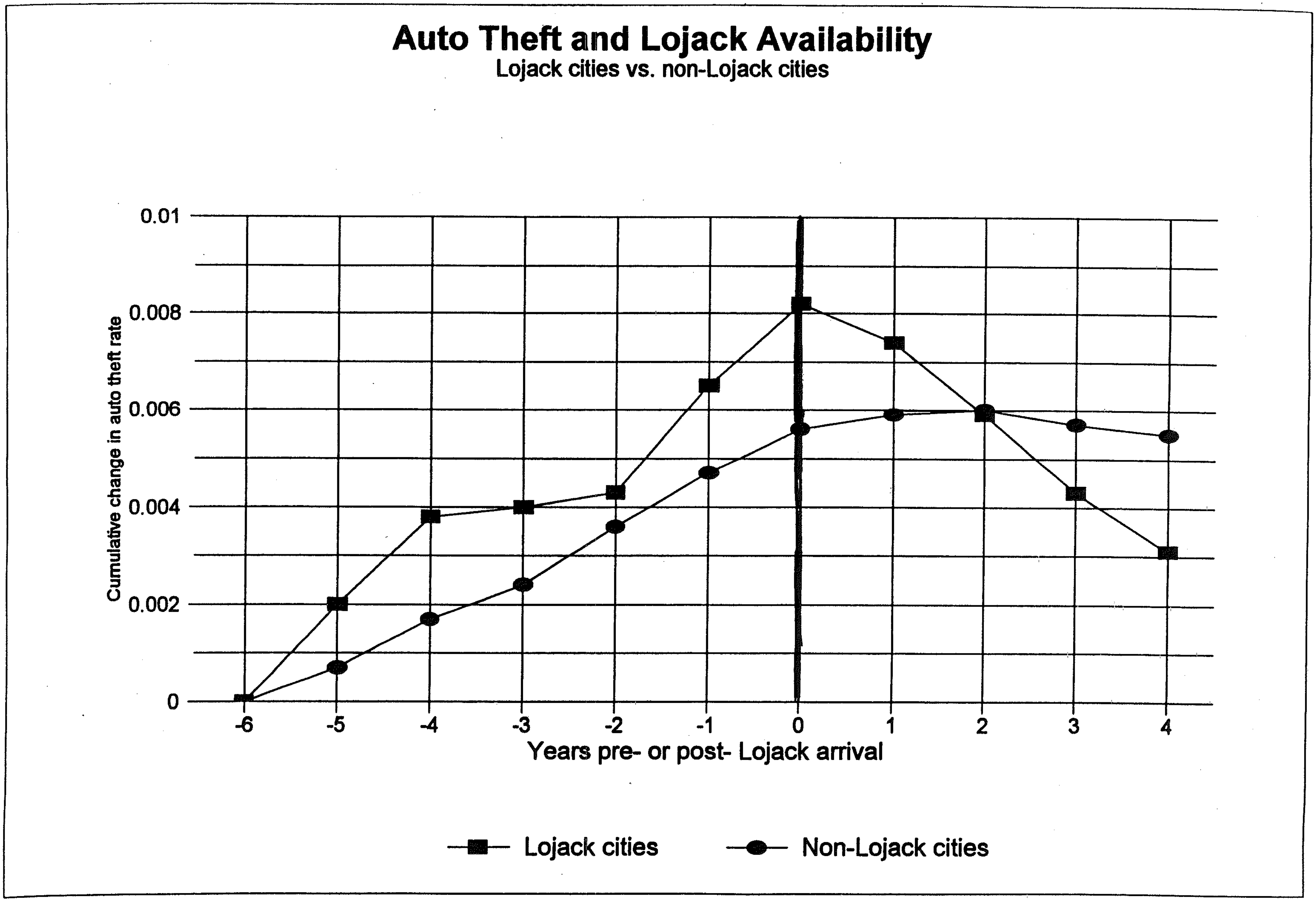
Auto Theft and Lojack Availability
Lojack cities vs. non-Lojack cities
Cumulative change in auto theft rate
0.01
0.008
0.006
0.004
0.002
0
-6
-5
-4
-3
-2
-1
0
1
2
3
4
Years pre- or post- Lojack arrival
Lojack cities
Non-Lojack cities

Figure 3

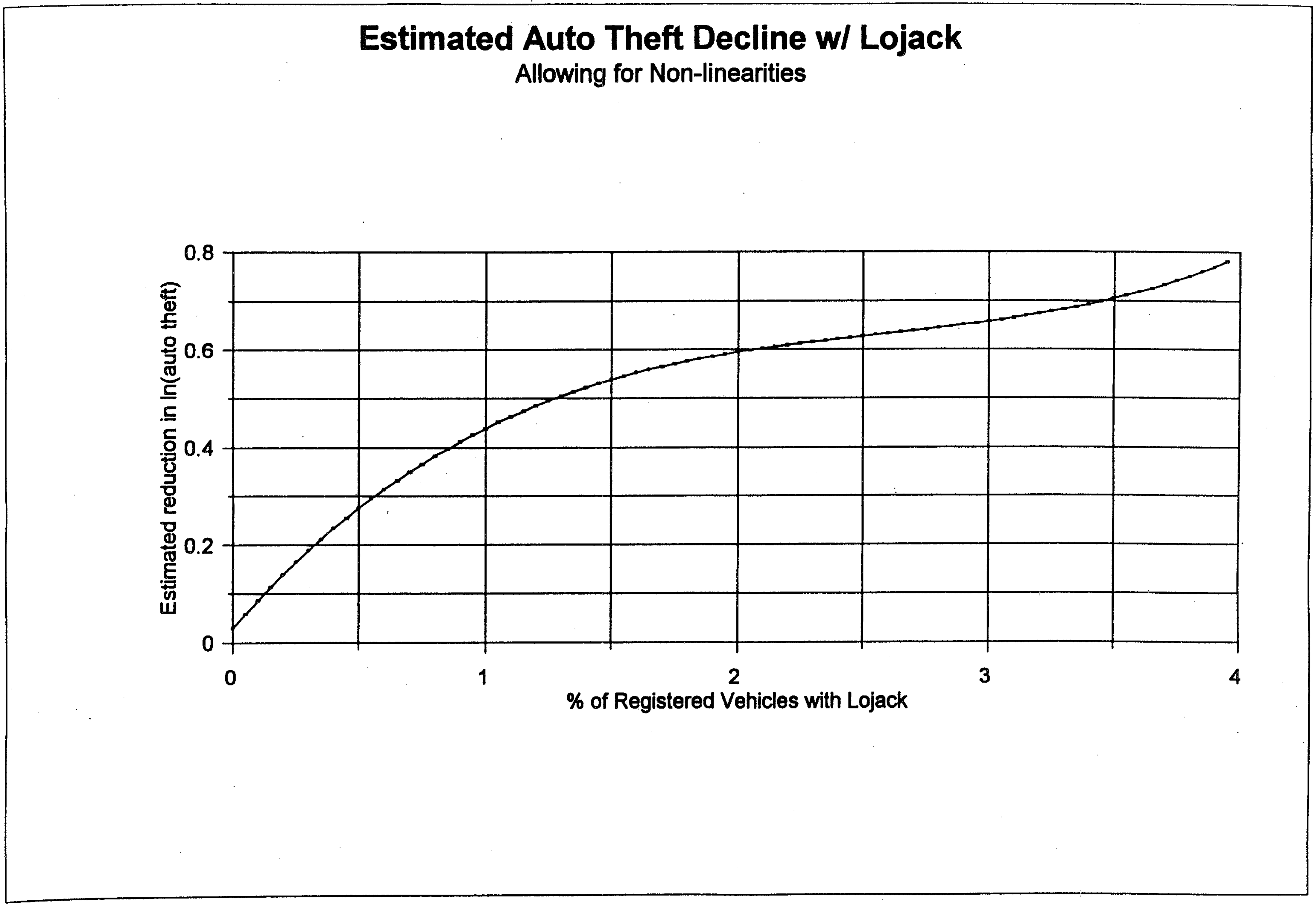
Estimated Auto Theft Decline w/ Lojack
Allowing for Non-linearities
Estimated reduction in ln(auto theft)
0.8
0.6
0.4
0.2
0
0
1
2
3
4
% of Registered Vehicles with Lojack

Table 1: Markets Served by Lojack with Date of Entry

Includes only markets served 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[1]	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

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

Table 2: Summary Statistics

Variable	Mean	Standard Deviation	Minimum	Maximum
All cities in sample:				
Lojack share (% of total 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 (x1000)	2.47	.96	1.32	7.81
Cities with Lojack coverage by 12/94				
Lojack share (%of total 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	.054

Table 2: Summary Statistics (con't)

Variable	Mean	Standard Deviation	Minimum	Maximum
Cities with Lojack coverage by 12/94				
Robbery, burglary, larceny per capita	.081	.025	.044	.156
Assault, rape, murder per capita	.011	.006	.001	.025
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 (x1000)	3.20	1.33	1.40	7.81

Notes: Data cover the period 1981-1994 for the 57 U.S. cities with population greater than 250,000 in 1981. For the 13 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 is from Employment and Earnings. State per capita income is in 1994 dollars, deflated using the CPI.

Table 3: Impact of Lojack on City Auto Theft Rates

Variable	(1)	(2)	(3)	(4)	(5)	(6)
Lojack share	-.200 (.028)	-.242 (.031)	-.611 (.133)	-.234 (.035)	-.293 (.037)	-.784 (.219)
(Lojack share)^2	-------	-------	.212 (.097)	-------	-------	.332 (.152)
(Lojack share)^3	-------	-------	-.027 (.015)	-------	-------	-.046 (.023)
Unemployment rate	-------	.017 (.009)	.019 (.009)	-------	.019 (.009)	.020 (.009)
State real per capita income (x1000)	-------	.016 (.014)	.021 (.014)	-------	.018 (.015)	.022 (.015)
% Black	-------	-.002 (.009)	-.002 (.009)	-------	-.001 (.008)	-.002 (.008)
% Aged 0-17	-------	.102 (.030)	.114 (.030)	-------	.106 (.026)	.117 (.026)
% Aged 18-24	-------	-.004 (.039)	.004 (.040)	-------	-.009 (.039)	.003 (.039)
% Aged 25-44	-------	.008 (.039)	.014 (.039)	-------	.019 (.036)	.018 (.036)
ln (sworn officers/ per capita)	-------	-.001 (.131)	.018 (.131)	-------	-.003 (.132)	.028 (.132)
Year dummies?	Yes	Yes	Yes	Yes	Yes	Yes
City-fixed effects?	Yes	Yes	Yes	Yes	Yes	Yes
Instrument using years of Lojack availability?	No	No	No	Yes	Yes	Yes
Adjusted R-squared	.876	.882	.883	-------	-------	-------
N	768	751	768	751	768	751

Notes: Dependent variable is ln(reported auto thefts per capita). Data covers the period 1981-1994 and includes 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. In columns 4-6, the number of years that Lojack has been available in a given market is used as an instrument for Lojack's market share. 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. All columns include year dummies and city-fixed effects in addition to the variables shown. White standard errors in parentheses. The number of observations varies across columns due to missing data.

Table 4: Impact of Lojack on Outlying Area Auto Theft Rates

Variable	(1)	(2)	(3)	(4)
Lojack share	-.045 (.019)	-.056 (.019)	-.071 (.024)	-.107 (.033)
Unemployment rate	-------	-.004 (.007)	-------	.000 (.008)
State real per capita income (x1000)	-------	-.002 (.015)	-------	.001 (.015)
% Black	-------	-.0002 (.0003)	-------	-.0003 (.0003)
% Aged 0-17	-------	.118 (.022)	-------	.122 (.025)
% Aged 18-24	-------	.089 (.036)	-------	.084 (.037)
% Aged 25-44	-------	.052 (.035)	-------	.065 (.032)
ln (police/per capita)	-------	.123 (.112)	-------	.099 (.121)
Year dummies?	Yes	Yes	Yes	Yes
State-fixed effects?	Yes	Yes	Yes	Yes
Instrument using years of Lojack availability?	No	No	Yes	Yes
Adjusted R-squared	.874	.907	-------	-------
N	434	403	434	403

Notes: 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 covers the period 1981-1994. Only states with at least once city with 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 3 and 4, the number of years that Lojack has been available in a given market is used as an instrument for Lojack's market share. Unemployment, % Black, police, and age categories refer to the entire state, not just the outlying areas. All columns include year dummies and state-fixed effects in addition to the variables shown. White-standard errors in parentheses. The number of observations varies across columns due to missing data.

Table 5: Impact of Lojack on Crimes Other than Auto Theft

	Substitutable Crimes (Robbery, Burglary, Larceny)				Non-Substitutable Crimes (Assault, Rape, Murder)			
Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Lojack share	-.016 (.011)	-.059 (.015)	.013 (.018)	-.039 (.016)	-.040 (.008)	-.015 (.011)	-.042 (.024)	-.014 (.026)
Unemp. rate	-----	.025 (.004)	-----	.024 (.005)	-----	-.022 (.006)	-----	-.022 (.007)
State real per capita income (x1000)	-----	-.019 (.009)	-----	-.019 (.008)	-----	.003 (.010)	-----	
% Black	-----	-.004 (.004)	-----	-.004 (.004)	-----	-.001 (.006)	-----	-.001 (.006)
% Aged 0-17	-----	-.064 (.013)	-----	-.065 (.013)	-----	-.016 (.018)	-----	-.016 (.019)
% Aged 18-24	-----	-.041 (.022)	-----	-.039 (.020)	-----	-.020 (.029)	-----	-.020 (.029)
% Aged 25-44	-----	.102 (.024)	-----	.098 (.019)	-----	-.012 (.022)	-----	-.012 (.027)
ln (sworn police per capita)	-----	.070 (.063)	-----	.071 (.068)	-----	.396 (.090)	-----	.396 (.096)
Year dummies?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
City-fixed effects?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Instrument w/ yrs. of Lojack?	No	No	Yes	Yes	No	No	Yes	Yes
Adjusted R^2	.800	.839	----	----	.925	.945	----	----
N	768	750	768	750	759	742	759	742

Notes: 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. Non-substitutable 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 covers the period 1981-1994 and includes 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. Where indicated, the years that Lojack has been available in a market is used as an instrument for Lojack share. 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. All columns include year dummies and city-fixed effects in addition to the variables shown. White-standard errors in parentheses. The number of observations varies across columns due to missing data. For this preliminary draft, some of the covariates were not available for 1994, so the even columns only include the years 1981-1993.

Table 6: Sensitivity of Lojack Coefficients to Alternative Specifications

	Coefficient on Lojack share for:			
Specification	City Auto Theft	Outlying Auto Theft	Substitutable Crimes	Non-Substitutable Crimes
Baseline (from earlier tables)	-.293 (.037)	-.107 (.033)	-.039 (.019)	-.014 (.026)
Region-year interactions	-.369 (.065)	-.182 (.080)	.048 (.033)	-.031 (.047)
City-trends	-.218 (.075)	-.276 (.088)	-.073 (.040)	-.094 (.053)
Instrument for Lojack share with years since Lojack began seeking regulatory approval	-.463 (.065)	-.160 (.065)	-.030 (.033)	-.041 (.045)
Instrument for police per capita using mayoral and gubernatorial elections	-.455 (.077)	-.141 (.084)	-.057 (.040)	-.035 (.058)
Excluding Boston from sample	-.285 (.063)	-.151 (.072)	.030 (.032)	-.012 (.045)
Excluding Newark from sample	-.285 (.037)	-.095 (.033)	-.046 (.019)	-.002 (.026)

Notes: All table entries are coefficients on Lojack share 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 are employed in addition to the listed changes in specification. The number of years that Lojack has been available in the market is used as an instrument for the Lojack market share in all rows except where an alternative instrument for Lojack is listed. The first row of values represents baseline estimates from previous tables for comparison purposes.

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