Costly Inspections and Little Abatement: An Evaluation of I/M Efficiency

Chris Giguere[1], Ph.D. Candidate, North Carolina State University, csgiguer@ncsu.edu

Selected Paper prepared for presentation at the 2016 Agricultural & Applied Economics Association
Annual Meeting, Boston, Massachusetts, July 31-August 2

25 May 2016

ABSTRACT[2]:

Automobile emissions inspection and maintenance (I/M) programs are used by 31 states and Washington D.C. as well as a number of foreign counties to maintain or improve ambient air quality. Past literature provides evidence that the current design of most programs in the United States is ineffective. The efficiency of these programs, however, has yet to be analyzed. I fill a considerable gap in the literature by developing a comprehensive estimation framework to evaluate the efficiency of I/M. I use data from the North Carolina I/M program between 1999 and 2013 to estimate seven empirical models required by the framework. The costs *and* benefits from both I/M induced repairs *and* scrappage are then calculated for various regimes using different inspection frequencies and automobile exemptions. My results indicate that the North Carolina I/M program, as it existed between 1999 and 2013 was inefficient. The estimated mean benefits, costs, and net benefits were $28.5, $73.0, and -$44.5 per year respectively, in millions of June 2015 U.S. dollars. The recent increase in automobile exemptions (*selective automobile targeting*) in North Carolina's program is estimated to decrease benefits and costs by 11 and 49 percent. Thus net benefits will increase by 63 percent to -$16.3 million per year. Further reductions to the scope of automobiles inspected are estimated to generate positive net benefits. For example, a regime that inspects only automobiles older than 5 years and are driven more than 20 thousand miles per year is estimated to generate net benefits of $2.13 million per year. These efficiency gains are possible because automobiles are selected for inspections based on where they sit on their emissions trajectory. Programs that fail to account for this "location" are estimated to inspect too many automobiles and yield negative net benefits.

---

[2] The author thanks Roger von Haefen, Laura Taylor, Wally Thurman, Steven Sexton, Randy Rucker, Reed Watson, Dan Benjamin, and other participants at The Property and Environment Research Center (PERC) summer 2014 workshops and Camp Resources XXII for helpful comments and suggestions. In addition, the author thanks Dave Willis at the North Carolina Division of Air Quality, Robert Sawyer at the North Carolina Division of Motor Vehicles, Ismail Elshareef at Edmund's.com, Inc. for providing data. Lastly, the author thanks Scott Ruffner and Julius Scotton for donating their JAVA programming expertise.

1. Introduction

Automobile transportation is an integral component of the U.S. economy but generates many externalities. Foremost are global and local air pollutants and other toxic emissions that adversely affect human health, agriculture, property, labor productivity, and the environment.[1] In fact, the U.S. Environmental Protection Agency (EPA) reports that automobiles account for a majority of local air pollutants, such as carbon monoxide (CO), carbon dioxide (CO_2), nitrogen oxides (NO_X), and volatile organic compounds (VOC), in the United States.[2] In response regulators have established a number of policies designed to reduce emissions and improve ambient air quality. Most policies targeting local air pollutants in the United States were established to maintain compliance with the Clean Air Act and its Amendments.[3] Examples include exhaust emissions standards for motor vehicles, on-board diagnostic (OBD) control systems on automobiles, and clean fuel standards. In addition, a relatively overlooked example, and the focus of this paper, is automobile emissions inspection and maintenance (I/M).

State environmental regulators use I/M to identify and repair (or scrap) noncompliant automobiles with high levels of emissions. In principle, the abatement should improve air quality to be compliant with National Ambient Air Quality Standards (NAAQS). The relationship between I/M induced abatement and air quality improvements, however, is weak and poorly

---

[1] See Bleasdale, 1952; Bleasdale, 1973; Ashmore et al., 1988; Krupa and Kickert, 1989; Schenone and Lorenzini, 1992; Hassan et al., 1995; Schwartz, 1995; Wahid et al., 1995; Alberini et al., 1997; Agrawal et al., 2003; Chay and Greenstone, 2003; Gryparis et al., 2004; Neidell, 2004, 2005, 2009; Bell et al., 2004; Currie and Neidell, 2005; Currie et al., 2009a, 2009b, 2013; Graff-Zivin and Neidell, 2009, 2012; Karnosky et al., 2007; Moretti and Neidell, 2011; Graff-Zivin, 2012; Hanna and Oliva, 2013; and Chang et al., 2014.

[2] U.S. EPA. "Cars, Trucks, Buses, and "Nonroad" Equipment." Accessed on 12 January 2016. http://www3.epa.gov/airquality/peg_caa/carstrucks.html

[3] Global air pollutants, such as carbon dioxide (CO_2), are regulated via multiple pieces of legislation including the Clean Air Act. For example, in 1975 Congress implemented Corporate Average Fuel Economy (CAFE) standards to reduce energy consumption and greenhouse gas (GHG) emissions.

understood (Kahn, 1996c; Sanders and Sandler, 2015). Furthermore, despite endorsement by the U.S. EPA, these programs have received a great deal of scrutiny since their inception in the 1970s.[4] In turn I/M programs across the country have been modified numerous times. For example, North Carolina recently increased I/M exemptions for registered automobiles with relatively low inspection failure rates. Specifically, in April 2015 the state extended its new automobile exemption from one to three model years with less than 70 thousand miles.[5]

Previous academic literature has focused on the effectiveness of I/M at reducing automobile emissions rather than overall efficiency.[6] Furthermore many of the repairs that do lower emissions are not durable or persistent (Wenzel et al., 2004; and Mérel et al., 2014). Additionally several evaluations have shown that I/M is generally neither an effective nor a cost-effective policy (Harrington et al., 2000; and Mérel et al., 2014).[7] One often cited cause of the high costs is the use of a *blanket* approach to inspections. Most I/M programs require nearly all registered automobiles to submit to periodic inspections and incur compliance costs. The social benefits, however, are generated from only a small number of noncompliant automobiles.[8] The high costs have led other researchers to suggest more selective targeting of automobiles.[9] The recent change to I/M in North Carolina is a real world application of *selective automobile targeting*.

While the selective targeting research suggests that the recent change to North Carolina's I/M program will increase its efficiency, two research questions remain. First, it is unclear from past

---

[4] See Glazer et al., 1995; Hubbard, 1997; Ando et al., 2000; Harrington et al., 2000; Washburn et al., 2000; and Eisinger and Wathern, 2008.

[5] Read House Bill 585 at http://www.ncleg.net/Sessions/2011/Bills/House/PDF/H585v6.pdf.

[6] Glazer et al., 1995; Kahn, 1996b; Hubbard, 1997; Ando et al., 2000; Harrington et al., 2000.

[7] Reitz (1996) and the National Research Council (2001), however, claim that I/M is more cost-effective than other methods of reducing air pollution. Fowlie et al. (2012b) find the marginal abatement cost of nitrogen oxides from automobiles is less than half from power plants.

[8] See Lawson, 1993; Beaton et al., 1995; Kahn, 1996b; and Harrington et al., 2000.

[9] See Glazer et al., 1995; Washburn et al., 2001; Bin, 2003; and Moghadam and Livernois, 2010.

research how efficient these programs are. Second, it is unclear how much additional efficiencies could be realized from selective targeting along margins other than age and odometer reading.

One reason for these lingering questions is the absence of a comprehensive measure of the costs and benefits of I/M. For example, the cost-effectiveness analysis in Mérel et al. (2014) focuses only on emissions related repairs for a sample of the treated automobiles. Similarly other researchers have relied on *samples* of I/M data covering less than three years which may lead to biased results when the sample does not reflect the steady-state.[10] The steady-state refers to a stationary failure distribution, which "occurs when every vehicle in the eligible population has been tested at least once" (Moghadam and Livernois, 2010). A one year sample from I/M with biennial inspections could yield unreliable conclusions.[11]

I employ two main tools to answer these research questions. First, I develop a conceptual estimation framework that provides comprehensive accounting of costs *and* benefits from both I/M induced repairs *and* scrappage. Second, I use an extensive dataset of *all* emissions inspections in North Carolina between 1999 and 2013 to estimate seven empirical models. An advantage of the framework is that it can be used to extend the work of Moghadam and Livernois (2010), among others, by estimating changes to I/M's efficiency under various regimes. I estimate the efficiency for several different inspection frequencies, such as biennial and triennial, as well as a number that selectively target based on different automobile attributes such as age, odometer reading, drive type, body type, or engine size.

---

[10] See Kahn, 1996a; Kahn, 1996b; Harrington et al., 2000; Washburn et al., 2001; Bin, 2003; and Beydoun and Guldmann, 2006.

[11] A minimum of one (two) year(s) of panel data are needed to identify the steady-state of an (a) annual (biennial) I/M program if no additional automobiles were registered during the period.

My results suggest that the North Carolina program, as it existed between 1999 and 2013, is not efficient and generates net benefits of -\$44.5 million per year.[12] This result is driven by the costs incurred by owners of the 92 percent of automobiles that pass I/M tests as well as limited abatement due to poor repair durability. While the state's recent increased exemption will reduce I/M compliance costs to automobile owners by 44 percent to \$41 million, it fails to reduce them to the level of the social benefits of I/M. I estimate that the average annual net benefits of I/M under this regime will be -\$16.3 million holding the characteristics of fuel, the automobile fleet, and driving behaviors constant.[13]

The framework described in section 4 can also be used to estimate the efficiency of other potential I/M regimes, several of which generate positive net benefits. The California Smog Check regime appears to be a potential Pareto improvement over the North Carolina I/M program. The most efficient selective targeting regime is one that requires only automobiles older than 5 years that are driven more than 20 thousand miles annually to report for periodic inspections. Both the extensions and results of this framework should be of interest to policy makers and researchers alike.

---

[12] A comparison of benefits to costs is relevant for two reasons. First, the Clean Air Act requires that the U.S. EPA engage in benefit-cost analysis (BCA) when administering environmental programs (42 U.S. Code §7612). Second, Executive Order 13563 requires government agencies to "propose or adopt a regulation only upon a reasoned determination that its benefits justify its costs." In addition, the order also requires government agencies to "tailor its regulations to impose the least burden on society, consistent with obtaining regulatory objectives." Because some environmental regulations explicitly rule out BCA this applies only to the maximum degree allowed by law. For example, some air toxics regulations ignore costs for unacceptable risks (Farrow and Toman, 1998) and the U.S. EPA is prohibited from weighing costs when setting federal air quality standards (Kahn, 1996a; McLaughlin, 2008).

[13] Data on exhaust emissions of nitrogen oxide are currently unavailable. Assuming nitrogen oxide emissions behave like hydrocarbons and carbon monoxide, I estimate that social benefits of I/M induced repair and scrappage would increase 7 percent to \$34.3 million per year.

This chapter proceeds as follows. First, section 2 examines the background of I/M in the United States. Section 3 then discusses the relevant past literature and section 4 describes the extensive dataset used. Next, section 5 introduces the estimation framework and section 6 presents results of the analysis. Finally, section 7 concludes.

2. I/M background

Automobile emissions inspection and maintenance (I/M) programs are currently used by 31 states and the District of Columbia in the United States.[14] These areas include I/M in a portfolio of environmental programs and regulations that demonstrate to the U.S. EPA the area's effort to attain or maintain compliance with federal air quality standards. Table 1 summarizes the characteristics of the 32 programs in the United States. There is significant heterogeneity among U.S. programs along a number of margins including inspection frequency, geographic coverage, type of test used, and new model year exemptions. While some areas choose annual inspections, most use a biennial frequency for automobiles registered in some jurisdictions. Most programs also use a decentralized network of automobile service stations, rather than a centralized station managed by a specific contractor or government agency, that conduct on-board diagnostic (OBD) emissions tests to determine compliance. In addition, most I/M programs in the United States have exemptions for particular classes of automobiles such as farm use, classics, and automobiles with diesel engines. The typical I/M program also exempts automobiles from the most recent three model years from inspections.

---

[14] In addition, many foreign countries use periodic automobile emissions inspections.

States use I/M for one of two reasons. First, the Clean Air Act requires some areas in nonattainment with federal air quality standards to have I/M.[15] Other states adopt them as part of a portfolio of programs designed to satisfy Clean Air Act regulations.[16] Regardless of their motivation, the 32 areas using I/M include it in their state implementation plan (SIP), which describes the policies and programs used to attain or maintain compliance with federal air quality standards. The SIP is periodically revised by state and local air quality regulators in all 50 states and submitted to the U.S. EPA for approval. It forms a contract between the state and the U.S. EPA; federal highway funding may be withheld from states that deviate.[17] Thus, North Carolina had to wait three years for U.S. EPA approval before implementing its 2012 legislation.[18]

There have been a number of changes to I/M programs in the United States since their introduction. These have largely been made in response to criticism focusing on their inability to lower automobile emissions.[19] In addition, these changes have primarily focused on more cost-effectively identifying noncompliant automobiles rather than incentivizing durable repairs

---

[15] The Clean Air Act requires areas that violate air quality standards for ozone and carbon monoxide to have I/M programs (42 U.S. Code § 7511a, § 7512a). It also specifies I/M program requirements for areas in *serious*, *severe*, *or extreme* nonattainment of ozone standards. The programs must use, at a minimum, computerized emission analyzers (including on-road testing devices), a repair cost limit of $450, and enforcement through denial of registration.

[16] For example, Vermont is in full compliance with NAAQS but uses I/M "to reduce the impact of mobile source emissions on air quality and human health." See VT DEC. "Mobile Sources Section." Accessed on 7 January 2016. http://www.anr.state.vt.us/air/mobilesources/index.htm

[17] If the U.S. EPA determines that SIPs were not submitted in a timely manner, or if programs fail to be implemented, federal funding of major highway construction may be withheld or more stringent requirements may be imposed for new source permits (Schneeberg; Spink and Bigioni, 2010). Federal Transportation Aid to states is considerable at around $825 million annually (NC Progress Board, 2003). The withdrawal of federal highway funds may not be a credible threat, however. Between 1990 and 1997 there were 855 occasions where the U.S. EPA intended to use this sanction but only followed through 14 times (McCarthy, 1997).

[18] A final ruling, "Approval and Promulgation of Implementation Plans; North Carolina; Inspection and Maintenance Program Updates," was published by the U.S. EPA on 20 November 2014. The change in automobile emissions was finally implemented on 1 April 2015.

[19] See Glazer et al., 1995; Kahn, 1996b; Hubbard, 1997; Ando et al., 2000; and Harrington et al., 2000.

(Ando et al., 2000). For example, many early I/M programs relied on idle tailpipe tests, which fail to mimic everyday driving decisions and may thus fail to identify some noncompliant automobiles or incorrectly fail some compliant automobiles.[20] Today, as shown in table 1, most programs use second generation on-board diagnostic control system (OBD-II) emissions tests.

The change in the type of test used to determine noncompliance represents a major shift. It was facilitated by the Clean Air Act Amendments of 1990 that required that all new automobiles sold in the United States be equipped with these control systems starting in model year 1996 (U.S. Code §7521). As OBD-equipped automobiles replaced older models this technology soon became a lower cost method of emissions inspections. The equipment necessary to conduct OBD inspections was much cheaper than dynamometers and tailpipe measurement tools but also provided less information.[21] Specifically, OBD inspections do not measure actual emissions but instead report a binary pass/fail result. Not surprisingly, this change was also met with protest from critics citing a lack-of-overlap between automobiles identified as noncompliant by OBD and tailpipe tests.[22] More recently OBD tests have been under fire for their involvement in the Volkswagen AG defeat device scandal.

---

[20] Furthermore, idle tests have been shown to be ineffective for automobiles with fuel-injectors (Harrington et al., 2000) and measure emissions concentrations but not rates; an issue that can complicate meaningful analysis of emissions reductions.

[21] A dynamometer is an automobile treadmill that will enable an inspection technician to measure tailpipe emissions while the automobile progresses through a simulated drive.

[22] A number of papers including Barrett et al. (2005), Eisinger and Wathern (2008), Hedglin (2006), Eastern Research Group (2006), and National Research Council (2001) discuss a “lack- of-overlap” in results from the different tests. Gardetto et al. (2005), however, found that vehicles that failed tailpipe tests also had failed the OBD test at a statistically significant level. They also argue that in total OBD test provide larger benefits relative to tailpipe test because repairs from OBD failure yield more abatement.

3. Literature Review

This chapter builds on several broad areas of past economic research. Most importantly it extends the work of those papers, shown in table 2, that have analyzed the effectiveness or cost-effectiveness of I/M. Nearly all previous economic evaluations have sought to answer questions about the effectiveness, rather than efficiency, of I/M. Despite their extensive use around the world I/M has received relatively limited attention from economists.[23] Examples of economic evaluations include Glazer et al. (1995), Kahn (1996b), Kahn (1996c), Hubbard (1997), Ando et al. (2000), Harrington et al. (2000), Moghadam and Livernois (2010), Mérel et al. (2014), and Sanders and Sandler (2015).[24] The selective targeting literature, shown in table 3, is the second area that this chapter builds on and is closely to the cost-effectiveness papers listed in table 2. Examples include Glazer et al. (1995), Ando et al. (2000), Washburn et al. (2001), Bin (2003), and Moghadam and Livernois (2010). The selective targeting literature either evaluate I/M programs or discuss how differentiated treatment based on automobile attributes could improve the efficiency of I/M. Thus, the selective targeting literature builds on another body of research, also shown in table 2, that has found correlations between automobile attributes and emissions. Finally, this chapter also indirectly extends the research on emissions reductions and

---

[23] They have, however, provided crucial data for a wide range of other economic analyses such as the analysis of fraud (Hubbard, 1998; Pierce and Snyder, 2008; and Oliva, 2012), demand elasticities for fuel or vehicle-miles traveled (VMT) (Gillingham, 2013), and correlations between automobile attributes and emissions (Khazzoom, 1995; Anilovich and Hakkert, 1996; Kahn, 1996a; Kahn, 1996b; Harrington, 1997; Washburn et al., 2001; Bin, 2003; and Beydoun and Guldmann, 2006).

[24] Government or industry outsourced evaluations of I/M include National Research Council (2001), Legislative Audit Commission (2001), Office of the Inspector General (2003), Barrett et al. (2005), Morrow and Runkle (2005), Eastern Research Group, Inc. (2006), Eastern Research Group, Inc. (2008), Program Evaluation Division (2008), Program Evaluation Division (2012), and NC DMV and NC DAQ (2012).

abatement from automobile repairs (Ando et al., 2000; Wenzel et al., 2004; Mérel and Wimberger, 2012; and Mérel et al., 2014).

Table 2 categorizes whether the previous economic evaluations of I/M focus on questions of effectiveness, cost-effectiveness, or efficiency. The papers that analyze the *effectiveness* of I/M examine the extent to which the programs produce abatement from repairs or scrappage, or improve air quality. Other papers attempt to rank I/M relative to other programs by estimating the abatement per dollar or *cost-effectiveness*. The difference between cost-effectiveness and *efficiency* lies with the units used to measure the benefits of the program. *Efficiency* requires that the mass of abated emissions be multiplied by the social value (MED) of emissions so that net benefits can be calculated. Thus while effectiveness and efficiency are mutually exclusive categorizations, cost-effectiveness and efficiency are not. By evaluating the efficiency of I/M I help to fill a major gap in the literature.

The literature highlighted in table 2 largely agree that I/M is not effective at meeting its goals. Glazer et al. (1995), for example, summarizes previous analyses of I/M and discusses factors that have lead to the failure of California's Smog check. Foremost among these is the inability of I/M to lower automobile emissions.[25] A similar conclusion was arrived at by Kahn (1996b) who compared data from both the California Smog check and random California roadside audits. Wenzel et al. (2004) and Mérel et al. (2014), like Kahn (1996b), also reported that inspection induced repairs do not affect automobile emissions.

---

[25] Kahn (1996c) and Sanders and Sandler (2015) have analyzed the effectiveness of I/M at meeting its air quality improvement goal. Kahn (1996c) found that while the Illinois I/M program decreased ambient ozone it did little to decrease ambient concentrations of carbon monoxide. The results of Sanders and Sandler (2015), however, show that the opposite is true. They found that the California Smog Check program decreased carbon monoxide and had almost no effect on ozone. Such conflicting results suggest that the relationship between I/M and air quality is not well understood. Furthermore, these results suggest that I/M may be only marginally effective at achieving its air quality improvement goal.

Glazer et al. (1995), Ando et al. (2000), and Moghadam and Livernois (2010) all agree on one point about I/M programs: efficiency could be improved by eliminating the common I/M requirement of universal testing of automobiles (the *blanket* approach). In fact, this undifferentiated approach is unique compared to other policy areas that often only inspect a sample of agents. Glazer et al. (1995) suggest that both the efficiency and effectiveness could be improved by focusing resources on the maintenance of the 10 percent or less of the fleet that account for more than 50 percent or more of aggregate emissions (Lawson, 1993; Beaton et al., 1995; Kahn, 1996b).

Kahn (1996c), Ando et al. (2000), and Moghadam and Livernois (2010) also agree that the efficiency of I/M could be improved by more careful targeting of automobiles for inspection.[26] Ando et al. (2000) argues that this could reduce costs because there is considerable variation in costs and repair durability. For example, there may be significant differences among different automobile vintages, drive types, or engine types. Similarly, Kahn (1996c) points out that the age distribution of the automobile fleet will impact I/M induced abatement as exhaust emissions standards are tightened. He argues that the benefits of I/M will decline as older automobile cohorts that were produced under more lenient exhaust emissions standards are phased out of the fleet while costs will increase as values of time rise.

This paper is also closely related to Moghadam and Livernois (2010) who estimate the abatement cost function for Ontario’s I/M program. Their cost-minimization model estimates the marginal abatement cost is so high that even a small reduction in the abatement target would lead to substantial reductions in costs to motorists. The savings can either be realized by testing less

---

[26] Washburn et al. (2001) also argues that selectively targeting automobiles likely to fail inspections would improve the efficiency of I/M.

frequently or inspecting fewer automobiles. For example, they found that the optimal age to begin periodic emissions testing is higher than has been adopted by many programs. Specifically, Moghadam and Livernois (2010) conclude that 70 percent of the maximum technically feasible abatement can be realized at a fifth of the cost by testing only three age cohorts. In addition, their cost-minimizing solution requires testing vehicles less frequently than is commonly practiced.[27] One drawback to this analysis, however, are that the models of failure and abatement estimated are overly parsimonious as only functions of automobile age.

The primary contribution I make in this paper is the application of a comprehensive framework for the evaluation of the *efficiency* of I/M. The framework, described in detail in chapter 2 of my dissertation, was developed with the help of several areas of previous literature and the insights drawn from previous analyses. It is comprehensive in that it estimates seven empirical models to calculate both the costs *and* benefits of abatement from both I/M induced repairs *and* scrappage. I improve on past evaluations of I/M by estimating the extent to which retirement of older automobile cohorts decreases the benefits of I/M.[28]

In addition, in this chapter I improve on and extend the past literature in several other ways. For example, Instead of considering the quantity of emissions abated, like Moghadam and Livernois (2010), I extend the analysis to estimate the social value of emissions abatement. In addition, I use a much more extensive dataset relative to past literature such as Kahn (1996c), Ando et al. (2000), and Moghadam and Livernois (2010). The dataset has 11 more years worth of emissions inspections data than has often been used. Like Ando et al. (2000) I also find large

---

[27] Moghadam and Livernois (2010) suggest these savings could be reallocated to different pollution sources or policies that have a lower marginal cost and potentially achieve an increase in abatement.

[28] Such as Kahn (1996c), Ando et al. (2000), Harrington et al. (2000), and Moghadam and Livernois (2010).

variation in I/M induced abatement. Finally, I combine the estimation framework and the extensive dataset from North Carolina to compare the efficiency of various I/M regimes including those that selectively target automobiles for inspection. The regimes include those from California and the new North Carolina program as well as variations of those suggested in the selective targeting literature. For example, Bin (2003) concluded that "targeting vehicles more than ten years old, with engines smaller than 2000 cubic centimeters, and more than 100,000 miles could improve the cost-effectiveness by increasing the likelihood of finding and scrapping or repairing high polluting vehicles." While several papers have discussed the use of selective targeting only Moghadam and Livernois (2010) have quantified how it may affect I/M's cost-effectiveness.

4. Data

This chapter uses a unique and extensive dataset of *all* emissions inspections from North Carolina to estimate the benefits and costs of I/M. It includes more than 29 million inspections conducted on more than 6.4 million unique automobiles between January 1999 and December 2013. I merged the inspection data with detailed automobile attributes data from Edmunds.com, Inc. and economic indicators from various government sources to create the main dataset I used to estimate the net benefits of I/M.

The inspection data was collected from the two divisions of the North Carolina state government that manage the I/M program. First the Division of Air Quality (DAQ) contributed the automobile inspection records, which required extensive cleaning. These data include the vehicle identification number, odometer reading, test start and end times and dates, emissions inspection results, registration county, and the inspection station identification number. Second the Division of Motor Vehicles (DMV) provided data on the locations of all the decentralized inspection stations across the state.

Automobile attributes were gathered from the Edmunds.com, Inc. Application Program Interface (API). The company authorized me to use a homemade Java program to search and download vehicle identification number (VIN) specific automobile attributes. Instead of collecting attributes for each of the more than 6.4 million unique cars and trucks, I sped up data collection considerably by using the “squish VIN” or what Mérel et al. (2014) call the “VIN prefix.” This truncated number includes only 10 (characters 1 through 8 and characters 10 and 11) of the 17 characters from the vehicle identification number and enabled me to extract information for a particular make-model year-model-trim type in one attempt. In other words, instead of collecting data for all of the 2007 Chevrolet Silverado 1500s registered in North Carolina, I extracted attributes for this automobile and merged it with all trucks in that cohort. The attributes gathered from Edmunds.com, Inc. include make, model, model year, fuel economy, engine size and type, transmission size and type, drive type, body style, and fuel type.

Finally I merged economic data from three broad sources into the dataset. First, I collected gasoline prices came from the U.S. Energy Information Administration (EIA). Second, Treasury Bill and unemployment rates were gathered from the Federal Reserve Economic Data (FRED). Third, the U.S. Census Bureau’s American Community Survey (ACS) provided median per capita income from each zip code tabulation area in North Carolina. The income data is vital for estimating the opportunity costs of time for automobile owners complying with I/M. Because I was unable to acquire anonymized automobile owner information I assume all owners get inspections at a station close to their home. Specifically, I use the zip code of the inspection station to merge per capita income data with automobile inspection results.

Attributes of the 6.4 million automobiles (29 million emissions inspections) are summarized in table 4a (4b). Table 4a reports that the average automobile in the dataset was built in 2001, weighed more than 3,500 pounds, had 5.5 cylinders, a 3.13 liter engine, with a 4.5 speed transmission, and got approximately 21 miles per gallon of gasoline. Less than 10 percent of the 6.4 million automobiles failed an emission inspection between 1999 and 2013, and only about 6 percent were repaired back to compliance. Those automobiles that failed inspection and were not repaired back to compliance were either issued an inspection waiver or were scrapped by their owners. Table 4b shows that the average emissions inspection was conducted on a 6.5 year old automobile with nearly 89,000 miles, that was driven almost 15,000 miles per year. Furthermore, it reports that the overall emissions inspection failure rate was 2.3 percent.[29]

Figure 1 illustrates that between 1999 and 2013 there were two significant changes to I/M in North Carolina. First, in 2002 second generation on-board diagnostic (OBD) control system tests began to be used instead of idle tailpipe inspections. The transition lasted until 2006 when idle tailpipe tests were finally phased out. Thus actual emissions levels are no longer observable and must be estimated from past inspections. During the transition period the percentage of registered automobiles in North Carolina that were manufactured in 1996 or later increased from 50 to

---

[29] It is possible that the failure rate observed by the I/M regulator could be biased downward. For example, the owner may decide to have the vehicle repaired in between inspections, a decision that would not be observed by the I/M regulator. This property, that leads some owners to repair their automobiles in between inspections so that they pass each emissions test, even though the cost "each period exceeds the expected penalty of violation" is defined by Harrington (1988) as the "leverage" of an environmental regulation. The ideal dataset would include such maintenance and repair data because it should be considered part of the additionality of I/M. Bennear et al. (2013) define additionality as the degree to which the policy results in actions that would not have occurred otherwise.

nearly 100 percent. Second, between 1999 and 2013 the number of North Carolina counties subject to emissions inspections increased from 9 to 48 of 100. The number of treated counties increased because the state determined it was necessary to meet federal air quality standards and counties were chosen based on population and daily VMT (NC PED, 2008). Figure 2 illustrates the spatial differentiation in North Carolina between 1999 and 2006.

5. Estimation framework and empirical models

In this section I describe the framework I developed to estimate the net benefits of I/M. First, subsection A explains the basic model shown in figure 3. Second, subsection B defines the change in emissions or I/M induced abatement from repairs and scrappage and illustrates them using figure 4. Third, subsection C formalizes the benefits and costs of I/M shown in figure 3 using equations 1 and 2. A thorough discussion of the framework and each of the seven empirical models are available in chapter 2 of my dissertation.

5. A. Overview

Figure 3 provides an overview of the benefits and costs from automobile emissions I/M. Each registered automobile i must report for an inspection in each time period t and will either be determined to be compliant ($f_{it}=0$; pass inspection) or noncompliant ($f_{it}=1$; fail inspection). Automobiles that are compliant with emissions standards do not generate social benefits from abatement and are costly to inspect. The owners of compliant automobiles incur an inspection fee (F) paid to the inspection station, a registration tax ($\boldsymbol{\tau}$) to the state government, and implicitly the opportunity cost of time (C^{OC}) for the amount of time spent on the inspection (dur^{1}).

Additional costs are incurred by owners of automobiles that are found to be noncompliant and are either repaired or receive waivers. Figure 3 shows that owners of repaired automobiles incur the costs of repairs (C^{REP}) as well as additional opportunity costs of time. An owner of a noncompliant automobile must spend time getting it repaired (dur^{R}) and re-inspected (dur^{2}). If the automobile once again fails inspection and the owner has spent at least the repair cost limit (C^{RCL}) towards repairs that improve emissions he or she may apply for an inspection waiver which also takes time (dur^{W}). The waiver permits the automobile to be legally driven for one year while in violation of emissions standards. If an owner decides to scrap his or her automobile the only costs incurred are the inspection fee (F) paid to the inspection station and opportunity costs of time for the inspection ($dur^{1} \times C^{OC}$). These would also be the same costs incurred by an owner who decides to drive his or her automobile illegally.[30]

As shown in figure 3, social benefits of emissions abatement are only generated by automobiles that are found to be noncompliant. If the automobile is found to be noncompliant the owner is faced with four choices: 1) repair the automobile to compliance; 2) apply for a waiver; 3) scrap the automobile; or 4) drive illegally. In many jurisdictions automobile registration is only available for compliant or waiver automobiles. Furthermore registered automobiles are required to display a colored sticker on the licence plate. This signal is a deterrent to driving illegally, particularly in more urbanized areas where it is more likely to be observed by law enforcement. This fourth option will be ignored in this analysis because the North Carolina program covers 48 of the most urban counties that comprise more than 80 percent of the state's

---

[30] My analysis ignores hassle costs which include finding a buyer or junkyard for the scrapped automobile.

population.[31] In North Carolina penalties for operating an unregistered automobile include a fine of up to $200 and imprisonment of up to 20 days.[32]

5. B. Emissions abatement

The change in emissions (*ΔE*) from I/M induced repairs or scrappage is estimated by integrating the area between two emissions trajectories as shown in figure 4. Figure 4's vertical axis measures the amount of emissions produced per mile, its top horizontal axis measures time in years, and its bottom horizontal axis measures vehicle usage in terms of vehicle-miles traveled. These emissions trajectories are drawn concave based on the results of Mérel et al. (2014) and confirmed using North Carolina data. As automobile *i* is driven over time it accumulates VMT and moves along the concave emissions trajectory *ET1*. The automobile is first determined to be noncompliant at time t=2 because its emissions (point A) exceed the federal exhaust emissions standards which are summarized in table 5. Upon failure automobile *i*'s owner chooses to repair it and pays for instantaneous abatement equal to the linear distance between points A to E. After the repairs automobile *i* will once again be driven and accumulate VMT but now along *ET2*.

The total abatement from I/M induced repairs is measured from the time (in cumulative vehicle-miles traveled or odometer reading) of repair until the automobile would have been retired in the absence of I/M. This counterfactual retirement is shown as time period *T'* or cumulative VMT *M'* in figure 4. One could narrowly define automobile retirement as the point

---

[31] North Carolina's I/M program covers 48 of 100 counties and more than 80 percent of the population.
[32] See North Carolina General Statues §20-111, http://www.ncleg.net/gascripts/statutes/statutelookup.pl?statute=20-111, and §15A-1340.23, http://www.ncga.state.nc.us/enactedlegislation/statutes/html/bysection/chapter_15a/gs_15a-1340.23.html.

when the automobile is sold for parts. Because it is unobservable to the I/M regulator whether an automobile is sold for parts or simply in a used market outside of the jurisdiction I will extend the definition of retirement to also include the latter case. Furthermore, I will define *scrappage* as retirement following an emissions inspection failure. Thus total abatement from I/M induced repairs in time *t*=2 is equal to area ACEG.

Figure 4 also illustrates the benefits of emissions abatement from I/M induced scrappage. In time *T* automobile *i* once again fails its inspection, at point G on *ET2*, and owner *i* decides to scrap it. In the absence of I/M the automobile would not have been retired until time period *T'* with cumulative VMT *M'*. The owner is also going to have to substitute their VMT demand to a "new" replacement automobile. I make four main assumptions about the new replacement automobile. First, the replacement is of the same size or class as the scrapped automobile. Second, the replacement is in compliance with exhaust emissions standards in time period *T*. Third, the replacement has less than 70 thousand miles. Fourth, the replacement is the modal automobile that is registered for the first time in an I/M treated county in North Carolina during time period *T*.[33] In sum the replacement automobile is not necessarily recently manufactured but modestly used. Figure 4 illustrates the emissions trajectory of the compliant replacement automobile as *ET3*. Thus the abatement I/M induced scrappage in time period *T* is equal to area GHIJ. Total abatement from I/M generated by automobile *i* is the shaded region ADEH+GHIJ.

Figure 4 makes it clear that the total amount of abatement depends on several factors. First are the shapes of emissions trajectories *ET1*, *ET2*, and *ET3*. For example, the abatement from

---

[33] Those "new" automobiles registered in an I/M treated county for the *first* time were either recently purchased from a dealer or secondary market. The "new" used automobiles were registered in a county that was not treated with I/M in time period *T-1*. If, however, it had previously registered in a non-I/M county it would not be considered a new replacement.

repairs in figure 4 is dependent on the counterfactual emissions trajectory *ET1*; the amount of emissions per mile automobile *i* would have produced had it not failed its inspection. Second, abatement depends on the degree of noncompliance, or the amount of excess emissions produced by the noncompliant vehicle. Excess emissions are those produced over and above the federal standards. Because federal emissions standards are tightened over time the amount of excess emissions is largely a function of vehicle age or usage, which may be functions of economic indicators.[34] Third, the benefits of repair depend upon the magnitude of instantaneous abatement, shown as the movement from point A to point E in figure 4. Fourth, the amount of abatement also depends on the number of vehicle-miles traveled the automobile would have produced had it not failed its inspection or in the absence of I/M. Thus, the abatement from inspecting older automobiles that produce significant excess emissions is reduced to the extent that automobiles are driven less intensively over time.

5. C. Estimating benefits and costs

The North Carolina data from emissions inspections conducted between 1999 and 2013 are used to estimate seven models that predict variables required to calculate either the benefits or costs of I/M or both. First, as shown in figure 3, it is necessary to estimate both inspection failure (f_{it}) and the repair-waiver-scrap choice (r_{it}, w_{it}, and s_{it}). In order to operationalize the framework these discrete outcomes will be estimated as probabilities. Second, the change in emissions (ΔE) from I/M induced repairs or scrappage is complex and requires empirical models to predict four

---

[34] Kahn (1996a) finds significant decreases in automobile emissions after exhaust emissions standards are tightened. Kahn (1996b) discusses the diminishing returns to air pollution abatement and Kahn (1996c) questions when I/M can be eliminated.

essential elements: 1) annual vehicle-miles traveled (vmt_{it}), 2) emissions per mile (epm_{iem}), 3) instantaneous abatement from repairs (apm_{iem}), and 4) cumulative vehicle-miles traveled (Σvmt_{it}) at automobile retirement. Finally, I also estimate the duration (in minutes) of the emissions inspection (dur^1 and dur^2) for quantifying the value of the automobile owner's foregone time.

Six of the seven empirical models are used to estimate the benefits of I/M. The expected benefits that were summarized in figure 3 are formalized with equation 1. Benefits are a function of abated emissions from each emission *e*, which include carbon monoxide and hydrocarbons in this analysis. If automobile *i* were to pass the emissions inspection ($f_{it} = 0$) at time t=2 it will generate zero benefits because it will be neither repaired nor scrapped. The term B^R in equation 1 measures the abatement benefits from automobile *i*'s I/M induced repairs ($r_{it} = 1$ or $w_{it} = 1$) as the difference between counterfactual emissions (ce^R_{ite}) and repaired emissions (re_{ite}) from the automobile's current odometer reading (Σvmt_{it}) until its counterfactual retirement odometer reading ($cvmt_{it}$). This is the area between *ET1* (counterfactual emissions) and *ET2* (repaired emissions) from figure 2. Because a scrapped automobile's owner will need a replacement, the benefits from scrappage, B^S in equation 1, are estimated net of the average emissions produced by "new" automobiles (ne_{ite}) over the incremental counterfactual miles as before. In either case the social value of emissions abatement is calculated by multiplying the tons of abated emissions by their social cost (C_{gte}^{SCE}) which are borrowed from Matthews and Lave (2000) and Mendelsohn and Muller (2009).[35]

---

[35] The social cost of hydrocarbon emissions comes are borrowed from Muller and Mendelsohn's (2009) county-level estimates of the marginal external damages (MED) of volatile organic compounds (VOCs). The social cost of carbon monoxide emissions come from Matthews and Lave (2000). These numbers were chosen because, as shown in table 4, they are the most current estimates for these two emissions.

$$B_{it}^{IM} = (Pr(f_{it}))\times[\sum_{e}^{E}[B_e^R + B_e^S]] \qquad \textit{Equation } 1$$

where

$$B_{ite}^{R} = (Pr(r_{it}) + Pr(w_{it}))\times(\int_{\Sigma vmt_{it}}^{cvmt_{it}}[ce_{ite}^{R}(x)\ - re_{ite}(x)]dx)\times C_{gte}^{SCE} = \Delta E_{ite}^{R}\times C_{gte}^{SCE}$$

$$B_{ite}^{S} = Pr(s_{it})\times(\int_{\Sigma vmt_{it}}^{cvmt_{it}}[ce_{ite}^{S}(x)\ - ne_{ite}(x)]dx)\times C_{gte}^{SCE} = \Delta E_{ite}^{S}\times C_{gte}^{SCE}$$

and

$$Pr(r_{it}) + Pr(w_{it}) + Pr(s_{it}) = 1$$

Equation 2 formalizes the costs described in figure 3. The terms C^C, C^R, C^W, and C^S refer to compliant, repaired, waiver, and scrapped automobiles respectively. Unlike equation 1, many variables in equation 2 are not estimated. Where data are unavailable I make conservative assumptions about I/M costs.[36] For example, the North Carolina I/M regulator does not observe repair costs and thus I cannot estimate them from the data. Thus I will assume that all automobile repairs cost exactly the repair cost limit ($C^{REP} = C^{RCL}$). In addition, I use the U.S. Census Bureau's American Community Survey's median per capita income from zip-code tabulation areas for the automobile owner's value of time or opportunity costs (C^{OC}_{itg}).[37] Lastly, I will conservatively assume that repairs take only 30 minutes and applying for a waiver takes 30 minutes ($dur^{w}_{it} = 30$). Furthermore, the values for the inspection fee (F), registration tax ($\boldsymbol{\tau}$), and repair cost limit (C^{RCL}) are calibrated to the North Carolina parameters of \$10.15, \$6.25, and

---

[36] Similarly administrative costs are ignored in this analysis. According to the North Carolina Program Evaluation Division (NC PED, 2008) it costs the Division of Motor Vehicles and Division of Air Quality approximately \$41 million dollars per year to administer the I/M program. These costs include those associated with setting policies and procedures, the oversight of the decentralized inspection stations, data collection and management, and the auditing of collected data.

[37] Per capita income is merged with the North Carolina I/M data using the zip code from the inspection station the automobile owner visited. It is assumed that owners choose stations located near their homes.

\$200. The only variables in equation 2 that are estimated are the probability of failure (f_{it}), the repair-waiver-scrap choice (r_{it}, w_{it}, and s_{it}), and the inspection durations (dur^{1} and dur^{2}).

$$C_{it}^{IM} = F + (C_{itg}^{OC} \times (dur_{it}^{1})) + (C_{it}^{C} + C_{it}^{R} + C_{it}^{W} + C_{it}^{S}) \qquad \textit{Equation } 2$$

where

$$C_{it}^{C} = [(1 - Pr(f_{it})) \times \tau]$$

$$C_{it}^{R} = [Pr(f_{it}) \times Pr(r_{it}) \times ((\tau + C^{REP}) + (C_{itg}^{OC} \times (dur_{it}^{R})) + (C_{itg}^{OC} \times (dur_{it}^{2})))]$$

$$C_{it}^{W} = [Pr(f_{it}) \times Pr(w_{it}) \times ((\tau + C^{RCL}) + (C_{itg}^{OC} \times (dur_{it}^{R})) + (C_{itg}^{OC} \times (dur_{it}^{2})) + (C_{itg}^{OC} \times (dur_{it}^{w})))]$$

and

$$C_{it}^{S} = [Pr(f_{it}) \times (1 - Pr(s_{it})) \times \tau]$$

The benefits and costs will be aggregated for each automobile *i* in time period *t* to calculate the annual net benefits of I/M as shown in equation 3. Table 5 defines each term included in equations 1, 2, and 3. The next subsection briefly explains the importance of each of the seven models I estimate using North Carolina I/M data collected between 1999 and 2013. Chapter 2 of my dissertation carefully describes the independent variables included in each of these models.

$$NB_{t}^{IM} = \sum_{i}^{I} (B_{it}^{IM} - C_{it}^{IM}) \qquad \textit{Equation } 3$$

6. Results

Figure 5 plots the estimated benefits and costs, in millions of June 2015 U.S. dollars, of North Carolina's I/M program between 2000 and 2012.[38] Most importantly figure 5 illustrates that the program, as it existed during that time, was inefficient. Mean annual benefits from I/M induced abatement from repairs and scrappage were $28.5 million compared to an average annual cost of $73.0 million. The mean net benefits of this program were -$44.5 million per year.

The variation in benefits and costs over time, illustrated in figure 5, is largely due to several factors. The first is the number of automobiles inspected annually. Between 2002 and 2006, as previously discussed in section 4, the North Carolina program was expanded from 9 to 48 counties. Compliance costs to automobile owners across the state increased accordingly. Similarly, the sharp decrease in benefits and costs in 2009 was largely caused by a decrease in automobile registrations (an increase in automobile retirement) arising from the Great Recession.

The benefits and costs of I/M are also affected by the characteristics of the automobile fleet. For example, the age distribution and usage intensity affect the benefits and costs of I/M in several ways. To illustrate how, consider automobiles produced between 1995 and 1998. Table 5 shows that federal hydrocarbon exhaust emissions standards were tightened for automobiles produced during those years. As these automobiles were driven they progressed along their emissions trajectory and eventually some began to fail annual emissions inspections.

Figure 6 illustrates the sources of carbon monoxide and hydrocarbons emissions abatement, in thousands of tons, between 2000 and 2012. It shows that nearly all of the I/M induced

---

[38] This analysis omits data from 1999 and 2013. The former is excluded because VMT is unobservable for automobiles inspected in the first year of data. The latter is omitted because retirement is unobservable in the last year of data.

abatement comes from carbon monoxide emissions. Between 2000 and 2005 hydrocarbon emissions abatement from I/M induced repairs increased somewhat steadily before falling constant. Nearly all of this hydrocarbons abatement came from automobiles produced after 1995 (when standards were tightened). The steady increase in hydrocarbons abatement between 2000 and 2005 was a result of these automobiles moving along their emissions trajectories as they were driven and eventually failing annual inspections.

By 2008 many of the model year 1995-1998 automobiles had been retired or scrapped as shown in figure 7. It clearly shows that very few automobiles are older than 10 years. As 1995-1998 automobiles were retired they made up a smaller proportion of the fleet each inspection cycle. Thus the tons of hydrocarbon abatement from that cohort decreased. At the same time, newer automobiles moved along their emissions trajectory and eventually began to fail inspections. Because newer automobiles, for example those produced between 1999 and 2003 (see table 5), were produced under tighter standards, total abatement from inspecting those automobiles would be less than inspecting earlier *dirtier* model year automobiles. These newer automobiles were less likely to fail but comprised a relatively larger proportion of the fleet and were moving along their emissions trajectories at a faster rate. Abatement from inspecting these newer automobiles, however, did help to counteract potential reductions from the retirement of earlier *dirtier* automobiles. Thus hydrocarbons abatement eventually became constant as shown in figure 6 and total abatement began to fall for later *cleaner* model year automobile cohorts.

The overall inefficiency of North Carolina’s I/M program, as it existed between 2000 and 2012, was driven by several factors. Foremost among these are number of automobiles inspected versus the number of federal exhaust emissions standards violators. Annually only about 50 thousand noncompliant automobiles are identified out of more than 2 million inspected. In other words, the overall failure rate is about 2.5 percent. Furthermore, approximately 73 percent of the noncompliant automobiles are either repaired or scrapped. The remaining 27 percent of noncompliant automobiles receive waivers and are not repaired in full.

Second, the abatement from repairs is limited and very heterogeneous.[39] Figure 8 illustrates the distribution of the social value of emissions abatement from I/M induced repairs. The mean (median) social value of I/M induced abatement from repairs is \$331 (\$340) and the standard deviation is \$186. To put this number in perspective consider that the value of legal emissions produced annually by automobiles in North Carolina would at maximum be about \$57.[40] Despite this social value of abatement exceeding the average cost of I/M compliance there are far more automobiles incurring costs than generating benefits.

Figures 10 and 11 also help to illustrate the heterogeneity in the social value of emissions abatement. Figure 9 plots the social value of abatement from I/M repairs across odometer reading. It shows, consistent with figure 4, that abatement is generally positively correlated with usage. Figure 10 plots more of a quadratic or concave relationship between the social value and automobile age. The young automobiles, on the left side of figure 10, with high social values of emissions abatement are also those automobiles plotted on the right hand side of figure 9. Such results suggest that North Carolina’s recently modified *selective automobile targeting* regime may increase the efficiency of the program.

---

[39] This result is consistent with the findings of past research including Ando et al. (2000) and Mérel et al. (2014).

[40] Federal exhaust standards, reported in table 5, make it clear that some automobile emissions are allowed by law. The average automobile in North Carolina can produce 74, 3.5, and 7 thousand grams of carbon monoxide, hydrocarbon, and nitrogen oxide emissions legally in a year. This translates into 0.0818 (\$51.95), 0.0039 (\$2.96), and 0.0077 (\$2.55) short tons (in the social value) of carbon monoxide, hydrocarbon, and nitrogen oxide emissions.

The estimation framework discussed in section 5 was also used to compare the efficiency of various I/M regimes. Figure 11 plots the estimated benefits and costs for several different I/M regimes. The “Old NC” regime refers to North Carolina’s program as it existed between 2000 and 2012; the same regime’s benefits and costs are also plotted in figure 5. The “New NC” regime refers to the North Carolina program after April 1, 2015; the *selective automobile targeting* regime. Figure 11 shows that benefits are expected to decrease 11 percent while costs will decrease by 49 percent; net benefits should improve by 63 percent to -$16.3 million in June 2015 U.S. dollars per year. While the newly adopted regime increases the efficiency of I/M in North Carolina it still does not generate positive net benefits.

Figure 11 also shows that other regimes that are more efficient regimes than the one recently adopted by North Carolina do exist. For example, had North Carolina adopted biennial inspections rather than *selective automobile targeting* net benefits would be expected to be -$12.9 million per year. Alternatively triennial inspections are estimated to generate net benefits equal to -$0.9 million per year. In addition, California’s I/M regime combines biennial inspections and exemptions to automobiles from the most recent six model years. Net benefits under this regime in North Carolina are expected to generate net benefits equal to -$1.1 million. The final regime, “Perfect S.T.,” in figure 11 plots the benefits and costs for a program that could perfectly *selectively target* or inspect only those automobiles for inspections that will generate positive net benefits. This purely theoretical regime is clearly the most efficient possible and would be estimated to generate net benefits equal to $6.1 million per year.

Previous research including Bin (2003) and Moghadam and Livernois (2010) have suggested alternative regimes to those previously described. This chapter builds on this work by employing the estimation framework described in section 5 to evaluate the efficiency of other types of *selective automobile targeting*. I used the framework described in section 5 to estimate the net benefits of more than 1,900 different I/M regimes. All selectively target automobiles by their odometer reading, age, number of engine cylinders, engine size in liters, number of transmission speeds, weight, fuel economy, size, drive type, body type, annual VMT, age and odometer, and age and VMT.

Figure 12 plots the median benefits and costs, in 2015 U.S. dollars, of I/M regimes that selectively target based on odometer reading in 10 thousand mile increments. The figure shows that regimes that require automobiles with more than 130 thousand cumulative vehicle-miles traveled to be tested generate positive net benefits (the median net benefits are equal to $0.4 million). As the regime increases the cut-off point for inspection exemptions, and thus decreases the proportion of the fleet inspected, the costs of I/M decrease more than the benefits and the efficiency of the program increases. In fact, testing automobiles with more than 150 thousand miles is the 42nd most efficient regime of all those examined; it is estimated to generate annual net benefits of $1.4 million. Several other regimes plotted in figure 12 are also some of the most efficient regimes analyzed as shown in table 8.

Table 8 reports the median estimated net benefits, in June 2015 U.S. dollars, for inspection years 2000 through 2012. It shows two important results. First, table 8 reveals a significant gap, $3.9 million, in efficiency between the top two most efficient programs. Second, excluding perfect selective targeting, the most efficient regimes are those that inspect automobiles based on where they are along their emissions trajectory in terms of age and annual VMT or odometer reading. In fact all regimes that selectively target based on other automobile attributes generate negative net benefits.

Table 8 shows that the most efficient I/M regimes inspect automobiles based on where they sit on their emissions trajectories. Thus usage intensity is the most efficient margin I/M can selectively target automobiles along. Simply targeting based on automobile age like the California program fails to account for the automobiles position on its emissions trajectory. Targeting automobiles based on age alone cannot generate efficiency improvements comparable to those that account for usage intensity. Nearly all such regimes generate negative net benefits. Figure 13 plots the benefits and costs for regimes that selectively target by automobile age. The inefficiencies exist because abatement from repairs and scrappage is highly dependent on the driving decisions of automobile owners.[41]

Figure 18 plots the benefits and cost, in June 2015 U.S. dollars, for the I/M regimes suggested by Bin (2003) and Moghadam and Livernois (2010). The regime suggested by Bin (2003) targets automobiles more than 10 years old, with less than 2,000 cubic centimeter engines, and more than 100 thousand miles. It is estimated to generate net benefits equal to -\$0.52 million per year. Figure 18 shows that both benefits and costs are extremely low because very few automobiles meet these criteria. The regimes suggested by Moghadam and Livernois (2010) are much more inclusive and likewise have much higher costs than the regime suggest by Bin (2003). The two Moghadam and Livernois (2010) regimes are optimal for different assumptions about how the instantaneous abatement from repairs vary with automobile usage. The first regime biennially automobiles older than 4 and less than 12 years old and generates net

---

[41] It is also affected by exogenous tightening of exhaust emissions standards. Other exogenous policies that seek to reduce road congestion and deter private transportation may also reduce efficiency of I/M.

benefits equal to -\$1.86 million per year. The second regime also inspects automobiles older than 12 and less than 19 years annually and generates benefits equal to -\$4.00 million per year. These two regimes are inefficient because they fail to account for where the automobile sits on its emissions trajectory.

7. Conclusion

Automobile emissions inspections are used all over the world and affect tens of millions of consumers but receive relatively little attention in the economic literature. The attention that has been awarded to them, however, generally results in less than favorable conclusions or observations. This may have been motivation for North Carolina's recent change to its I/M program; one that is in many ways now more nationally representative.

The estimation framework I developed in chapter 2 and discussed in section 5 of this chapter was used to evaluate the efficiency of I/M. I estimated seven empirical models using an extensive dataset from the North Carolina I/M collected between 1999 and 2013. The results of the analysis confirm several conclusions from previous literature. First, a very small fraction of the fleet is noncompliant. Second, the value of abatement is limited relative to the costs of compliance causing North Carolina's I/M to largely fail a benefit-cost test. Third, *selective automobile targeting*, like the regime recently adopted by North Carolina, can improve the efficiency of I/M programs.

The low failure rate may suggest one of several things. First, it may either suggest that failure is perceived as so economically costly to owners that they keep their automobiles well maintained, at least at the inspection. This is an indirect abatement incentive and is known in the literature as “enforcement leverage.” In the context of I/M, enforcement leverage is likely a negligible source of abatement. It is doubtful owners would go to great lengths to maintain their automobiles given that the expected cost of I/M is only about $30. The maximum cost of noncompliance is $216.40 plus opportunity costs of time for approximately 30 minutes. Avoiding such low costs does not seem to be a reasonable incentive for mid-inspection cycle repairs that may cost considerably more.

Alternatively the results may indicate that inspections are no longer generating much social value. This was suggested by Fowlie (2015) in a recent blog post concerning the application of Goodhart’s law to pro-cycling, education reform, and emissions testing. Goodhart’s law says that once evaluation criteria become established they cease to provide a reliable measure. It is clear that Volkswagen AG designed their automobiles to cheat the test. It could be the case that manufacturers have the technology to design automobiles that are capable of meeting current exhaust standards and pass periodic inspections. Perhaps then it is time to once again tighten exhaust standards. Another possible explanation may be that it is simply the result of periodic tightening of exhaust emissions standards. Similar to the results presented in section 6, Kahn (1996b) also found that aggregate emissions decrease as *dirtier* model year automobiles are retired from the fleet. In addition, Kahn (1996c) suggests at some point it may be best to discontinue the use of I/M.

The results of this analysis indicate that I/M can provide value in terms of efficient emissions but not as they are often designed. Figure 20 summarizes the results of the analysis using a simple graph. It plots a linear downward sloping marginal benefit (MB) curve and a linear upward sloping marginal cost (MC) curve. The horizontal axis measures the proportion of the automobile fleet periodically inspected by I/M. The vertical axis measures the value of marginal costs and benefits in dollars. Figure 20 shows that the proportion of the fleet currently inspected (P^{NCIM}) exceeds the economically efficient proportion. The shaded region, ABC, in figure 20 illustrates the social costs of over-inspection. The recently adopted North Carolina I/M regime is estimated to increase the efficiency of I/M by 63 percent, raising net benefits from -$44.5 million to -$16.3 million in June 2015 U.S. dollars per year. Under both regimes the marginal cost of the last automobile inspected exceeds its marginal benefit from abatement. Increasing exemptions further based on the automobiles position on its emissions trajectory could allow North Carolina’s I/M program to generate positive net benefits. For example, table 8 shows that a regime that tests only automobiles older than 5 years and are driven more than 20 thousand miles per year is estimated to generate net benefits of $2.13 million per year.

There are several limitations to the data that may impact the estimation of the net benefits of I/M. First, the use of idle tailpipe emissions are a lower quality substitute for real-time emissions or accelerated simulation mode (ASM) tests where the engine is under a varying load. Second, the use of the OBD tests provides no data to regulators about actual emissions, idle or otherwise. In addition, both repairs and expenditures are unobservable to the program and the low repair cost limit may cannibalize abatement that would have otherwise taken place. Third, using data from 1999-2005 to infer emissions from 2006-2013 may be problematic. Fourth, an ideal dataset would also include information about the owners of the automobiles and identify automobiles by the same household. In addition, it would be ideal to have information about the preferences of these owners. For example, it would identify all automobiles in a household, the census block, and periodic maintenance practices and expenses. In addition, the ideal dataset would be able to identify which *scrapped* automobiles are exported to other markets versus demolished for parts. Finally, there is no data available about the untreated automobile fleet. The ideal dataset would overcome such limitations.

This chapter represents a first attempt at a comprehensive I/M evaluation framework. In the long term I plan to develop the ideal dataset. Portable emissions measurement systems (PEMS) could be used to collect real time emissions data from in-use automobiles on public roads and highways. Such information would overcome the first two limitations of the dataset. It could eliminate the need to make assumptions about nitrogen dioxides and would allow for an accurate accounting of the legal emissions produced by automobiles. In addition, a survey of North Carolina drivers could overcome the second two limitations. The survey could cover driver preferences and inquire about mid-I/M-cycle automobile repairs. Finally, data about the untreated fleet from the North Carolina Division of Motor Vehicles (DMV) would provide robust control group. Unfortunately the state's price tag on this data considerably exceed dissertation research budgets. Such survey information and regulator data would permit a detailed evaluation of I/M's abatement additionality.

8. Works Cited

Alberini, Anna, Winston Harrington, and Virginia McConnell. 1998. “Fleet Turnover and Old Car Scrap Policies.” *Resources for the Future Discussion Paper* 98-23.

Arlot, Sylvain and Alain Celisse. 2010. “A survey of cross-validation procedures for model selection.” *Statistics Surveys* 4: 40-79

Ando, Amy, Virginia McConnell, and Winston Harrington. 2000. “Costs, Emissions Reductions, and Vehicle Repair: Evidence from Arizona.” *Journal of the Air and Waste Management Association* 50: 509-521.

Anilovich, I., A.S. Hakkert. 1996. “Survey of vehicle emissions in Israel related to vehicle age and periodic inspection.” *The Science of the Total Environment* 189/190, 197–203.

Barrett, Richard A., Ronald A. Ragazzi, and James A. Sidebottom. 2005. “Colorado OBD-II Vehicle Evaluation Study. Final Report.” *Colorado Department of Public Health and Environment, Air Pollution Division*

Bennear, Lori S., Jonathan M. Lee, and Laura O. Taylor. 2013. “Municipal Rebate Programs for Environmental Retrofits: An Evaluation of Additionality and Cost-Effectiveness.” *Journal of Policy Analysis and Management* 32(2): 350-372.

Beydoun, Mustapha. 2004. “Vehicle Characteristics and Urban Air Pollution: Socioecomomic and Environmental Policy Issues.” *Unpublished dissertation*

Beydoun, Mustapha, Jean-Michel Guldmann. 2006. “Vehicle characteristics and emissions: Logit and regression analyses of I/M data from Massachusetts, Maryland, and Illinois.” *Transportation Research Part D* 11, 59-76.

Bin, Okmyung. 2003. “A logit analysis of vehicle emissions using inspection and maintenance testing data.” *Transportation Research Part D* 8, 215-227

Breimann, L., J.H. Friedman, R.A. Olshen, and C.J. Stone. 1984. “Classification and regression trees.” *Wadsworth Statistics/Probability Series*. Wadsworth Advanced Books and Software, Belmont, CA

California Inspection and Maintenance Review Committee (IMRC). 2000. Smog Check II Evaluation, Full Report; Sacramento, CA.

Calvert, J.G., J. B. Heywood, R. F. Sawyer and J. H. Seinfeld. 1993. “Achieving Acceptable Air Quality: Some Reflection on Controlling Vehicle Emissions.” *Science,* Vol. 261, No. 5117 (Jul. 2, 1993), pp. 37-45

Clean Air Act, The. U.S. Code 42 (2004), §7401-7626

Cleves, Mario, Roberto G. Gutierrez, William Gould, Yulia V. Marchenko. 2010. *An Introduction to Survival Analysis Using Stata, 3rd Ed.* Stata Press.

Delphi. 2011. “Worldwide Emissions Standards: Passenger Cars and Light Duty Vehicles 2011-2012”

Delphi. 2013. “Worldwide Emissions Standards: Passenger Cars and Light Duty Vehicles 2013-2014”

Eastern Research Group, Inc., 2006. Arizona Alternative Compliance and Testing Study (AZACTS) – summary of activities and recommendations to date. Final report prepared for the Arizona Department of Environmental Quality, Air Quality Division, Phoenix, AZ, by Eastern Research Group, Inc., Austin, ERG No. 0147.00.008.002.

Eisinger, Douglas S. and Peter Wathern. 2008. “Policy evolution and clean air: The vase of US motor vehicle inspection and maintenance.” *Transportation Research Part D* 13: 359-368

Executive Order 13563 of January 18, 2011, Improving Regulation and Regulatory Review. *Federal Register* 76(14) (2011): 3821-3823. http://www.gpo.gov/fdsys/pkg/FR-2011-01-21/pdf/2011-1385.pdf

Fankhauser, S. 1994. “The social costs of greenhouse gas emissions: An expected value approach.” *Energy Journal* 15 (2).

Farrow, Scott and Michael Toman. 1998. “Using Environmental Benefit-Cost Analysis to Improve Government Performance.” *Resources for the Future* Discussion Paper 99-11

Fowlie, Meredith, Christopher R. Knittel, and Catherine D. Wolfram. 2012b. “Sacred Cars? Optimal Regulation of Stationary and Non-stationary Pollution Sources.” American Economic Journal: Economic Policy 4(1): 98-126

Fowlie, Meredith. 2015. “Vehicle emissions testing where the rubber hits the road.” Energy Institute at Haas. 23 November 2015. https://energyathaas.wordpress.com/2015/11/23/vehicle-emissions-testing-where-the-rubber-hits-the-road/

Friesen, L. 2003. “Targeting enforcement to improve compliance with environmental regulations.” *Journal of Environmental Economics and Management* 46(1): 72-85

Gardetto, Ed, Jim Lindner, Tandi Bagian. 2005. “High-mileage study of on-board diagnostic emissions.” *Journal of the Air and Waste Management Association* 55, 1480–1486.

Grambsch, P.M, and T. M. Therneau. 1994. “Proportional hazards tests and diagnostics based on weighted residuals.” *Biometrika* 81: 515-526

Greenstone, Michael, Elizabeth Koptis, and Anne Wolverton. 2013. "Developing a Social Cost of Carbon for U.S. Regulatory Analysis: A Methodology and Interpretation." *Review of Environmental Economics and Policy* 7(1): 23-46

Hahn, Robert W. (1995). "An Economic Analysis of Scrappage." *The RAND Journal of Economics* 26(2): 22-242.

Harford, J.D. 1991. "Measurement error and state-dependent pollution control enforcement." *Journal of Environmental Economics and Management* 21(1): 67-81

Harford, J.D., W. Harrington. 1991. "A reconsideration of enforcement leverage when penalties are restricted." *Journal of Public Economics* 45(3): 391-395

Harrington, Winston. 1988. "Enforcement leverage when penalties are restricted." *Journal of Public Economics* 37(1): 29-53

Harrington, Winston, Virginia McConnell, Amy Ando. 2000. "Are vehicle emission inspection programs living up to expectations?" *Transportation Research Part D* 5, 153-172

Hedglin, P., 2006. OBD code clearing – I/M impact and potential solutions. Presented at the 22nd Annual Clean Air Conference, Colorado State University, Breckenridge, CO, September 24–27, Bureau of Automotive Repair, Engineering and Research Branch, Denver.

Hubbard, Thomas N. 1997. "Using inspection and maintenance programs to regulate vehicle emissions." *Contemporary Economic Policy* 15, 52-62.

Jacobsen, Mark R. and Arthur A. van Benthem. 2013. "Vehicle scrappage and gasoline policy." *National Bureau of Economic Research* Working Paper 19055

Kahn, Matthew E. 1994. "Do vehicle emissions testing programs improve air quality?" Columbia University Discussion Paper No. 687

Kahn, Matthew E. 1996a. "New evidence on trends in vehicle emissions." *Rand Journal of Economics* 27, 183–196.

Kahn, Matthew E. 1996b. "The Efficiency and Equity of Vehicle Emissions Regulation: Evidence from California's Random Audits," *Eastern Economic Journal* 22, 457–65.

Kahn, Matthew E. 1996c. "New estimates of the benefits of vehicle emissions regulation." *Economic Letters* 51, 363-369.

Kaplan, E.L., P. Meier. 1958. "Nonparametric estimation from incomplete observations." *Journal of the American Statistical Association* 53: 457-481

Knittel, Christopher R. 2009. "The Implied Cost of Carbon Dioxide under the Cash for Clunkers Program." *Working paper*

Knittel, Christopher R., Ryan Sandler (2013). "The Welfare Impact of Indirect Pigouvian Taxation: Evidence from Transportation." *NBER working paper 18849*

Krstajic, D., L.J. Buturovic, D.E. Leahy, S. Thomas. 2014. "Cross-validation pitfalls when selecting and assessing regression and classification models." *Journal of Cheminformatics* 6, 10

Lawson, Douglas R. 1993. "*Passing the test* Human behavior and California's smog check program." *Journal of the Air and Waste Management Association* 43, 1567–1575.

Mérel, Pierre, Aaron Smith, Jeffrey Williams, and Emily Wimberger. 2014. "Cars on crutches: How much abatement do smog check repairs actually provide?" *Journal of Environmental Economics and Management* 67: 371–395

Matthews, H. Scott, Lester B. Lave. 2000. "Applications of Environmental Evaluation for Determining Externality Costs." *Environ. Sci. Technol.* 34: 1390-1395

McCarthy, James E. 1997. "Highway Fund Sanctions for Clean Air Act Violations." CRS Report for Congress.

McLaughlin, Patrick A. 2008. "Not considering costs in setting NAAQS: a costly mistake." *George Mason University Mercatus Center Working Paper* 08-42

Moghadam, Arian Khaleghi, John Livernois. 2010. "The abatement cost function for a representative vehicle inspection and maintenance program." *Transportation Research Part D* 15, 285-297.

Mosteller, F. and J.W. Tukey. 1977. Data analysis and regression. Reading, Massachusetts. Addison-Wesley

Muller, Nicholas Z., Robert Mendelsohn. 2007. "Measuring the damages of air pollution in the United States." *Journal of Environmental Economics and Management* 54: 1-14

Muller, Nicholas Z., Robert Mendelsohn. 2009. "Efficient Pollution Regulation: Getting the Prices Right." *The American Economic Review* 99(5): 1714-1739

National Research Council, 2001. Evaluating Vehicle Emissions Inspection and Maintenance Programs. The National Academies Press, Washington D.C.

NC DAQ. 2003. "Smokestacks on Wheels." North Carolina Department of Environment and Natural Resources, Division of Air Quality. http://daq.state.nc.us/news/brochures/smokewheels.pdf

NC DOT DMV, NC DENR DAQ. 2012. “Study of the Potential Impacts of Exempting Motor Vehicles from Emissions Inspections: A Report to the Joint Legislative Transportation Oversight Committee, the Environmental Review Commission, the Joint Legislative Commission on Governmental Operations, the House and Senate Appropriations Subcommittees on Natural and Economic Resources, the House Appropriations on Transportation, and the Senate Committee on Appropriations on Department of Transportation.” North Carolina Department of Transportation, Division of Motor Vehicles and North Carolina Department of Environment and Natural Resources, Division of Air Quality.

NC PED. 2008. “Doubtful Return on the Public's $141 Million Investment in Poorly Managed Vehicle Inspection Programs.” North Carolina General Assembly, Program Evaluation Division.

Nordhaus, William D. 1991a. “To Slow or not to Slow: The Economics of the Greenhouse Effect,” *Economic Journal* 101(407): 920-937.

Nordhaus, William D. (1991b). “A Sketch of the Economics of the Greenhouse Effect,” *American Economic Review, Papers and Proceedings* 81 (2): 146-150.

Nordhaus, William D. (1992). “The DICE Model: Background and Structure of a Dynamic Integrated Climate Economy Model of the Economics of Global Warming.” *Cowles Foundation Discussion Paper*, 1009, New Haven, Connecticut.

Nordhaus, William D. (1993a). “Optimal Greenhouse Gas Reductions and Tax Policy in the 'DICE' Model,” *American Economic Review, Papers and Proceedings* 83(2): 313-317.

Nordhaus, William D. (1993b). “Rolling the 'DICE': An Optimal Transition Path for Controlling Greenhouse Gases.” *Resources and Energy Economics* 15: 27-50.

North Carolina Progress Board. 2003. “Our State, Our Money: A Citizen’s Guide to the North Carolina Budget.” http://www.osbm.state.nc.us/new_content/Citizen_Guide_to_Budget.pdf

Oliva, Paulina. 2012. “Environmental Regulations and Corruption: Automobile Emissions in Mexico City.” *Working paper*

Peck, Stephen C., Thomas J. Teisberg. 1993b. “Global Warming Uncertainties and the Value of Information: An Analysis Using CETA,” *Resource and Energy Economics* 15: 71-97.

Peterson, Jonathan R., and Henry S. Schneider. 2014. “Adverse Selection in the used-car market: evidence from purchase and repair patterns in the Consumer Expenditure Survey.” *RAND Journal of Economics* 45(1): 140-154

Picard, Richard R., and R. Dennis Cook. 1984. “Cross-validation of regression models.” *Journal of the American Statistical Association* 79(387): 575-583

Raymond, M. 1999. “Enforcement leverage when penalties are restricted: a reconsideration under asymmetric information.” *Journal of Public Economics* 73(2): 289-295

Reitze Jr., A.W., 1996. “Federalism and the inspection and maintenance program under the Clean Air Act.” *Pacific Law Journal* 27, 1461–1520.

Riveros, Hector G., Enrique Cabrera, Pilar Ovalle. 2002. “Vehicle inspection and maintenance, and air pollution in Mexico City.” *Transportation Research Part D* 7: 73-80

Sanders, Nicholas J. and Ryan Sandler. 2015. “Do Smog Checks Affect Smog? Emissions Inspections, Station Quality and Local Air Pollution.” *Working paper*

Sandler, Ryan. 2012. “Clunkers or Junkers? Adverse Selection in a Vehicle Retirement Program.” *American Economic Journal: Economic Policy* 4(4): 253–281

Schneeberg, Sara. “Federal – State Partnership in Implementing Air Quality Standards under the U.S. Clean Air Act.” U.S. EPA Office of General Counsel. http://www.epa.gov/ogc/china/partnership.pdf

Schneider, Henry S. 2012. “Agency Problems and Reputation in Expert Services: Evidence from auto repair.” *Journal of Industrial Economics* LX(3) 406-433

Shao, J. 1993. “Linear model selection by cross-validation.” *Journal of the American Statistical Association* 88(422): 486-494

Siceloff, Bruce. 2015. “Road Worrier: NC air quality agency wants to reduce auto emissions tests.” *The News & Observer.* 6 April 2015. http://www.newsobserver.com/news/local/news-columns-blogs/article17571191.html

Spink, Marcia, and Neil Bigioni. 2010. “Sanctions, Federal Implementation Plans (FIPs), and SIP Calls Under the Clean Air Act.” http://www.epa.gov/eogapti1/video/Sanctions1110/MarciaPresentationSanctions&FIPs_FINAL_8_26_10.pdf

Stedman, Donald H., Gary A. Bishop, J. E. Peterson, P. L. Guenther. 1991. “On-Road CO remote sensing in the Los Angeles Basin: Final Report.” *California Air Resources Board*, Sacramento, CA

U.S. EPA. 1992. I/M Costs, Benefits, and Impacts. Office of Mobile Sources, Ann Arbor, November.

U.S. EPA. 1994. “Automobile emissions: an overview.” *Office of Mobile Sources*. EPA-400-F-92-007. http://www3.epa.gov/otaq/consumer/05-autos.pdf

U.S. EPA. 2011b. “The Benefits and Costs of the Clean Air Act from 1990 to 2020.” *Office of Air and Radiation*

U.S. EPA. “Air Emission Sources.” Accessed on 13 August 2014. http://www.epa.gov/air/emissions/index.htm

U.S. EPA. “Cars, Trucks, Buses, and “Nonroad” Equipment.” Accessed on 12 January 2016. http://www3.epa.gov/airquality/peg_caa/carstrucks.html

VT DEC. “Mobile Sources Section.” Accessed on 7 January 2016. http://www.anr.state.vt.us/air/mobilesources/index.htm

Washburn, Scott, Joseph Seet, Fred Mannering. 2001. “Statistical modeling of vehicle emissions from inspections/maintenance testing data: an exploratory analysis.” *Transportation Research Part D* 6: 21-36

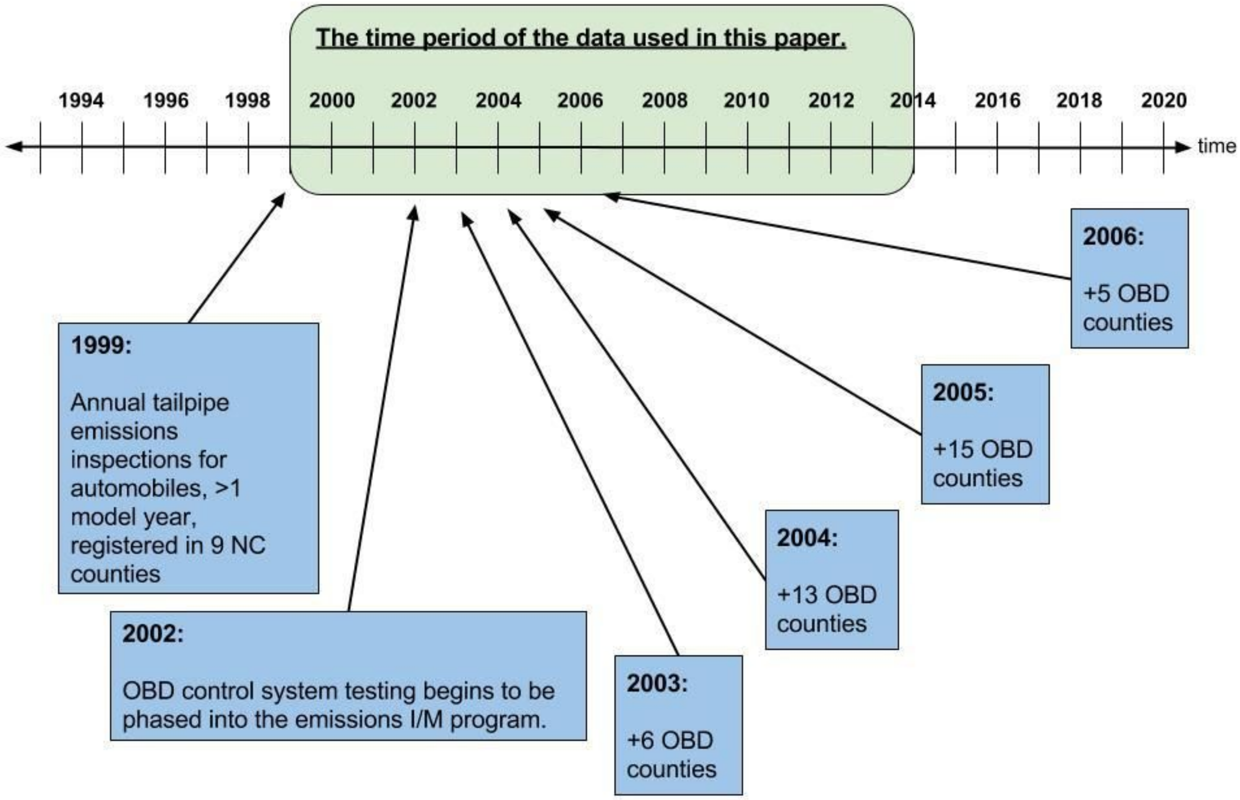
Wenzel, T. 1999 . “Using Program Test Result Data to Evaluate the Phoenix I/M Program; Report to the Arizona Department of Environmental Quality.” Lawrence Berkeley National laboratory: Berkeley, CA.

Zhang, Yongli, and Yuhong Yang. 2015. “Cross-validation for selecting a model selection procedure.” *Journal of Econometrics* 187: 95-112

9. Figures and Tables

Figure 1

Figure 1: The history of North Carolina's I/M program



Notes: Adapted from NC PED (2008).

Figure 2

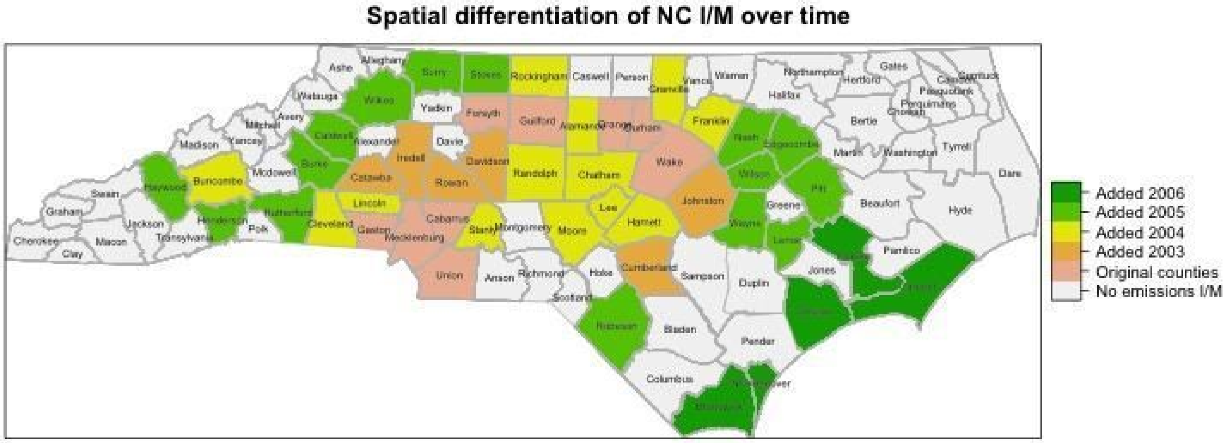
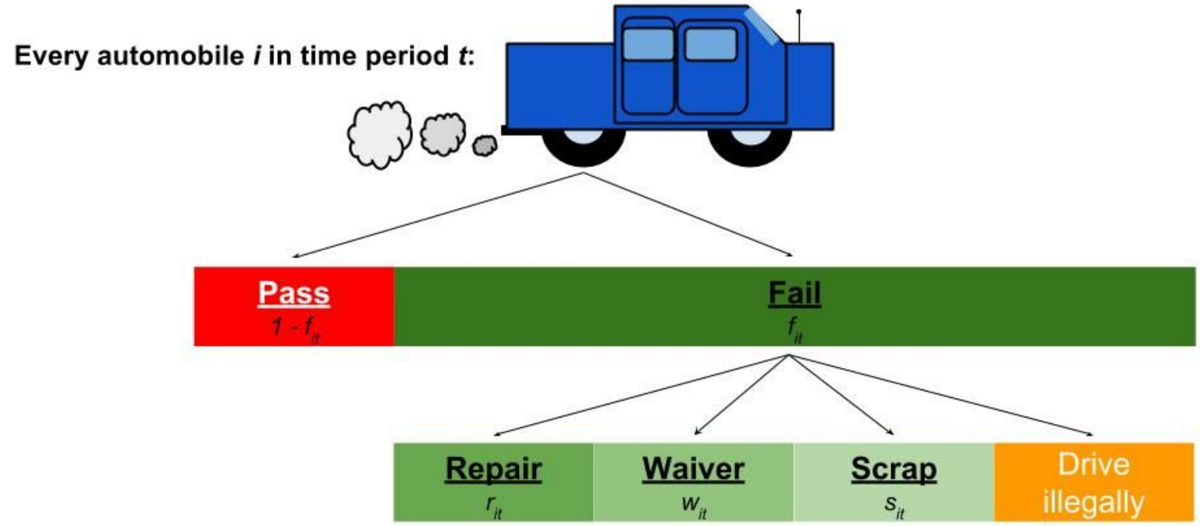


Figure 3

Figure 3: The benefits and costs of emissions inspection programs



	Pass	Repair	Waiver	Scrap	Drive illegally
Benefits to automobile *i* in time period *t*:	0	$\Delta E^r \times C^{SCE}$	$\Delta E^w \times C^{SCE}$	$\Delta E^s \times C^{SCE}$	0
Costs to automobile *i* in time period *t*:	$F + \tau + (dur^1 \times C^{OC})$	$F + \tau + C^{REP} + ((dur^1 + dur^R + dur^2) \times C^{OC})$	$F + \tau + C^{RCL} + ((dur^1 + dur^R + dur^2 + dur^W) \times C^{OC})$	$F + (dur^1 \times C^{OC})$	$F + (dur^1 \times C^{OC})$

Figure 4

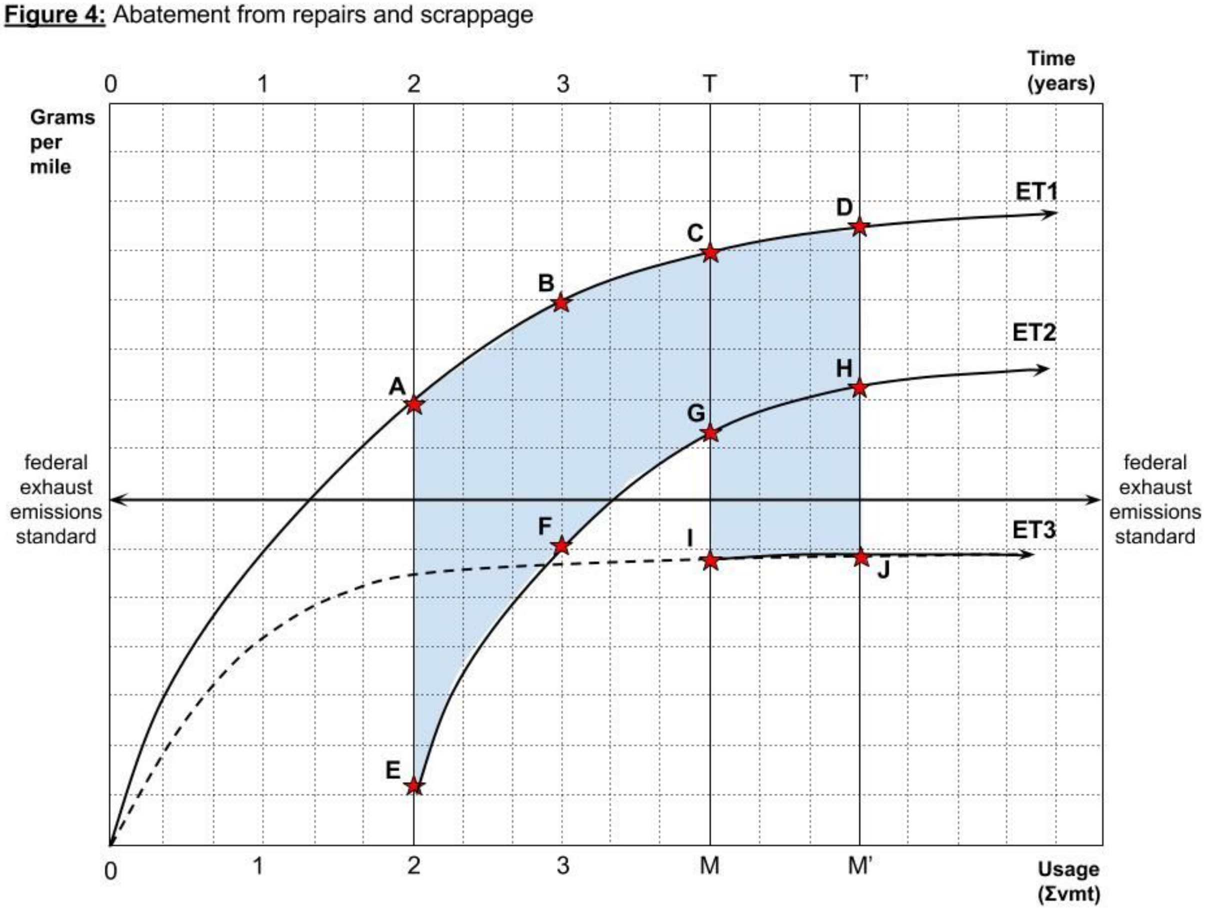


Figure 4: Abatement from repairs and scrappage
Time (years)
0
1
2
3
T
T'
Grams per mile
ET1
D
C
B
ET2
H
A
G
federal exhaust emissions standard
federal exhaust emissions standard
F
I
ET3
J
E
0
1
2
3
M
M'
Usage (Σvmt)

Figure 5

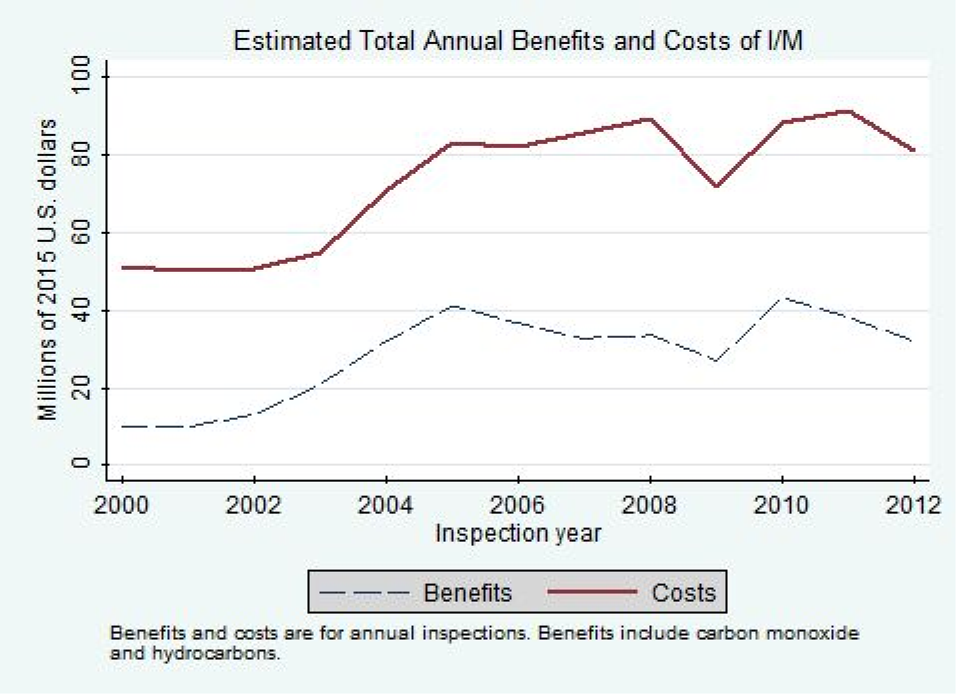


Figure 6

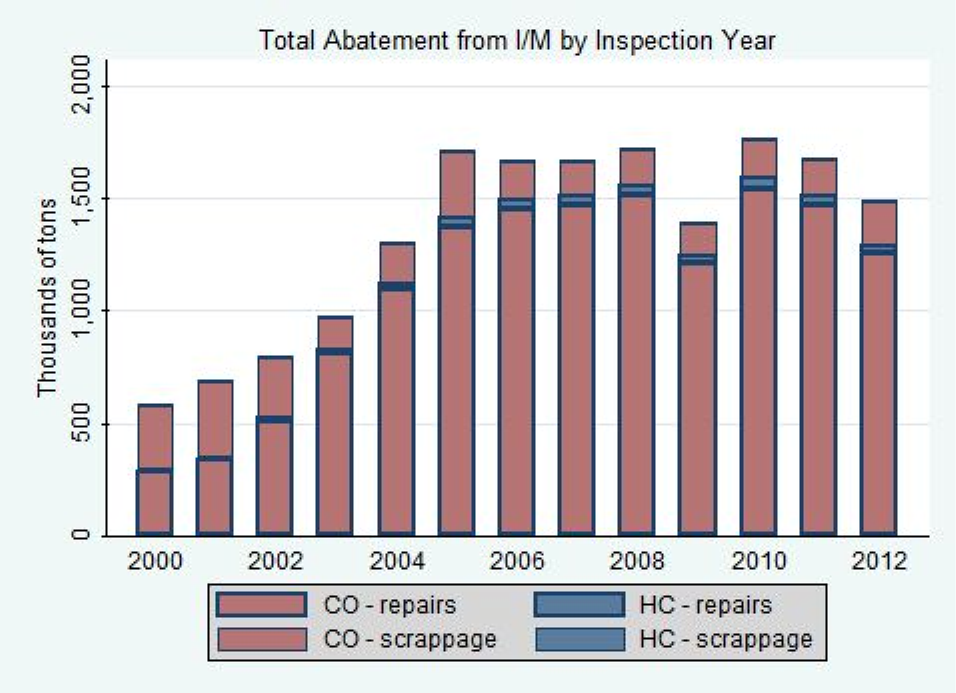


Figure 7

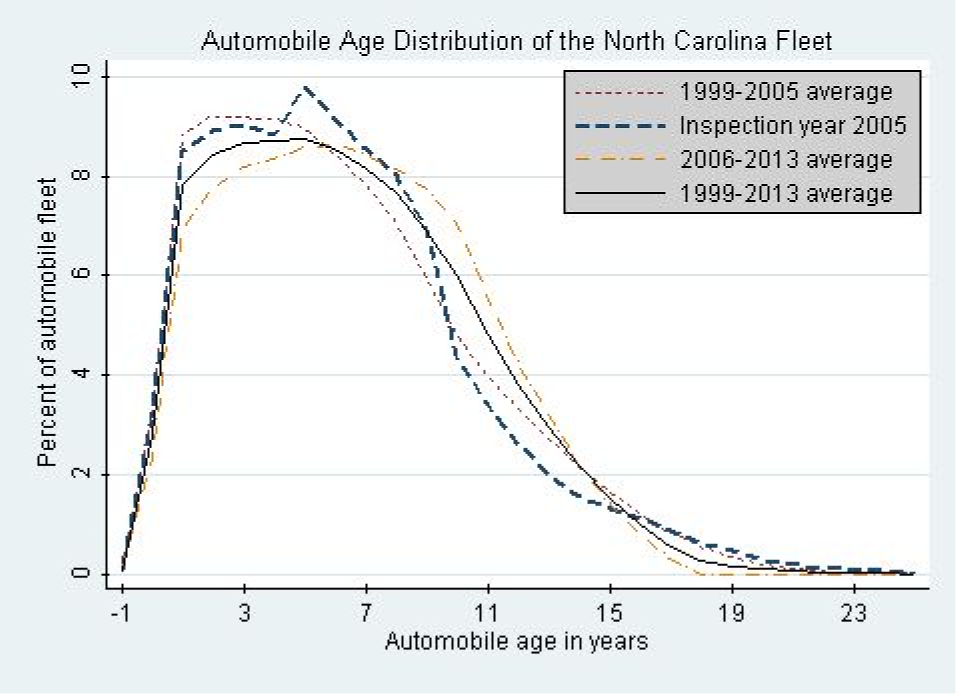
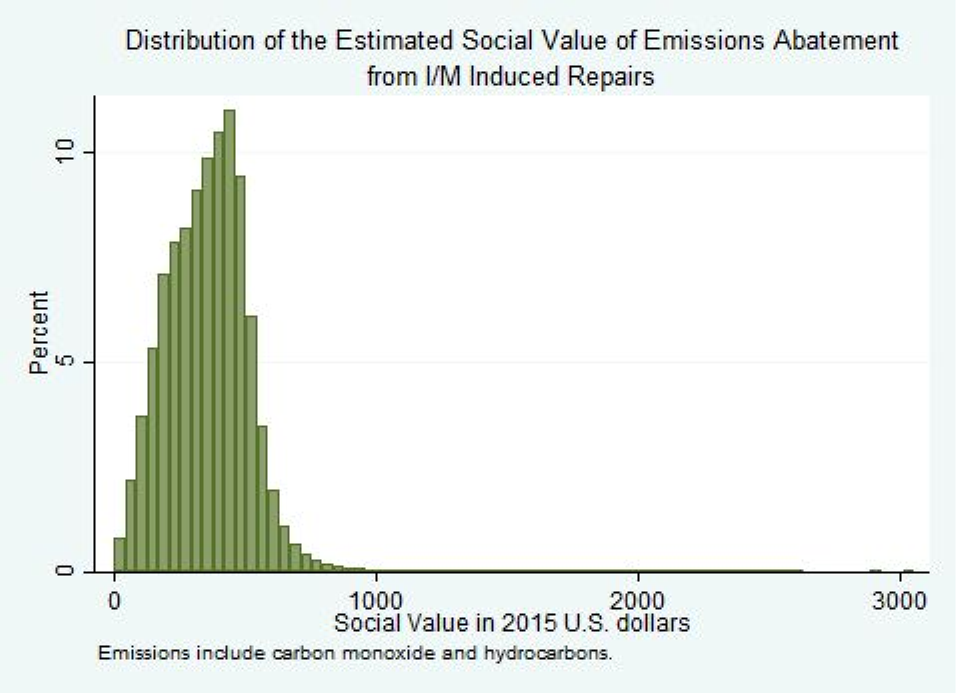


Figure 8



Emissions include carbon monoxide and hydrocarbons.

Figure 9

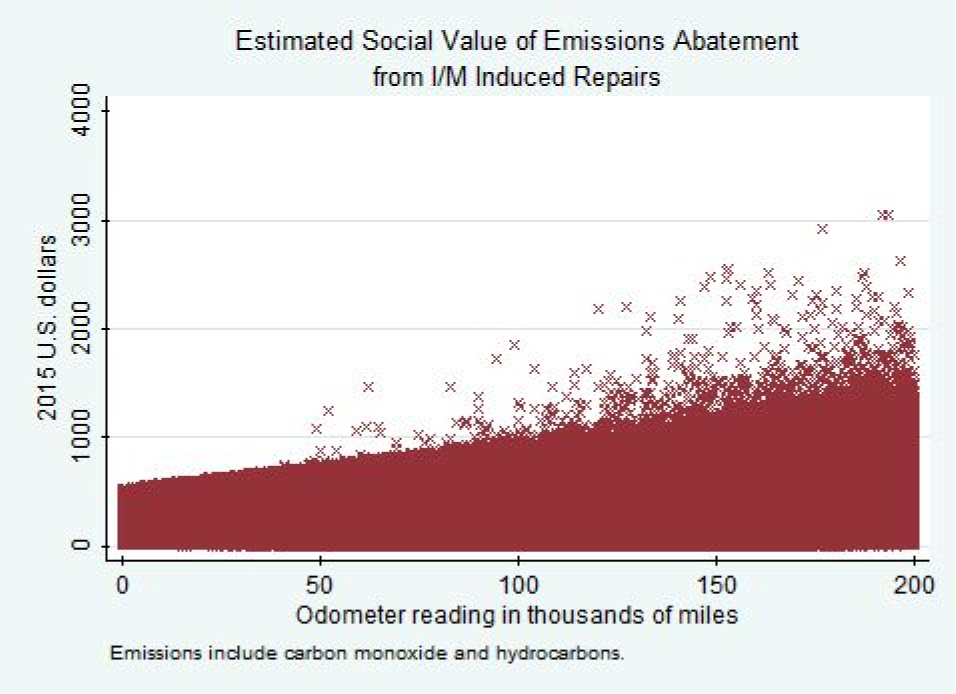


Figure 10

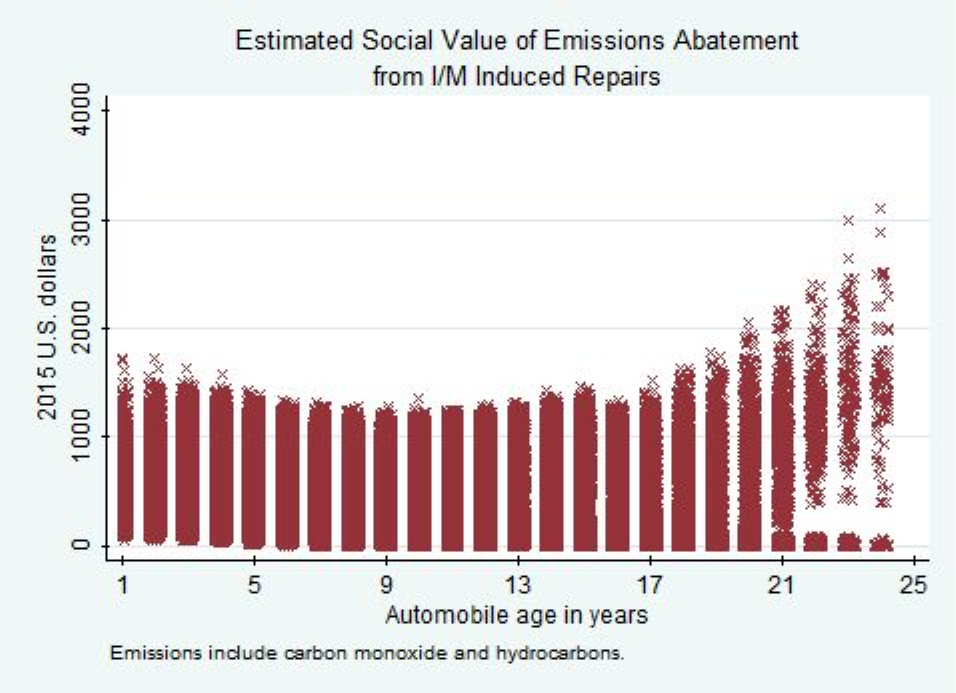


Figure 11

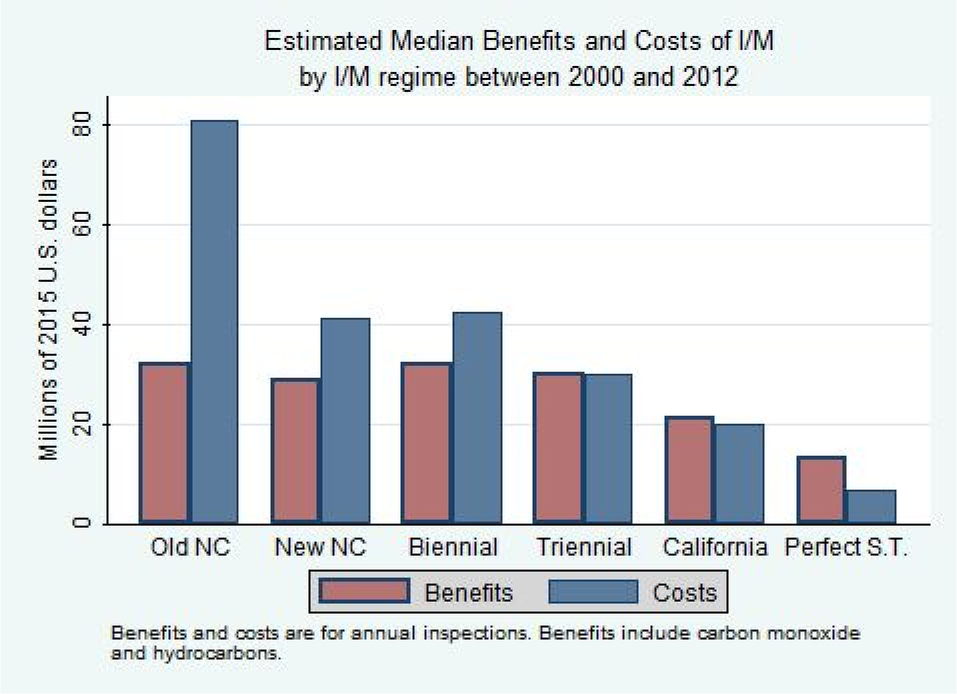


Figure 12

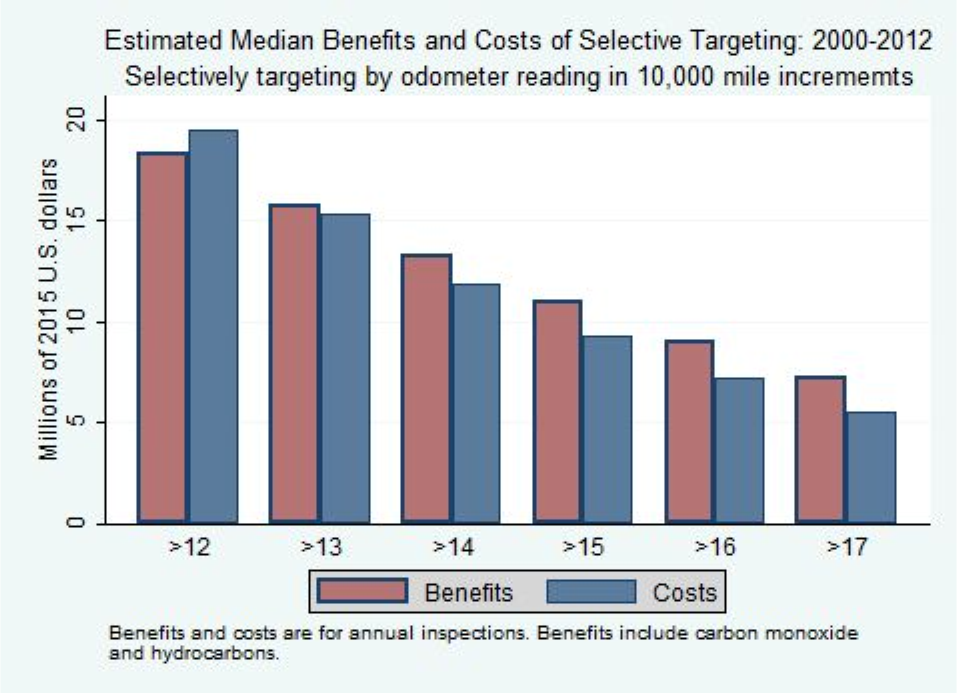


Figure 13

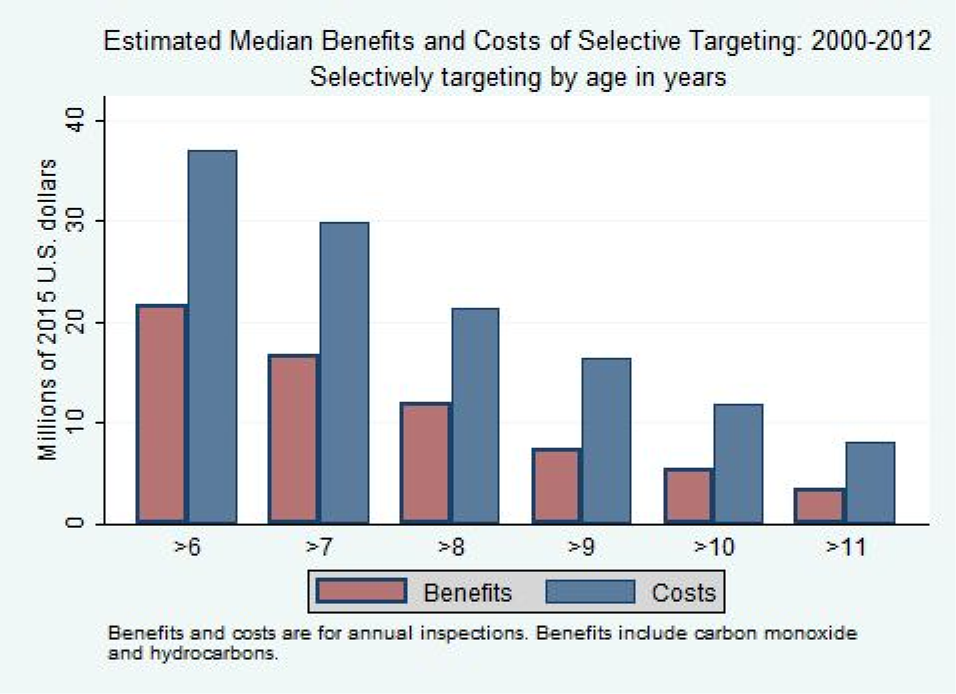


Figure 14

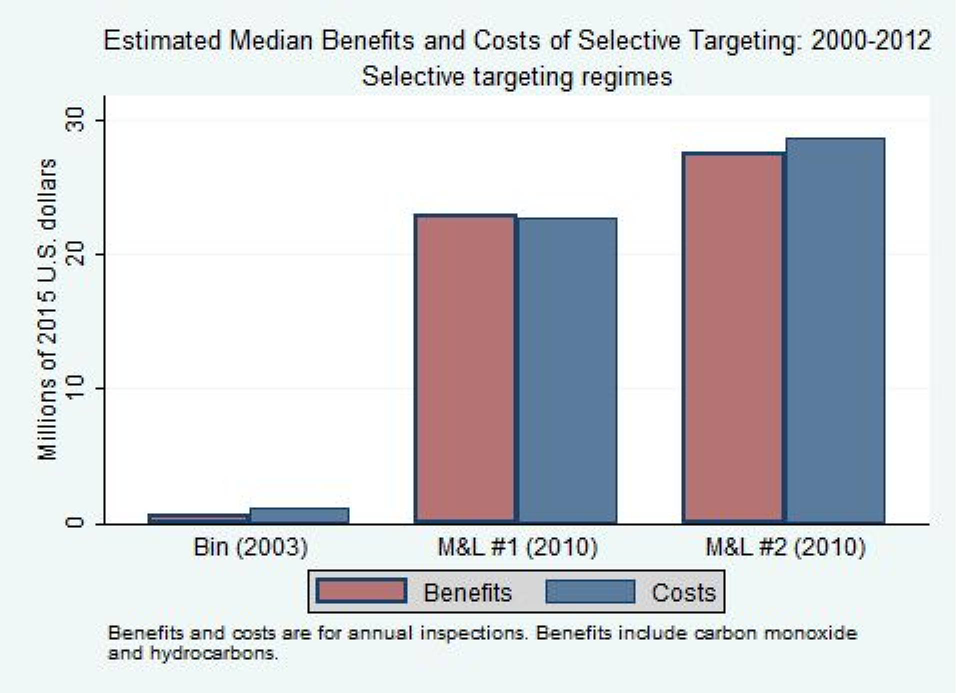


Figure 15

Figure 15: The social cost from the over-inspection of automobiles

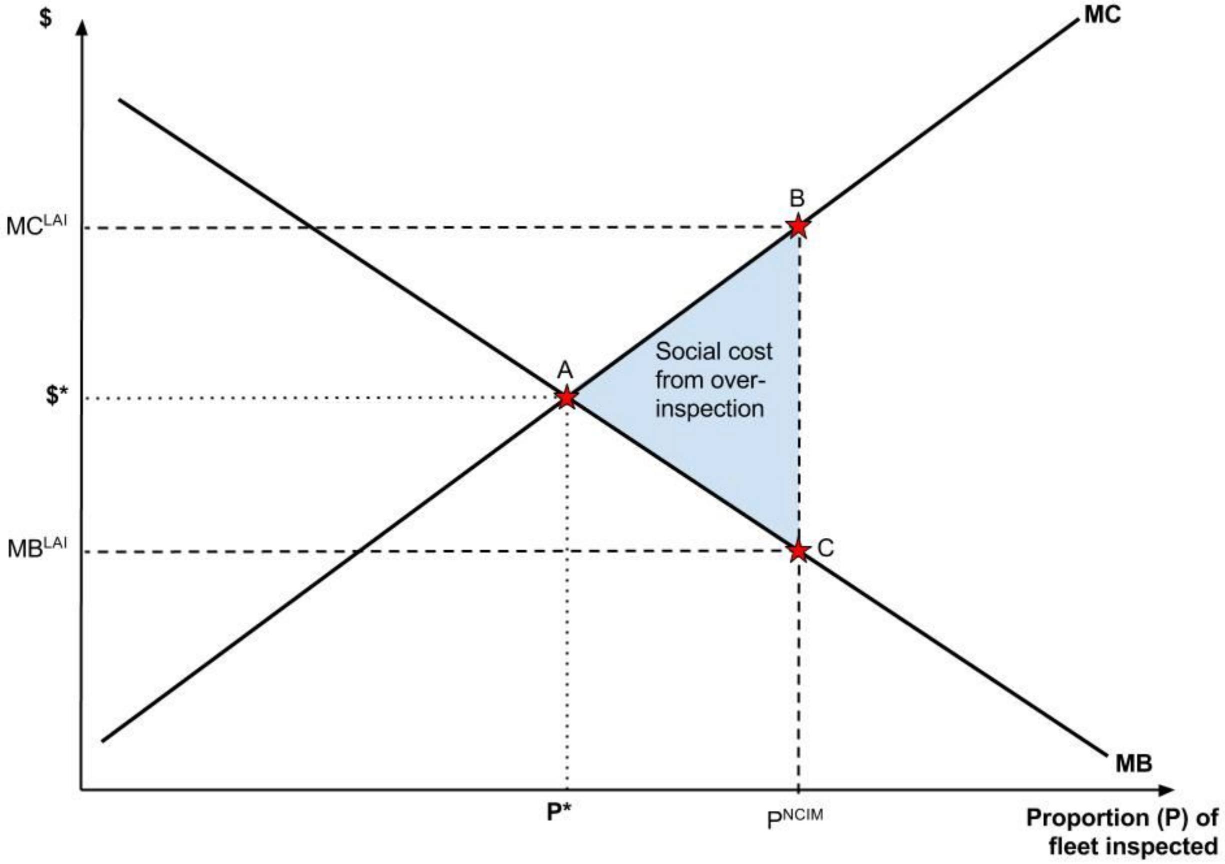


Table 1: Summary statistics for I/M programs in the United States

	# of obs.	# of programs	Mean	Median	Std.Dev	Min	Max
Annual inspections?	32	15	0.47	0	0.51	0	1
Biennial inspections?	32	20	0.63	1	0.49	0	1
Statewide emissions inspections?	32	9	0.28	0	0.46	0	1
All diesel vehicles are exempt from emissions inspections?	31	11	0.35	0	0.49	0	1
Centralized emissions inspection program?	32	11	0.34	0	0.48	0	1
Vehicles get OBD and tailpipe emissions inspections?	30	3	0.1	0	0.31	0	1
Number of years new vehicles are exempt?	31	-	2.77	3	1.76	0	6
Inspection Fee	30	-	16.23	15	11.88	0	40.5
Repair cost limit	25	-	478.5	450	249.27	150	855

Notes: Observations are the number of I/M programs in the United States for which data is available; in total there are 32 U.S. I/M programs.

Table 2: Analyses of I/M programs

Paper	I/M program	Time period	Effectiveness	Cost-Effectiveness	Efficiency
Glazer et al. (1995)	California, USA	NA	✓		
Kahn (1996b)	California, USA	1992 - 1993	✓		
Kahn (1996c)	Illinois, USA	pre-1986 versus post-1986	✓		
Hubbard (1997)	NA	NA	✓		
Ando et al. (2000)	Arizona, USA	1995 - early 1996	✓	✓	
Harrington et al. (2000)	Arizona, USA	January 1995 - May 1996	✓	✓	
Moghadam and Livernois (2010)	Ontario, Canada	1999 - 2001		✓	
Mérel et al. (2014)	California, USA	July 2000 - August 2010	✓	✓	
Sanders and Sandler (2015)	California, USA	1998 - 2012	✓		

Notes: The papers that analyze the *effectiveness* of I/M examine the extent to which the programs produce abatement or improve air quality. Other papers may attempt to rank I/M relative to other programs by estimating the abatement per dollar or *cost-effectiveness*. The difference between cost-effectiveness and *efficiency* lies with the units used to measure the benefits of the program. *Efficiency* requires that the mass of abated emissions be multiplied by the social value of emissions so that net benefits can be calculated. Thus effectiveness and efficiency are mutually exclusive categorizations, but cost-effectiveness and efficiency are not. Cost-effectiveness is a necessary, but not a sufficient condition for efficiency.

Table 3: Papers discussing automobile attributes and emissions

Paper	Emissions	Selective targeting	Finding
Glazer et al. (1995)		✓	"Universal inspections are not necessary. Data suggest that it may be wise for Smog Check program to stop treating all cars equally."
Khazzoom (1995)	✓		"The [results] show that for all three pollutants and all equations estimated, the impact of MPG on the emission rate is statistically zero."
Anilovich and Hakkert (1996)	✓		"A strong vehicle age influence on emission levels was observed." "The measurements of the sample demonstrate poor compliance that worsens with vehicle age."
Kahn (1996a)	✓		"Find evidence of large differences in vehicle emissions across model years, makes, and sizes. Vehicle emissions have not fallen monotonically with vehicle model year. Instead … emissions fall when new-car emissions regulation becomes more stringent."
Harrington (1997)	✓		"It is found that better fuel economy is strongly associated with lower emissions of CO and HC and that the effect gets stronger as vehicles age."
Ando et al. (2000)		✓	"Our results all suggest that consideration of the costs and cost-effectiveness in designing I/M policy is critical. Because there is great variation in costs and effectiveness of repair across vehicles, costs could be reduced if there were better targeting of which vehicles are tested and which are repaired. Clearly, relatively new vehicles are less likely to fail, so they should be tested less frequently. Older vehicles, which are more likely to fail, can be tested more frequently."
Washburn et al. (2001)	✓	✓	"Our results show that vehicle age, vehicle manufacturer, number of engine cylinders, odometer reading, and whether or not oxygenated fuels were in use all play a significant role in determining I/M emission test results and these statistical findings can be used to form the basis of the selective sampling of vehicles for I/M testing."
Riveros et al. (2002)	✓		"Some of the results of this analysis include: the finding of a typical exhaust emissions distribution

			curve for each vehicle manufacturer, with differences for each brand and model for the same manufacturer, the fact that not all new vehicles pass the I/M test…”
Bin (2003)		✓	“Vehicle age, engine size, and odometer reading all play a significant role in determining the probability of emission test failure. Information from this study can be used as a groundwork for the selective sampling of vehicles which might improve the cost-effectiveness of the I/M programs.”
Beydoun and Guldmann (2006)	✓		“Vehicle age, fuel economy, mileage, engine characteristics, weight, make, general maintenance, and time of year are found to be strong determinants of emissions and test failure rates. The emission models estimated with the Massachusetts data show broad variations in the effects of the independent variables across makes, for both cars and trucks.”
Moghadam and Livernois (2010)		✓	“The model predicts that the marginal abatement cost for a major representative program is so high that even a small reduction in abatement target leads to substantial cost savings to motorists. In addition, even for quite high levels of abatement target, the optimal testing age is substantially higher and the frequency of testing is much lower than is common in many jurisdictions.”

Notes: The column headings “Emissions” and “Selective targeting” are a shorthand means of differentiating the results of the papers listed in table 3. The “Emissions” papers examine the relationship between automobile attributes and emissions. The “Selective targeting” papers suggest selective targeting as a way of improving the efficiency of I/M programs.

Table 4a: Summary of the 6.4 million unique automobiles registered in North Carolina between 1999 and 2013

Variable	Description	Mean	Std. Dev.	Min	Max
model year	*Vehicle's model year*	2001	6.15	1981	2013
weight	*Tot. weight w/ std. eqp.*	3,577	773.58	1,620	7,956
cylinders	*Num. of engine cylinders*	5.5	1.39	3	12
engsize	*Engine size in liters*	3.13	1.06	1	8.4
speeds	*Num. transmission speeds*	4.45	0.71	1	9
mpg	*Avg. city-highway MPG*	20.93	5.06	8	98
VIN fail	*1 if automobile ever fails*	0.09	0.29	0	1
VIN repair	*1 if automobile ever repair*	0.06	0.24	0	1

Notes: Observations are automobiles, as identified by the unique vehicle identification number (VIN), registered in North Carolina between 1999 and 2013. The 6.4 million automobiles registered in the state had a combined 29 million emission inspections during that time.

Table 4b: Summary of the 29 million emissions inspections from North Carolina between 1999 and 2013

Variable	Description	Mean	Std. Dev.	Min	Max
model year	*Automobile's model year*	2000	5.30	1981	2013
weight	*Tot. weight w/ std. eqp.*	3,570	756.69	1,620	7,956
cylinders	*Num. of engine cylinders*	5.54	1.39	3	12
engsize	*Engine size in liters*	3.16	1.05	1	8.4
speeds	*Num. transmission speeds*	4.34	0.61	1	9
mpg	*Avg. city-highway MPG*	20.64	4.87	8	98
Inspection failure	*1 if vehicle ever fails*	0.023	0.15	0	1
CO gpm	*CO exhaust emissions in gpm*	3.67	8.33	0.07	291.93
HC gpm	*HC exhaust emissions in gpm*	0.24	0.29	0.001	34.45
automobile age	*Automobile's age*	6.50	4.02	-1	24
odometer	*Odometer reading*	88,703	55,578	1,001	399,998
annual VMT	*Annual vehicle-miles tr.*	14,921	12,205	501	384,174

Notes: Observations are emissions inspections in North Carolina between 1999 and 2013. The 29 million inspection observations came from the 6.4 million automobiles registered in the state.

DATA PROVIDED BY edmunds.com

Table 5: FTP limits established by the Clean Air Act

Model year	**Emission limits in grams per mile (g/m)**		
	Hydrocarbons	**Carbon monoxide**	**Nitrogen oxide**
1975-1976	1.5	15	3.1
1977-1979	1.5	15	2
1980	0.41	7	2
1981-1993	0.41	3.4	1
1994	0.41	3.4	0.4
1995-1998	0.31	3.4	0.4
1999-2003	0.09	3.4	0.4
>= 2004	0.09	3.4	0.05

Notes: FTP limits comes from Calvert et al. (1996), Delphi (2011), and Delphi (2013).

Table 6: Summary of the estimated social costs of emissions per short ton

	HC	CO	NO	CO_2	CO_2 Equivalent
Nordhaus (1991a)					1989 USD 0.31-65.94
Nordhaus (1991b)					1989 USD 7.30
Ayres and Walter (1991)					1989 USD 30 - 35
Nordhaus (1992)					1989 USD 5.30
Nordhaus (1993a)					1995 USD 5.24
Nordhaus (1993b)					1989 USD 5
Peck and Teisberg (1993b)					1990 USD 12-14
Fankhauser (1994)	1991 USD 108		1991 USD 2,895	1991 USD 20	
Matthews and Lave (2000)		1992 USD 520			
Muller and Mendelsohn (2007)	2002 USD 400		2002 USD 300		
Muller and Mendelsohn (2009)	2002 USD 730		2002 USD 260		
Knittel (2009)				2009 USD 207	
Greenstone, Kopits, Wolverton (2013)				2007 USD 21.40	
Range of Social Cost in 2013 US Dollars / short ton	\$184.72 – \$945.30	\$863.42	\$336.68 - \$4,951.62	\$24.04 - \$224.77	\$0.58 - \$122.11
Avg. Annual Benefit of Excess Emissions Abated per Vehicle	**\$5.51**	**\$763.90**	**\$61.78**		

Notes: The last row of Table 6 reports an average annual benefit of excess emissions abated per failing or noncompliant vehicle. These dollar values assume the vehicle was manufactured according to Tier 2 bin 5 exhaust standards, was driven the dataset average of 14,700 miles per year, and produced excess emissions of 300, 1200, and 1000 percent of the federal standard for hydrocarbons, carbon monoxide, and nitrogen oxides, respectively. In addition these values assume the social cost is the maximum value from row 14 of Table 6. Thus, the average benefit in terms of abated emissions from identifying and repairing an average noncompliant vehicle is \$831.20 in 2013 U.S. dollar basis.

Table 7: Description of variables and notation in equations 1, 2, and 3

	Definition
i	Subscript referring to a particular automobile as identified by its vehicle identification number (VIN).
t	Subscript referring to a particular inspection year, 2000 - 2012.
e	Subscript referring to a particular emission, carbon monoxide (CO) or hydrocarbons (HC).
g	Subscript referring to a particular zip-code or county of registration.
$B^{IM}_{i\ t}$	Benefits of emissions abatement from I/M for automobile *i* in time *t*.
$Pr(f_{i\ t})$	Probability that automobile *i* fails its emissions inspection in time *t*. $Pr(f_{i,t})$ + (1 - $Pr(f_{i,t})$) = $Pr(f_{i,t}) + Pr(p_{i,t}) = 1$.
$B^{R}_{i\ t\ e}$	Social value of abatement of emission *e* from repairs to automobile *i* in time *t*.
$B^{S}_{i\ t\ e}$	Social value of abatement of emission *e* from scrappage of automobile *i* in time *t*.
$Pr(r_{i\ t})$	Probability that automobile *i* is repaired following a failed emissions inspection in time *t*. $Pr(r_{i,t}) + Pr(w_{i,t}) + Pr(s_{i,t}) = 1$.
$cvmt_i$	The counterfactual odometer reading for scrapped automobiles. The number of cumulative vehicle-miles traveled automobile *i* would have produced at retirement in the absence of I/M.
$\Sigma vmt_{i\ t}$	The odometer reading, or cumulative vehicle-miles traveled, for automobile *i* at its inspection in time *t*.
$ce^{R}_{i\ t\ e}$	The counterfactual emissions of emission *e* for automobile *i* in time *t*. For the example automobile described in section 3 in reference to figure 2, $ce^{R}_{i,t,e}$ is emissions trajectory *ET1*.
$re_{i\ t\ e}$	The quantity of emission *e* produced by repaired automobile *i* in time *t*. For the example automobile described in section 3 in reference to figure 2, $re_{i,t,e}$ is emissions trajectory *ET2*.
$\Delta E^{R}_{i\ t\ e}$	Abated emissions from I/M repairs. For the example automobile described in section 3 in reference to figure 2, $\Delta E^{R}_{i,t,e}$ is the area between emissions trajectories *ET1* and *ET2* from the time of automobile *i*'s repair until it would have been retired in the absence of I/M.
$Pr(s_{i\ t})$	Probability that automobile *i* is scrapped following a failed emissions inspection in time *t*. $Pr(r_{i,t}) + Pr(w_{i,t}) + Pr(s_{i,t}) = 1$.

$ce^{S}_{i,t,e}$	The counterfactual emissions of emission *e* for automobile *i* in time *t*. For the example automobile described in section 3 in reference to figure 2, $ce^{S}_{i,t,e}$ is emissions trajectory *ET2*.
$ne_{i,t,e}$	The quantity of emission *e* produced by the average "new" automobiles in time *t*. For the example automobile described in section 3 in reference to figure 2, $ne_{i,t,e}$ is emissions trajectory *ET3*.
$C^{SCE}_{g,t,e}$	Social costs, or marginal external damages (MED), of emissions.
$\Delta E^{S}_{i,t,e}$	Abated emissions from I/M scrappage. For the example automobile described in section 3 in reference to figure 2, $\Delta E^{S}_{i,t,e}$ is the area between emissions trajectories *ET2* and *ET3* from the time of automobile *i*'s scrappage until it would have been retired in the absence of I/M.
$Pr(w_{i,t})$	Probability that automobile *i* receives a waiver following a failed emissions inspection in time *t*. $Pr(r_{i,t}) + Pr(w_{i,t}) + Pr(s_{i,t}) = 1$.
$C^{IM}_{i,t}$	Cost of emissions I/M compliance for automobile *i* in time *t*.
F	Inspection fee paid by automobile owner *i* to the inspection station in time *t*.
τ	Tax paid by automobile owner *i* to the state government in time *t*.
$C^{OC}_{i,t,g}$	The opportunity cost of time for automobile *i* registred in county *g* in time *t*.
$dur_{i,t}$	Duration of automobile *i*'s emissions inspection in time *t*.
C^{RCL}	The repair cost limit for automobile *i* in time *t*.
$C^{C}_{i,t}$	State government fee for compliant automobile *i*.
$C^{R}_{i,t}$	State government fee and repair cost for repaired automobile *i*.
$C^{W}_{i,t}$	State government fee, repair cost, and opportunity cost of time for waived automobile *i*.
$C^{S}_{i,t}$	State government fee for scrapped automobile *i*.
NB^{IM}_{t}	Net benefits of emissions I/M in time *t*.
Notes:	

Table 8: Ranking efficiency of I/M regimes

Rank	Selective targeting regime description	Net benefits
1	Perfect selective targeting	6.07
2	Age > 5 and annual VMT > 20,000 per year	2.13
3	Age > 6 and annual VMT > 20,000 per year	2.09
4	Age > 4 and annual VMT > 20,000 per year	1.97
5	Age > 7 and annual VMT > 20,000 per year	1.86
6	Age > 1 and odometer > 200,000	1.80
7	Age > 0 and odometer > 200,000	1.80
8	Odometer > 200,000	1.80
9	Age > 2 and odometer > 200,000	1.79
10	Age > 3 and odometer > 200,000	1.78
11	Age > 4 and odometer > 200,000	1.74
12	Age > 0 and odometer > 190,000	1.72
13	Odometer > 190,000	1.72
14	Age > 1 and odometer > 190,000	1.72
15	Age > 2 and odometer > 190,000	1.72
16	Age > 3 and odometer > 190,000	1.71
17	Odometer > 170,000	1.68
18	Age > 0 and odometer > 170,000	1.68
19	Age > 1 and odometer > 170,000	1.67
20	Age > 2 and odometer > 170,000	1.67
519	Odometer > 190,000	0.00

Notes: Net benefits, in millions of June 2015 U.S. dollars, are the median of those estimated for years 2000 through 2012.