Vehicle Emissions Inspection Programs: Equality and Impact

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Abstract

I evaluate the distributional impact and cost efficiency of Vehicle Emissions Inspection Programs. Using a unique dataset that combines vehicle emissions inspection results with owner address data, I find that the Arizona Vehicle Emissions Inspection Program constrains the vehicle repair decisions of people in the low end of the income distribution more than people in the high end. Individuals with a lower annual income are both (i) more likely to drive vehicles that fail inspection at a higher average rate, and (ii) more likely to fail inspection conditional on vehicle characteristics. This implies that programs designed to induce vehicle repair or fleet update will have a different impact on emissions depending on the characteristics of the *owners* of the vehicles targeted in the program, not just on the characteristics of the vehicles themselves. I also find that the social cost of administering the Vehicle Emissions Inspection Program in Arizona is more than twice the social benefit using a $7 million value of statistical life. This cost and benefit analysis suggests that exempting the 10 newest model year vehicles from inspection, instead of the current policy of exempting the five newest model years, would increase the social benefit ratio of this program.

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1 Introduction

The 1990 Amendments to the Clean Air Act mandated vehicle emissions inspection programs (VEIP) in large, metropolitan areas which do not meet certain federal air quality standards. The ostensible purpose of the program is to reduce pollution by identifying high polluting vehicles and requiring that owners have them repaired. Currently, 32 states, plus Washington DC, require some level of vehicle emissions testing in some areas. The purpose of this paper is to evaluate the progressivity, environmental impact, and cost efficiency of vehicle emissions inspection programs.

Data for this study comes from the Arizona vehicle emissions inspection program. Arizona is required by the Environmental Protection Agency (EPA) to run a VEIP in two metropolitan areas, Phoenix and Tucson, that do not meet minimum air quality standards. The Arizona Department of Environmental Quality (ADEQ) administers the program and the program is implemented by a private contractor. The Arizona data is detailed, contains many data points, and contains information on many inspection methods. This makes it a good starting point for investigating Vehicle Emissions Inspection Programs.

One open question in the environmental economics literature is how environmental policies impact individual at various points on the income distribution differently. To address this question in the context of vehicle emissions inspection programs, I create a novel data set that combines emissions inspection data with confidential vehicle owner address data provided by the Arizona Motor Vehicle Division (MVD). Knowing owner address gives a measure of the vehicle owner's characteristics, including income, through the American Community Survey.

Using this combined dataset, I find that the Arizona VEIP constrains the vehicle repair decisions of people in the low end of the income distribution more than people in the high end. Low income vehicle owners are both (i) more likely to drive vehicles that fail inspection at higher average rates, and (ii) more likely to fail an inspection conditional on vehicle characteristics. A failed inspection constrains vehicle owners to purchase vehicle repairs that they did not purchased otherwise.

These findings imply that programs designed to induce vehicle repair or update the fleet will have a different impact on pollution depending on the characteristics of the *owners* of the vehicles targeted for repair or replacement, not just on the characteristics of the vehicles themselves.

Next, I ask whether vehicle emissions inspection programs reduce pollution, and whether they are cost effective. Using the universe of emissions inspection results from the 2013-2014 inspection cycle in Arizona, I find that the Arizona VEIP does reduce pollution by identifying high polluting vehicles and mandating that they be repaired. However, the social cost of this program, paid in testing fees and vehicle repair costs, is approximately twice the social benefit using a $7M value of statistical life. Surprisingly, the high social cost is primarily driven by testing fees; many vehicles must be inspected to identify relatively few violators.

I also stratify vehicles based on vehicle model year and perform the same benefit/cost ratio test on each stratum. I find that for vehicles registered in Tucson, in no stratum is the benefit of the inspection program higher than the cost. For vehicles registered in Phoenix, the social benefit of the program exceeds social cost only for vehicles older than ten model years. This finding suggests that if the ten newest model year vehicles were exempted from inspection, instead of the current policy of exempting only the five newest model years on a rolling basis, the overall benefit/cost ratio of the program would go up and the number of vehicles inspected annually would be reduced by half.

The paper is organized as follows. Section two introduces the dataset created for this study. Section three evaluates the distributional impact of the program. Section four shows how the benefit/cost analyses were done. Section five concludes.

2 Data

The dataset used for this study was created by combining information from three government agencies:

1. *Arizona Department of Environmental Quality*. The ADEQ data contains the universe of emissions inspection results for the 2013-2014 emissions inspection cycle. It includes basic vehicle characteristics (including vehicle identification number, make, model, model year), odometer reading, whether the vehicle passed inspection, the level of pollutants emitted during each test (where available), and the cost of repairs made between a failing test and a retest (self-reported by the vehicle owner).

2. *Arizona Motor Vehicle Division*. The MVD data contains owner home address data by VIN for every vehicle registered in Arizona during 2013-2014.

3. *American Community Survey*. The ACS 2014 5-year estimates give median resident characteristics by home location, including annual income of households by zip code and census block group.

This study focuses on data from the 2013-2014 emissions inspection cycle. Using two years of data is appropriate for a number of reasons. First, most vehicles in the data set were inspected every other year, so the natural cycle of testing is two years. Second, there are systematic differences between vehicles tested during odd years and those tested during even years because the testing program was not implemented gradually. Averaging over two consecutive years alleviates these differences. Finally, there was concern that a longer study period would conflate cross-vehicle variation with long run advances in emission reduction technology.

There are four broad types of vehicle emissions tests used in Arizona. They are:

1. *On-Board Diagnostic (OBD)*. Vehicles newer than 1995 model year are inspected using this test. Data that has been continually recorded by the vehicle's on-board sensors is used to evaluate whether the vehicles passes inspection. As long as certain on-board monitoring systems are working and monitored pollution did not exceed 2.5 times a federally mandated level, the vehicle passes inspection. In the 2013-2014 testing cycle, 76% of vehicles were tested with On-Board Diagnostics.

2. *Inspection/Maintenance 147 (IM147)*. Most 1981-1995 model year light duty gasoline-powered vehicles in Phoenix are inspected using the IM147 test. In this test, the vehicle is driven on rollers (called a dynamometer) at varying speeds to simulate urban driving. The exhaust of three pollutants (hydrocarbons, carbon monoxide, and oxides of nitrogen) is directly measured. Levels of all three pollutants, measured in grams per vehicle mile, must be below a certain threshold to pass. In the 2013-2014 testing cycle, 6% of vehicles were tested with the IM147 test.

3. *Loaded/Idle*. Model year 1967-1980 vehicles (and some newer vehicles registered in Tucson), are inspected with the Loaded/Idle test. Exhaust is tested while the vehicle idles and again at approximately 25 miles-per-hour. Exhaust of hydrocarbons and carbon monoxide must be below a certain threshold to pass. About 10% of vehicles were tested with the Loaded/Idle test. This test is generally considered to be less precise than the similar IM147, but is still used for vehicles grandfathered out of the newer requirements.

4. *Opacity Test*. Diesel vehicles are tested by measuring the opacity of the exhaust. About 6% of vehicles were inspected with this test.

Approximately two million vehicles are inspected annually in Arizona at an annual inspection cost of $36 million paid by vehicle owners. Table 1 reports summary statistics for emissions inspections in the 2013-2014 testing cycle. The majority of inspections were done in Phoenix. More than nine in ten vehicles pass the inspection on the first try. Table 2 reports summary statistics for the vehicles tested during the 2013-2014 testing cycle. Vehicle characteristics are make, model, model year, and odometer reading. For convenience, I group vehicle makes into

Table 1: Emissions test summary statistics (annual average)

Number of Tests	1,905,159
Location	
Phoenix	79.3%
Tucson	20.7%
Pass on	
First test	91.0%
Retest	6.6%
Never	2.4%
Test Type	
OBD	75.9%
IM147	5.6%
Loaded/Idle	10.0%
Opacity	6.1%
Exempt/Other	2.4%

the six most common manufacturers, plus a category for other vehicles. Vehicle models are grouped into one of four model categories by size. Examples of those categories are given in Table 2.

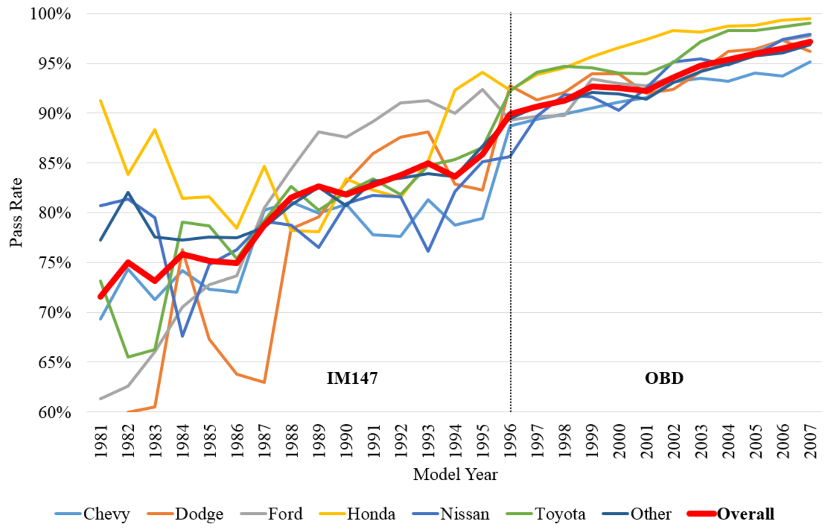
This study will focus on model year 1967-2008 non-diesel vehicles. Current policy exempts the five newest model years from inspection, so vehicles manufactured after 2008 are not fully represented in the 2013-2014 data. Also, vehicles older than the 1967 model year are exempt from inspection.

Figure 1 shows the vehicle inspection pass rate for model years 1981-2008. Newer vehicles pass emissions inspections at a higher rate. Honda brand vehicles pass inspection more than average, and this is especially pronounced for newer model Hondas and for Hondas made during the 1980s. Ford vehicles made during the early 1990s pass inspection at a rate higher than trend. Across all vehicles and all model years in the study data set, 91% of vehicles pass the emissions inspection on the first try.

Table 2: Vehicle summary statistics

Vehicle Type (example)	
Cars (Fusion)	45.0%
Light Trucks (Ranger)	26.6%
Medium Trucks (F150)	16.9%
Heavy Trucks (F350)	11.5%
Vehicle Make	
Chevrolet	15.8%
Ford	15.3%
Toyota	11.1%
Honda	7.5%
Dodge	6.8%
Nissan	6.3%
Other	37.3%
Model Year	
Less than 1990	4.1%
1990-1995	8.2%
1996-2000	19.4%
2001-2005	37.6%
2006-2008	26.7%
2009+	4.4%
Ave. Odometer	116,340 miles

Figure 1: Percent of cars that pass on the first try by model year. Cars older than 1996 model year are tested with the IM147 test. Cars 1996 model year and newer are testing using On-Board Diagnostics (OBD).



3 Distributional Impact

One open question in environmental economics is how environmental policies impact people at different points on the income distribution differently. For example, Jacobsen 2013, Benzhaf 2011, Fullerton 2011, and Bento 2013 each show how various environmental policies are regressive, costing the poor more than the rich. However, Bento and Freedman 2014 find that some air pollution mitigation programs increase home prices in poor areas more than in rich areas. They conclude that this one example of a progressive environmental policy.

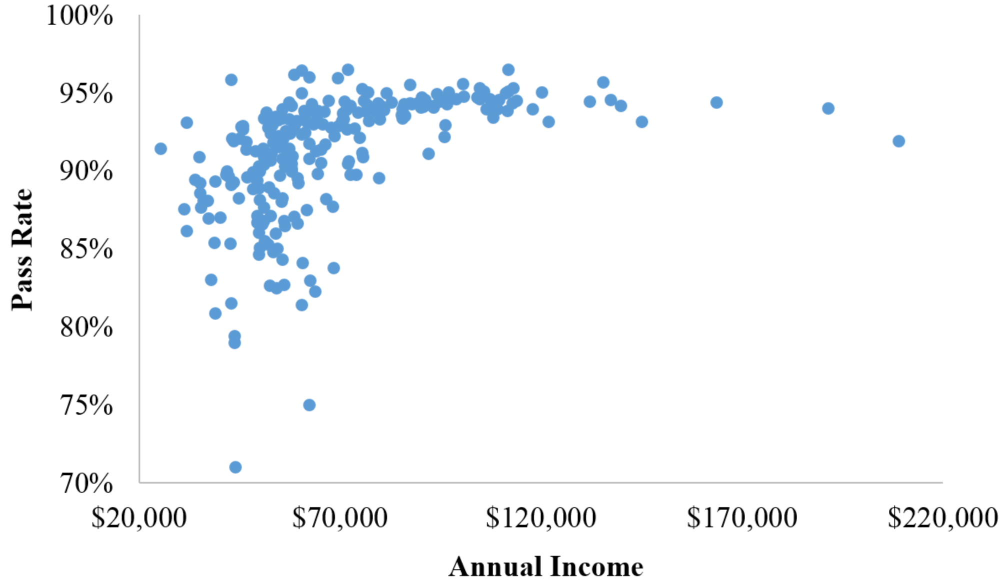
In this section, I ask, "Do vehicle emissions inspection programs impact the poor differently than the rich?" The answer is yes. Vehicle owners with lower median annual income are both (i) more likely to drive vehicles that fail the inspection at higher average rates, and (ii) more likely to fail an inspection conditional on vehicle characteristics. Owners of vehicles that fail inspection are required to purchase vehicle repairs that they did not choose to purchase prior to inspection. Hence, the Arizona VEIP constrains the repair decisions of lower income individuals more than higher income individuals.

To assign income data to specific vehicles, I define a household as one vehicle and assign each vehicle the median annual income reported in the ACS for the census block group in which that vehicle is registered. About 61% of addresses in the study data have only one vehicle registered at that address. For the 24% of addresses with two vehicles and 15% of address with three or more vehicles, I assign that household's full income to each vehicle. This assumption is not ideal, but is logical for the purposes of this paper. Income data is meant to capture variation in vehicle owner characteristics. I assume that vehicle owners in a household with three vehicles and $120k annual income are more similar to owners in a one-vehicle household with the same income than to owners in a one-vehicle household with $40k annual income. Further research on multiple-vehicle households is needed.

Using home address data to connect inspection results with a measure of owner income was done with the following procedure. First, inspection results for each vehicle were connected to a MVD addresses using the vehicle identification number. Those addresses were geocoded using a 2013 address locater file. Goecoded address were then spatially joined with census block group polygons published by the Census Bureau. This procedure connected a 12-digit GEOID to each vehicle inspected. ACS income data for each census block group was then merged with the MVD data based on GEOID.

Figure 2 shows the percent of vehicles at each income level that passed the vehicle emissions inspection on the first try. There is an upward trend, meaning that owners who live in areas with a higher median annual income are more likely to pass the emissions inspection on the first try. Vehicles associated with post

Figure 2: Percent of vehicles that passed emissions testing on the first try, by annual income in each zip code in which the vehicle was registered. Census block group median incomes were aggregated to the zip code level in this figure for presentational convenience.



office boxes and vehicles registered in areas with fewer than 20 observations were dropped. Addresses with many vehicles registered (usually apartment complexes and car dealers) were retained in the dataset, although dropping those data did not qualitatively change the results. Each dot in the figure does not represent an equal number of vehicles.

It is important to note that Figure 2 only maps the inspection pass rate of vehicles older than five model years. If I assume that households with higher annual incomes are more likely to own new vehicle than households with lower annual incomes, then Figure 2 under-represents the upward trend of pass rate in income.

3.1 Regression Analysis

A number of factors could contribute to a passing an emissions inspection, including both owner characteristics and vehicle characteristics. For example, if lower income owners all tend to drive older vehicles, one would expect the trend seen in Figure 2 because older vehicles fail inspections at a higher rate (see Figure 1). If, however, after controlling for observable vehicle characteristics, there is still a systematic difference in pass rate between low income and high income owners, some factor besides observable vehicle characteristics might contribute to inspection pass rate. In this section I will show that even after controlling for vehicle characteristics such as make, model, mode year, and odometer reading, lower income owners still pass vehicle inspections at a lower average rate.

To understand what vehicles characteristics and owner characteristics contribute to passing the inspection, I use a linear probability model to regress owner and vehicle characteristics on inspection passage rate. The assumed data generating process is

$$E = \beta_0 + \beta_1 w + \beta_2 V + \beta_3 X + \varepsilon \tag{1}$$

where
E = probability of passing the emissions test
w = annual income of owner
V = vehicle characteristics (odometer, make, model, model year)
X = controls (testing station, observation county, observation year)
ε = error

Table 3 summarizes the results. Column (1) displays the results of a naive linear probability model that includes all available data. Column (2) repeats the exercise with an assumed data generating process that maximizes fit and address multicollinearity. Column (3) repeats the exercise using income data aggregated to the zip code level. Column (4) repeats the exercise in a logit model because the dependent variable is almost always close to one. In the linear models, standard errors are clustered by the relevant income grouping.

In all specifications, the coefficient on odometer is negative and the coefficient on model year is positive. This is expected. Newer vehicles pass more often. Vehicles with higher miles pass less often. The coefficients on vehicle make show that Hondas are more likely to pass an emissions inspection than any other model in the study. The reference vehicle make is Chevrolet. Since all the coefficients under vehicle make are positive, this means that Chevrolets are least likely to pass the emissions inspection on average.

The coefficient on income is significant and positive, even when controlling for vehicle characteristics and location fixed effects. This implies that a person with lower annual income is less likely to pass the emissions inspection, even if he drove the same make, size, and mileage of vehicle as a person with higher annual income. The magnitude of the effect is approximately the same as that of odometer reading: a \$10k increase in the income of the owner has approximately the same effect on the probability of passing the emissions inspection as a reduction of 10,000 miles on the odometer.

The effect of income, even when controlling for vehicle characteristics, could be an indicator of how well different income groups service their vehicles. Perhaps individuals with a higher annual income change the oil more often, replace the tires

Table 3: Dependent variable is probability of passing emissions test. Linear model standard errors clustered by relevant income grouping. Logit coefficients are raw and standard errors are calculated using the delta method.

	(1) Naive	(2) Good Fit	(3) Income by Zip	(4) Logit
Income ($10k)	0.0020**	0.0032**	0.0032**	0.063**
	(0.000)	(0.000)	(0.000)	(0.000)
Odometer (10k)	-0.0028**	-0.0035**	-0.0035**	-0.048**
	(0.000)	(0.000)	(0.000)	(0.000)
Model Year	0.0038**	0.0005**	0.0005**	0.0012**
	(0.000)	(0.000)	(0.000)	(0.000)
Make				
Honda	0.044**	0.053**	0.054**	0.88**
	(0.0001)	(0.0001)	(0.0001)	(0.000)
Toyota	0.044**	0.052**	0.052**	0.82**
	(0.0001)	(0.0001)	(0.0001)	(0.000)
Nissan	0.020**	0.030**	0.031**	0.41**
	(0.0001)	(0.0001)	(0.0001)	(0.000)
Ford	0.019**	0.019**	0.019**	0.27**
	(0.0001)	(0.0001)	(0.0001)	(0.000)
Dodge	0.016**	0.024**	0.024**	0.35**
	(0.0001)	(0.0001)	(0.0001)	(0.000)
Other	0.015**	0.021**	0.021**	0.27**
	(0.0001)	(0.0001)	(0.0001)	(0.000)
Chevrolet	0	0	0	0
N	2,297,601	2,297,601	2,297,601	2,297,601
Rsq {Pseudo}	0.146	0.935	0.935	{0.165}
Clusters	3,960	3,960	305	

* $p < 0.05$, ** $p < 0.01$

more often, or get the vehicle aligned more often. These maintenance activities could contribute to the likelihood a vehicle will pass the emissions inspection.

There is also a positive income coefficient in the levels of the three measured pollutants (HC, CO, NOx). Even when controlling for vehicle characteristics and location fixed effects, higher income is associated with lower levels of HC, CO, and NOx. Results of these regressions are presented in Table 4.

The income effect is seen in other aspects of the data. Table 5 shows the average number of tests before the vehicle passes inspection, by quintile of the income distribution. People with lower annual income retest more often before passing. Table 6 shows the percent of vehicles tested that never pass the emissions inspection despite multiple tries, by quintile of the income distribution. People with lower annual income are more likely to never pass the emissions inspection.

3.2 Policy Implication

Data suggests that the Arizona vehicle emissions inspection program impacts people at different points on the income distribution differently. Specifically, vehicle owners with lower annual income are more likely to be constrained by the Arizona VEIP to make vehicle repairs they did not choose to make prior to the inspection. This difference persists even when controlling for vehicle characteristics.

This has policy implications. Programs designed to induce vehicle repair or fleet update may have a different impact on pollution depending on the characteristics of the *owners* of the vehicles targeted for repair or replacement, not just on the characteristics of the vehicles themselves. For example, replacing an old vehicle owned by a low income owner with a new vehicle could do *more* to reduce pollution than replacing the same vehicle owned by a high income owner. If the results of this Arizona study hold to be universally true, means testing as a requirement to participate in vehicle replacement or update incentive programs (such as the 2009 CARS program) could be considered.

4 Impact and Cost Effectiveness

While it is clear that a vehicle emissions inspection program does induce some vehicle owners to make emissions reducing repairs, what is the overall effect of the program? Further, if vehicle inspection programs do reduce emissions, are the emissions reductions high enough to justify the cost of the program? These questions are explored in this section.

Table 4: Results of linear probability regression. Dependent variable is level of pollutant specified, measured in grams emitted during first failing test. Standard errors clustered by census block groups.

	(1) CO	(2) HC	(3) NOx
Income ($10k)	-0.30**	-0.020**	-0.034**
	(0.000)	(0.000)	(0.000)
Odometer (10k)	0.16**	0.019**	0.040**
	(0.000)	(0.000)	(0.000)
Model Year	-0.76**	-0.013**	0.020**
	(0.000)	(0.000)	(0.000)
Make			
Honda	-1.73**	-0.39**	-0.58**
	(0.000)	(0.000)	(0.000)
Toyota	-4.701**	-0.48**	-0.70**
	(0.000)	(0.000)	(0.000)
Nissan	-1.74**	-0.34**	-0.36**
	(0.000)	(0.000)	(0.000)
Ford	-2.67**	-0.36**	-0.55**
	(0.000)	(0.000)	(0.000)
Dodge	-0.50	-0.063*	0.46**
	(0.251)	(0.013)	(0.000)
Other	-1.25**	-0.21**	-0.16**
	(0.000)	(0.000)	(0.000)
Chevrolet	0	0	0
Observations	108,556	108,556	108,556
R^2	0.074	0.122	0.087
Clusters	3,336	3,336	3,336

* $p < 0.05$, ** $p < 0.01$

Table 5: Average number of tests before the vehicle passes, by quintile of the income distribution.

Income Quintile	Number of Tests Before Pass
First ($13K - $49k)	1.31
Second ($49K - $59k)	1.25
Third ($59K - $71k)	1.22
Fourth ($71K - $91k)	1.18
Fifth ($91K +)	1.15

Table 6: Percent of vehicles that never pass emissions, by quintile of the income distribution.

Income Quintile	Percent Never Pass
First ($13K - $49k)	3.6%
Second ($49K - $59k)	2.5%
Third ($59K - $71k)	1.9%
Fourth ($71K - $91k)	1.3%
Fifth ($91K +)	0.9%

4.1 Impact

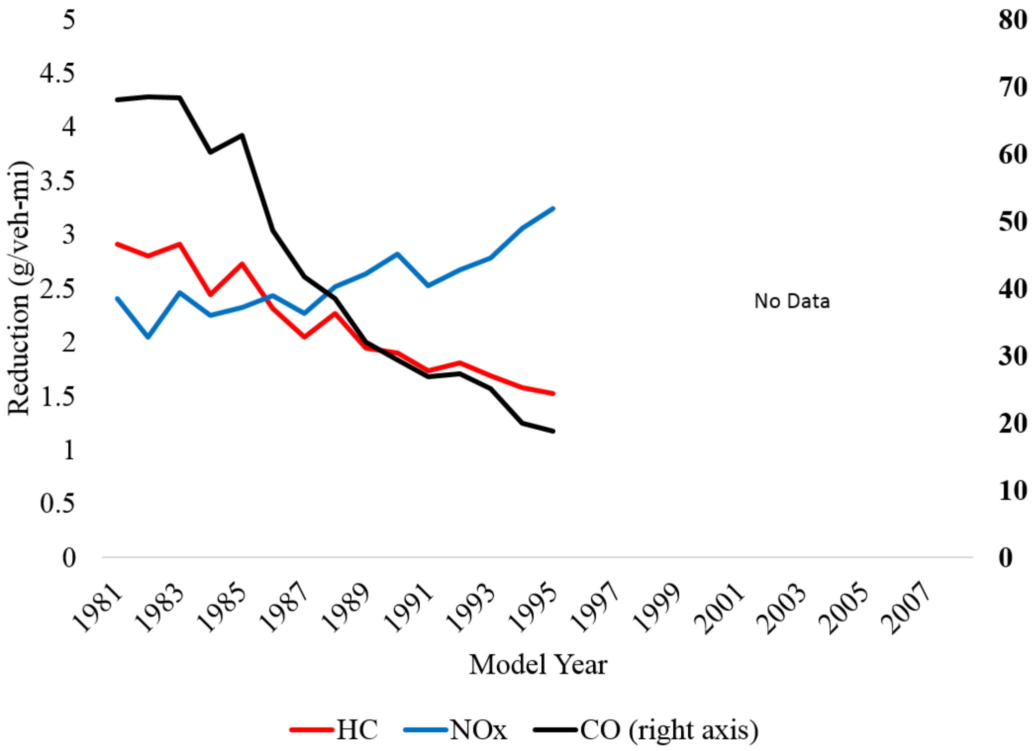
The total reduction in emissions from a vehicle emissions inspection program is not straightforward to calculate. The majority of vehicles are inspected by reading data from a vehicle's On-Board Diagnostic (OBD) system. OBD data does not provide a direct measure of emissions levels of the vehicle. It only reports binary information on whether the vehicle's engine monitoring systems are working, and whether certain emissions-*related* values have stayed within a required range.[1]

Despite these concerns, OBD is the standard method used by states that run a Vehicle Inspection/Maintenance program to test the majority of vehicles. As the percent of the vehicle fleet newer than 1996 model year increases over time, the portion of vehicle inspections done using the OBD test will increase.

However, a portion of the vehicles in this study were tested using the IM147 test, which directly measures levels of pollutants emitted by the vehicle. The method currently used by the EPA for measuring emissions reduction relies on differencing the pollution level of vehicles that fail the IM147 emissions inspection

[1] OBD testing has advantages and disadvantages. Advantages include continuous monitoring, speed, and convenience. OBD tests took 93 seconds on average, while IM 147 tests took 243 seconds. Disadvantages include opportunity for fraud, and lack of overlap between the set of vehicles that fail the OBD test and those that fail tailpipe emissions.

Figure 3: Reduction of pollutant by model year. CO is on right axis.



and the pollution level of those same vehicles when they pass a retest. The formula used, in units of grams per vehicle-mile, is

$$\Delta_{iyc} = \frac{\sum \frac{p_{iyc}^{fail}}{x_{yc}^{fail}} - \sum \frac{p_{iyc}^{retest}}{x_{yc}^{retest}}}{N_{yc}} \tag{2}$$

In (2), Δ is the average emissions reduction for each vehicle category, $i \in \{HC, CO, NOx\}$ is the measured pollutant, $y \in [1981, 1995]$ is vehicle model year, $c \in \{\text{light duty vehicles, light trucks, medium trucks}\}$ is a broad category of vehicle size, p is the total grams of pollutant emitted during the test, x is the miles driven during the test, and N is the number of vehicles in the emissions category.

Figure 3 shows average emissions reductions per vehicle-mile for each of the three measured pollutants across model years. No data is reported for model year 1996-2008 vehicles because they are inspected using the OBD test which does not provide emissions data.

Note that the data presented in Figure 3 only includes vehicles older than 1996 model year that fail the initial inspection and pass a subsequent inspection. This represents 1% of all vehicles inspections during the study period, and only 6% of the set of vehicles that fail the first test and pass a subsequent test. It also ignores the effect of the program on individuals who make emission reducing vehicle repairs *before* the first emissions inspection. This, however, may not be a bad assumption since retesting is free. An owner has incentive to try to pass an emissions inspection before paying for repairs.

Filling in the missing data for model year 1996-2008 requires an assumption. I assume that a smoothly varying inspection *pass rate* across model years equates to a smoothly varying *emissions reduction* across model years. Figure 1 shows that the inspection pass rate varies smoothly across model year, even as inspection method changes in 1996. Figure 4 shows that 15-, 16-, and 17-year-old vehicles have a smoothly varying inspection pass rate across time and test types. Further, while there is a discontinuous change in emissions *monitoring* technology between 1995 and 1996 model years, there is no discontinuous change in emissions *abatement* technology. This is all evidence that emissions reduction levels might vary continuously across model years.

Admittedly, the assumption used to fill in the missing 1996-2008 data is important to the results of this section. A few alternative assumptions, such as applying the 1995 reduction level to all subsequent model years, were explored. The results presented here are quite robust to the assumption used.

Figure 3 shows that in each of the three measured pollutants, there is a trend across model years, upward for NOx, and downward for HC and CO. I use OLS to estimate the trend and extrapolate emissions reduction levels for 1996-2008 model years from the 1981-1995 data. A simple data generating process with good fit is

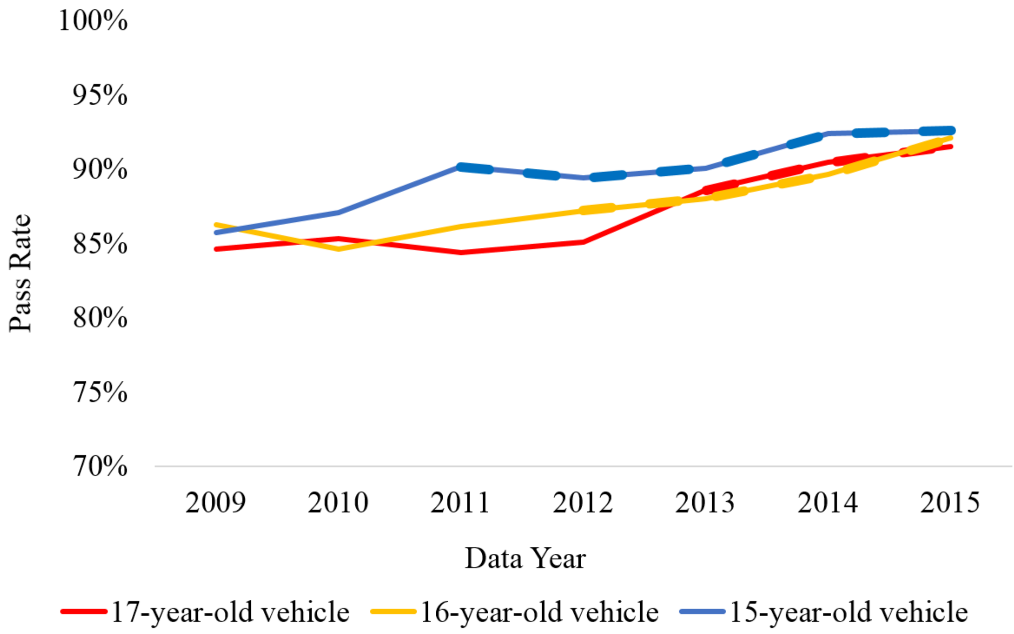
$$ln(\Delta_{iy}) = \beta_0 + \beta_1 y \qquad (3)$$

where Δ is measured emissions reduction, $i \in \{HC, CO, NOx\}$, and $y \in [1981, 1995]$ is vehicle model year. Here β_0 is a level parameter and β_1 is an exponential decay/growth parameter. Data is weighted by number of vehicles in each model year.

Using the estimated parameters $\tilde{\beta}_0$ and $\tilde{\beta}_1$, and the data generating process assumption, I extrapolate expected emissions reduction for $y \in [1996, 2008]$ model years. Figure 5 shows the OLS fitted trend line and extrapolated values for each of the three pollutants in all relevant model years.

With assumed emissions reduction values for each model year vehicle, estimating the impact of the Arizona VEIP is straightforward. In Table 7, the per-vehicle-mile reduction in pollutant is estimated by taking a weighted average of emissions reductions for each model year 1981-2008, weighting each model year by the number of vehicles that fail an inspection and then later pass for that model year. If I assume each repaired vehicle is driven the national average of 13,500 miles per year, I can calculate the annual impact of the Arizona program in

Figure 4: Inspection pass rate for 15-, 16-, 17-year-old vehicles across time. The smooth portion of the line means the vehicle was inspected with the IM147 test; the dotted portion means the vehicle was inspected using the OBD test.



units of tons of pollutant per year. This is also shown in Table 7. For scale, the last column of Table 7 shows that the VEIP induced reduction of NOx is approximately 8% of the total NOx emission from on-road vehicles in the Phoenix 8-hour ozone non-attainment area, as reported by the Maricopa County Air Quality Department.

4.2 Cost and Benefit

The monetary cost of the Arizona vehicle emissions inspection program is given in the data. Monetary costs come from two sources: the fee for taking the test and the cost of vehicle repairs. The test fee is approximately \$20 per vehicle and is reported

Table 7: Reduction in grams per vehicle mile of Hydrocarbons (HC), Carbon Monoxide (CO), and Oxides of Nitrogen (NOx).

Pollutant	Extrapolated Reduction	Impact (tons/year)	Reduction (% of total)
HC	1.28 g/veh-mi	1612	
CO	14.5 g/veh-mi	18277	
NOx	3.57 g/veh-mi	4512	7.96%

Figure 5: Extrapolated reduction of pollutant for model years 1996-2008. CO is on right axis.

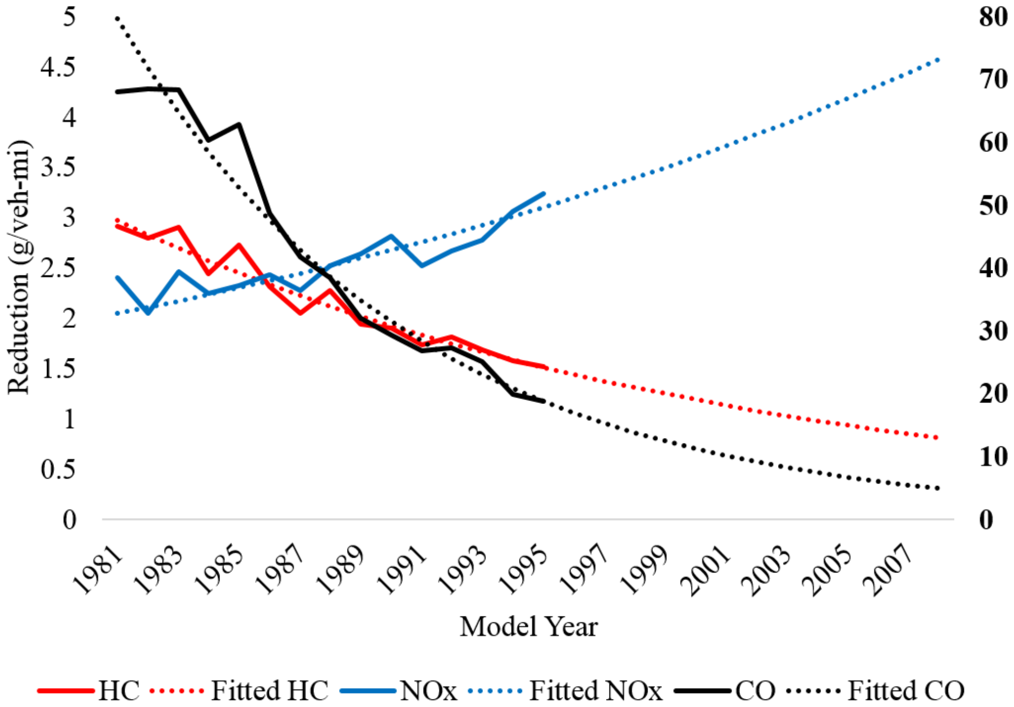


Table 8: Annual cost, averaged across the 2013-2014 testing cycle, of the Arizona Vehicle Emissions Inspection Program.

Average Annual Cost	$48,449,512	
Test fee	$35,861,995	74%
Repair cost	$12,587,517	26%

in the data. The cost of repairs is self-reported by the vehicle owner when a vehicle is brought back to the testing station for a retest. Time costs, psychological costs, or other intangible costs are not included in the data.

The average total annual cost for the 2013-2014 testing cycle is $36 million from testing fees and $12.6 million from *reported* vehicle repair costs. Only 17.1% of retests report any repair costs. This could be because the owner obtained free repairs, or because the owner chose not to report the cost of repair. Because of this, the number reported for repair costs represents a lower bound. The average repair cost for owners that reported a non-zero repair cost is $203 per vehicle. If I assume that the average repair cost applies to all repairs with a zero reported repair cost, then the total cost of repairs is $73.4 million and the total program cost is $109.5 million. Cost information is summarized in Table 8.

To calculate the benefit of the program, I use measures of social costs of pollutants from various published sources. The Environmental Protection Agency reports a social cost of carbon and a social cost of methane. I assume these costs represent the social benefit of a reduction in emissions of carbon monoxide and hydrocarbons, respectively. While methane is not the only hydrocarbon measured in the emissions tests, it is the closest proxy for which there is a published social cost. To measure the social benefit of a reduction in NOx, I use the Muller, Mendelsohn, Nordhaus (2011) AP2 model. The AP2 model gives a county-specific estimate of the marginal social damages of NOx.

The AP2 model assumes a $2 million value of statistical life (VSL), while the models used by the EPA have an implicit VSL assumption of approximately $7 million. All values are in 2014 dollars. Because VSL is a units conversion parameter in this exercise, I rescaled the values in the AP2 model to match a $7 million VSL assumption. These benefit value assumptions are summarized in Table 9.

To calculate the benefit/cost ratio of the Arizona VEIP, I multiply annual emissions reductions by social benefit, and divide by total cost of the program. In Table 10, I report a high and a low estimate. The high estimate (reported as column *(1)* in Table 10) is calculated assuming that VSL is $7 million and that *reported* repair costs represent all repair costs. The low estimate (reported as column *(2)* in Table 10) is calculated assuming VSL is $3.5 million and that the average vehicle

Table 9: Assumed benefits from a reduction of one ton of each measured pollutant. Prices in 2014 dollars.

Pollutant	**Benefit**	**Source**
Hydrocarbons	$1,141/ton	EPA, social cost of methane
Carbon Monoxide	$41/ton	EPA, social cost of carbon
Oxides of Nitrogen (Phoenix)	$6,824/ton	AP2 model, ground level
Oxides of Nitrogen (Tucson)	$2,675/ton	AP2 model, ground level

Table 10: Benefit/Cost ratio of the Arizona Vehicle Emissions Inspection Program.

City	**Benefit/Cost Ratio**		**Break-even VSL**
	(1)	*(2)*	
Phoenix	1.01	0.22	$6.9M - $31.8M
Tucson	0.45	0.10	$15.6M - $70M

repair cost of $203 was the true repair cost for each vehicle that did not report a repair cost.

These estimates imply that $100 spent on the VEIP in Phoenix produces between $22 and $101 dollars of social benefit, and that $100 spent on the VEIP in Tucson produces between $10 and $45 in social benefit. Adding time costs, psychological costs, and other intangible costs would further drive the benefit/cost ratio down.

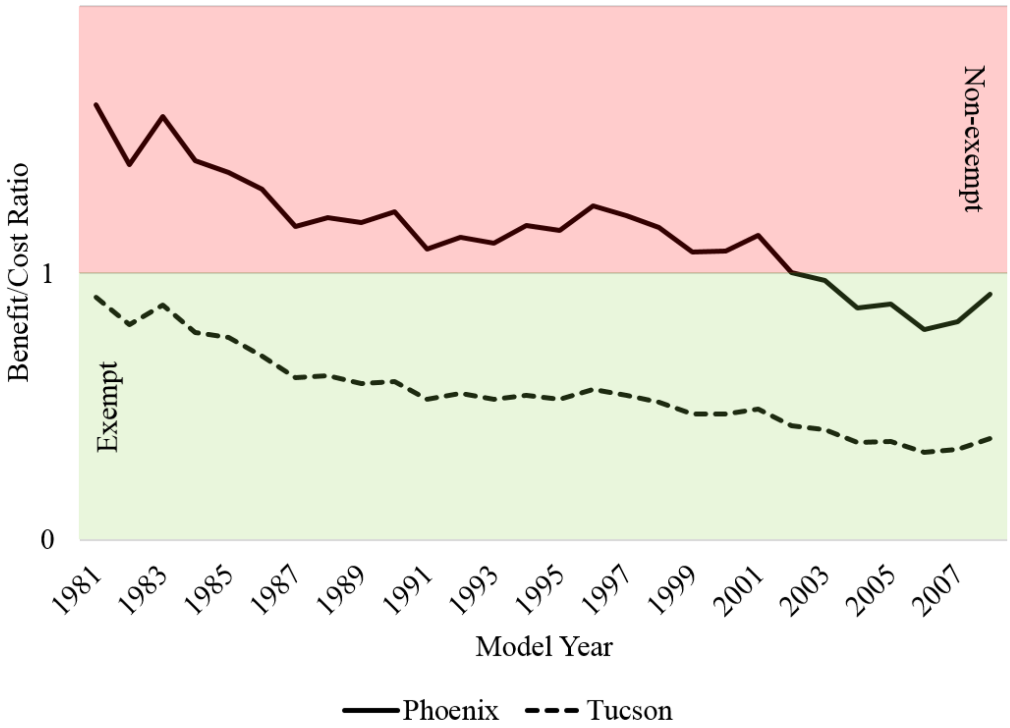
In the final column of Table 10, I report the VSL assumption needed for the VEIP to break even, meaning the measured social cost of the program is equal to the measured social benefit. These results imply that it is difficult to justify the VEIP in Tucson based on a benefit/cost analysis. Similarly, the Phoenix program is only justifiable under generous assumptions.

4.3 Cost and Benefit By Model Year

Current policy exempts from inspection the five newest model year vehicles on a rolling basis. Presumably, this is because new vehicles are unlikely to require emissions related repairs. Is exempting five model years the right number? In this section, I stratify the emissions inspection data by model year and ask, "Which model years would have been exempted from testing because the social cost of testing that model year exceeded the social benefit?"

I use the same benefit assumptions described in Table 9, a VSL of $7M, and only *reported* repair costs. I also assume that a counter-factual emissions inspection policy would have had no effect on the composition of the vehicle fleet, the repair

Figure 6: Benefit to cost ratio by vehicle model year. Assumes VSL is $7 million, reported repair costs represent all repair costs, and uses the extrapolation method for calculating emissions reduction for model years 1996-2008.



decisions of owners, or the average annual miles driven. The results are summarized in Figure 6.

In this counter-factual policy, all vehicles would be exempt from inspection in Tucson because the measured benefit of inspection does not exceed the estimated social cost for any model year. In Phoenix, vehicles newer than model year 2002 would be exempt from inspection. The difference between Tucson and Phoenix arises because the marginal benefit of decreasing NOx emissions is lower in Tucson than in Phoenix, as is shown in Table 9.

This result has policy implications. Policymakers could increase the benefit/cost ratio of the Arizona VEIP by canceling the Tucson program and exempting the 11 newest model years from inspection in Phoenix.

This exercise could easily be repeated for any stratum of vehicle characteristics. For example, one could evaluate the benefit/cost ratio of imposing a vehicle emissions inspection program on a bin of 1995 Light-Duty Nissan Trucks. Comprehensive results of such an exercise are not presented here, but follow an expected trend. Older, American made vehicles registered in Phoenix tend to score higher in a VEIP benefit/cost ratio analysis.

5 Conclusion

The Arizona vehicle emissions inspection program constrains the vehicle repair decision of people with lower annual income more than people with higher annual income. Individuals with a lower annual income are both (i) more likely to drive vehicles that fail the inspection at a higher average rate, and (ii) more likely to fail an inspection conditional on vehicle characteristics.

This result is significant because it informs policy. A program designed to induce vehicle repair or fleet update may have a different impact on emissions depending on the characteristics of the *owners* of the vehicles targeted in addition to the characteristics of the vehicles themselves.

Further, while the Arizona VEIP does reduce emissions, that the social benefit of the program does not exceed social cost in Tucson, and requires generous assumptions to exceed social cost in Phoenix. Even using generous assumptions, the social benefit of the program does not exceed social cost for model year 2002 and newer vehicles in Phoenix. This implies that exempting newer model year vehicles from VEIP requirements could be an effective means of increasing the benefit/cost ratio of these programs.

Further work is needed to fully understand the implications of emissions inspection programs. Open questions include, "What is the appropriate definition of a household when analyzing vehicle choice and repair decisions?", "How will moving to an OBD testing system impact our ability to measure pollution?", and "Is there a more efficient way to identify high polluting vehicles?"

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