APPENDIX A: FURTHER DISCUSSION OF DATA AND MODEL

Scrappage rate

In this study a vehicle is considered scrapped when it is no longer registered and is therefore not a legally operable vehicle. The scrappage rate for a given model year *m* at age *a* is calculated as the difference between number of vehicles observed in model year *m* at age *a* and the number of vehicles in model year *m* at age *a-1*, i.e. the number of vehicles removed from operation at age *a*, divided by the number of operable vehicles of model year *m* at the age *a-1*. For each calendar year, Polk & Co. provides Wards with counts of vehicles in operation as of each July 1st by model year for 14 years of age for passenger cars and light trucks. For example in yearbook 2001, Ward's reports the number of vehicles still in operation from model years 1987 through 2001. We collect these data through Ward's yearbooks (1981-2002). This data covers model years 1969 through 2002; total number observations for our regressions are 325. After 2002, Ward's Yearbooks no longer publish this data.

Records of cars older than 14 years are not reported. Although this censorship limits our ability to observe the tail of the scrappage curve, the behavior can be inferred from the patterns established before this cut-off. Occasionally counts increase for 1-year-old vehicles, implying a negative scrappage rate. New vehicle models tend to enter the market ahead of the calendar year, and are often sold through the next calendar year, therefore the scrappage of 1-year-old vehicles are removed from our analysis.

Turnover Rate

From Ward's Yearbooks, we obtain the total number of new registrations in each calendar year as of each July 1st. We also obtain from Ward's Motor Vehicle Facts and Figures the total number of operable vehicles in each calendar year as of each July 1st. The ratio of these values provides the turnover rate.

Vehicle Price Index

The decision to scrap depends on the current value of the vehicle and the repair and maintenance cost. Following Walker (1968), we define vehicle price index to be the ratio of used vehicle price index and motor vehicle maintenance and repair cost index. Both indexes are from the Bureau of Labor Statistics. They are seasonally adjusted averages of U.S. city and have a 1982-84 reference base. That is, BLS sets the average index level (representing the average price level)—for the 36-month period covering the years 1982, 1983, and 1984—equal to 100.

Used vehicle price index is an average across cars and trucks and is constructed from the N.A.D.A. Official Used Car Guide.[1] All prices are adjusted for depreciation of the vehicle. The price is based on a three month moving average of the current and last two months depreciation adjusted prices. For month t, the BLS compares the price $(D_t+D_{t-1}+D_{t-2})/3$ to the price $(D_{t-1}+D_{t-2}+D_{t-3})/3$, where D_t is the depreciation adjusted price for month t.

Data for Robustness Tests

Annual seasonally adjusted Gross Domestic Product (GDP) is from International Financial Statistics dataset. Annual average U.S. steel scrap price per metric ton is from the U.S.

1 For more detail see Pashigian (2001), and http://www.bls.gov/cpi/cpifacuv.htm.

Geological Survey[2], and U.S. imports vehicle sales data are from Ward's Yearbooks. Annual gasoline price data are from the Department of Energy. The seasonally adjusted new car and truck price indexes are from Bureau of Labor Statistics, with a base period as 1982 to 1984.

Table A.1: Data Statistics

Variable	Obs	Mean	Std.	Min	Max
Total number of cars being scrapped in year t	41	7,816,472	998,967	5,668,708	11,200,000
Total number of operable cars in year t	41	116,000,000	13,300,000	83,100,000	130,000,000
Turnover Rate	41	7.8%	2.0%	4.3%	12.6%
Used vehicle price index	42	111.40	41.33	32.98	158.70
Repair and maintenance cost index	42	139.95	64.84	39.27	257.58
Gasoline price	41	2.14	0.53	1.38	3.42
Gross Domestic Product	41	10142.06	2897.335	5835.247	14753.61
Percent of import	27	26.9%	6.1%	19.2%	37.7%
Steel scrap price	41	124.7	81.7	33.9	392.0
New car price index	38	119.5	24.3	62.9	144.2
New truck price index	29	136.3	15.7	101.3	152.0
Average car fuel economy	38	22.3	2.9	13.5	27.3
Average truck fuel economy	38	16.8	1.8	11.6	19.4

2 1969-1998 data are from: http://minerals.usgs.gov/minerals/pubs/metal_prices/, http://minerals.usgs.gov/minerals/pubs/commodity/iron_&_steel_scrap/360798.pdf. And 1999-2001 data are from http://minerals.usgs.gov/minerals/pubs/commodity/iron_&_steel_scrap/index.html#myb, http://minerals.usgs.gov/minerals/pubs/commodity/iron_&_steel_scrap/360303.pdf.

APPENDIX B: FURTHER DISCUSSION OF MODEL

Benefits of the 2-step Model

We primarily adopt the 2-step approach outlined above to make it comparable with earlier studies in this literature but it also presents a number of advantages over other potential models. The 2-step model allows for calculation of the expected vehicle lifetime and for an elasticity of scrappage with respect to vehicle price that is less constrained by functional form assumptions. Other empirical strategies tend to fall into two broad classes of models: hazard models (e.g. Manski and Golden, 1983; Chen and Lin, 2006; Knittel and Sandler, 2010) or one-step logit models (e.g. Hamilton and Macauley, 1999). Hazard models often assume that hazard rates are constant (for example using the Exponential distribution) or follow particular parametric distributions (for example using the Weibull or Gompertz distribution), which poorly follow the sigmoid shape of automobile scrappage rates (Feeney and Cardebring, 1988). While a Cox Proportional Hazard Model alleviates the need for these assumptions because it does not specify a base hazard rate, it does not provide a parametric formula for baseline scrappage rates, which is desirable for calculating expected vehicle lifetime. It can be useful for simulation models to have a parsimonious way to predict scrappage rates at any age with the three estimated parameters of the logit curve.[3] Alternatively it is possible to use a one-step logit model where explanatory covariates enter in to the exponent of the logit (e.g. Hamilton and Macauley, 1999). This method

3 Thus our analysis is similar in spirit to that of Knittel and Sandler (2010) with the exception that we assume the logistic curve for baseline hazard rates.

does control for the logistic shape of scrappage rates but as vehicle age increases, the age component will dominate the exponentiated term and overwhelm the influence of other covariates. Without careful consideration for how vehicle price interacts with age the scrappage elasticity with respect to vehicle age will tend towards zero.[4]

Alternative Formulation of the First Step

To estimate baseline scrappage rates, we follow the traditional literature and stratify the regressions by model year. We now present specifications that pool all observations and control for model year parametrically. These specifications are of the form:

where *a* is age, *m* is model year, and *L* and *k* are parameters to be estimated.

These regressions provide similar results with cars having vehicle lifetimes at the mean model year of 14-15 years and trucks of 16-17 years. The final truck nonlinear least squares truck regression could not converge and is omitted.

Table A.2: Robustness Check of Logistic Parameters of Engineering Scrappage

	1969-2014				
Passenger Cars	I	II	III	IV	V

4 In Appendix Table A.4 we perform the second step of our estimation for each vehicle age and show that although these estimates are less precise than the aggregate regressions, the scrappage elasticities with respect to vehicle price do not seem to trend systematically towards zero.

L_0	5.238***	10.686***	4.327***	5.350***	4.430
	(0.476)	(0.339)	(0.141)	(0.422)	(3.300)
L_1		0.224***		0.032*	0.338**
		(0.011)		(0.013)	(0.122)
L_2					0.011***
					(0.001)
k_0	5.703***	6.080***	6.640***	6.774***	6.865***
	(0.261)	(0.192)	(0.129)	(0.144)	(0.196)
k_1	-0.363***	-0.449***	-0.337***	-0.360***	-0.504***
	(0.033)	(0.024)	(0.011)	(0.015)	(0.040)
k_2					0.011**
					(0.004)
k_3			0.068***	0.066***	-0.005
			(0.003)	(0.003)	(0.009)
k_4					-0.002***
					(0.000)
Obs	0.884	0.950	0.977	0.978	0.982
R-Squared	456	456	456	456	456
Expected Lifetime[2]	14.36	14.96	14.63	14.82	14.73
95% C.I.	[14.06, 14.68]	[14.79, 15.13]	[14.51, 14.75]	[14.65, 14.99]	[11.41, 15.48]
Light Trucks					
L_0	6.542***	9.111***	7.686***	3.879*	
	(1.302)	(1.261)	(0.928)	(1.839)	
L_1		0.123***		-0.132**	
		(0.021)		(0.046)	
L_2					
k_0	5.163***	5.154***	5.512***	5.488***	
	(0.146)	(0.143)	(0.158)	(0.152)	
k_1	-0.236***	-0.241***	-0.252***	-0.223***	
	(0.023)	(0.022)	(0.020)	(0.021)	
k_2					
k_3			0.020***	0.029***	
			(0.003)	(0.004)	
k_4					
Obs	463	463	463	463	
R-Squared	0.915	0.922	0.927	0.929	
Expected Lifetime[2]	16.91	16.98	17.01	16.85	
95% C.I.	[16.71, 17.07]	[16.84, 17.12]	[16.88, 17.14]	[16.52, 17.07]	

APPENDIX C: FURTHER PRICE REGRESSIONS FOR CARS AND LIGHT TRUCK FLEET

The following tables further examine the robustness of the regressions used to find the scrappage elasticity with respect to vehicle price. These are done with other regressors controlling for the initial fuel economy of the vehicles sold in Table A.5. These measures will deteriorate overtime as the composition changes based on preferential scrappage of inefficient or efficient vehicles. Tables A.6 and A.7 perform regressions using the light truck fleet rather than the car fleet results presented in the main text. Generally these results are less precise than those of the car fleet, including those using the IV specification for which the instrument is weak. As documented in the main text Section 3.1, we speculate this is due to the substantial composition changes in the light truck fleet towards SUVs.

Table A.3: Other Car Regressions

	I	II	III
		Various Regressors	
Pt	-0.356**	-0.302*	-0.394***
	(0.140)	(0.170)	(0.121)
Rt	0.791***	1.028***	1.126***
	(0.193)	(0.155)	(0.059)
Ln(GDP)	-0.300**		
	(0.135)		
Ln(Average Initial Gallons per Mile)		0.031	
		(0.199)	
Ln(Average Initial Dollars per Mile)			-0.049
			(0.080)
Constant	5.363***	2.941***	3.359***
	(0.813)	(0.312)	(0.173)
N	41	35	35

Table A.4: Truck Regressions

	I	II	III	IV	V	VI	VII
				Various Regressors			
Pt		0.336	-0.085	-0.039	-0.052	-0.037	1.141*
		(0.366)	(0.278)	(0.251)	(0.299)	(0.286)	(0.550)
Rt	0.715***		0.743***	0.780***	0.744***	0.755***	0.224
	(0.261)		(0.226)	(0.202)	(0.250)	(0.244)	(0.267)
UP	-0.066						
	(0.250)						
Ct	0.022						
	(0.258)						
Ln(GDP)		-0.291	-0.056				0.757
		(0.247)	(0.216)				(1.039)
Ln(Gas Price)				0.042			0.230
				(0.209)			(0.340)
Ln(Gallons per Mile)					0.058		1.852
					(0.381)		(1.297)
Ln(Dollars per Mile)						0.025	
						(0.145)	
Ln(New Car Price)							2.641***
							(0.857)
Ln(Percent Imported)							0.975***
							(0.201)
Constant	2.689***	3.492	3.061*	2.613***	2.709***	2.631***	-12.223**
	(0.317)	(2.182)	(1.555)	(0.395)	(0.883)	(0.670)	(5.443)
N	41	41	41	41	35	35	28

Table A.5: Truck Regressions Continued

	I	II	III	IV	V	VI	VII
	< 10 years	< 10 years	< 10 years	< 10 years	< 10 years	AR1	AR2
Ln(Price Index)	-0.142	0.722*	1.152**	0.440	1.163**	-0.079	-0.080
	(0.238)	(0.351)	(0.479)	(0.501)	(0.494)	(0.289)	(0.285)
Ln(Turnover Rate)	0.616***	0.275	0.311	0.409	0.370	0.778***	0.778***
	(0.184)	(0.308)	(0.325)	(0.439)	(0.422)	(0.176)	(0.176)
Ln(GDP)		0.652	1.430	0.002	1.398		
		(0.786)	(0.934)	(0.744)	(0.898)		
Ln(Gasoline Price)		0.184	0.227	-0.076	0.143		
		(0.232)	(0.247)	(0.249)	(0.250)		
Ln(Initial Average Gallons per Mile)		2.562		4.412**			
		(1.578)		(2.100)			
Ln(New Car Price)		3.053**	1.062	4.368***	1.018		
		(1.127)	(0.794)	(1.345)	(0.774)		
Ln(Steel Price)				0.282	0.103		
				(0.213)	(0.173)		
Ln(Percent Imported)		1.097***	1.089***	1.251***	1.143***		
		(0.155)	(0.128)	(0.102)	(0.089)		
Constant	2.782***	-10.426**	-14.982***	-6.326	-14.686***	2.634***	2.635***
	(0.433)	(3.806)	(5.142)	(4.610)	(4.892)	(0.387)	(0.388)
ARMA							
L.ar						0.201	0.208
						(0.302)	(0.291)
L2.ar							-0.035
							(0.131)
N	41	28	28	28	28	41	41

Table A.6: Elasticity of Scrappage with Respect to Vehicle Price Instrument using CAFE Level

	I	II
Ln(Price Index)	37.857	0.522
	(1885.814)	(1.488)
Ln(Turnover Rate)	-14.133	0.628
	(741.084)	(0.442)
Ln(Gasoline Price)		0.187
		(0.435)
Constant	-26.419	2.247**
	(1443.865)	(1.049)
N	41	41
	First Stage	
F-Stat	0.001	1.530
R-Squared	0.324	0.429

Robust standard errors are in parenthesis. * significant at 10%, ** significant at 5%, *** significant at 1%.

APPENDIX D: LINEAR GASOLINE PRICE REGRESSIONS FOR CARS

We also examine the relationship between scrappage and gasoline prices using a linear specification similar to that used by Jacobsen and van Benthem (2013). This model does not average observations by vehicle age or calendar year as in the 2-stage specification above but rather controls for these factors with fixed effects as follows:

(A.2)

In this equation is the scrappage rate of vehicles that are of age and model year scrapped in calendar year , is the vector of dummy variables for age and model year, is the gasoline price in year calendar . The coefficient provides the marginal effect of gasoline price on scrappage rate.

Table A.7: Linear Regressions

	I	II	III	IV
		Age < 10	Other Covariates	
Ln(Gasoline Price)	-1.601**	0.747	1.713***	5.056***
	(0.667)	(0.707)	(0.621)	(0.578)
Ln(GDP)			4.990	33.780***
			(3.255)	(3.080)
Ln(New Car Price)			36.371***	49.554***
			(5.177)	(4.269)
Ln(Steel Price)			0.039	-0.172
			(0.288)	(0.215)
Ln(Percent Imported)			2.856***	2.559***
			(0.832)	(0.580)
Ln(Turnover Rate)				-12.812***
				(1.084)
Constant	5.931***	3.929***	-227.248***	-608.578***
	(1.341)	(1.331)	(29.473)	(46.007)
N	454	316	340	340

APPENDIX E: TIME SERIES TEST

Tale A.8: Residual Tests Results

		Passenger Cars		Light Trucks	
		Vehicle Price	Gasoline Price	Vehicle Price	Gasoline Price
Dickey Fuller Test		-3.308**	-0.139**	-4.252***	-4.687***
ERS Test	Lags				
	8	-1.403	-1.855	-1.071	-0.912
	7	-1.846	-2.265	-1.497	-1.211
	6	-2.144	-2.541	-1.335	-1.195
	5	-2.271	-2.904*	-1.307	-1.231
	4	-1.62	-2.484	-1.406	-1.315
	3	-1.533	-2.737	-1.341	-1.276
	2	-1.376	-2.257	-1.596	-1.539
	1	-1.796	-2.19	-2.637	-2.606
Regression on Lag					
	Lag	0.42	0.48	0.18	0.13
		(0.175)**	(0.167)***	(0.193)	(0.185)
	Const.	0.00	0.00	-0.01	-0.12
		(0.018)	(0.020)	(0.047)	(0.045)

Notes: We conducted three residual tests: Dickey Fuller test, ERS tests with 8 lags and regressing residual on the first lag. For the first two tests, t-statistics are as shown. For the regression, the coefficients are reported and standard errors are in parenthesis. * significant at 10%, ** significant at 5%, *** significant at 1%.