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Quantifying the external costs of vehicle use: Evidence from America's top-selling light-duty models

Jason D. Lemp, Kara M. Kockelman *

The University of Texas at Austin, Department of Civil, Architectural and Environmental Engineering, 6.9 E. Cockrell Jr. Hall, Austin, TX 78712-1076, USA

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ABSTRACT

Vehicle externality costs include emissions of greenhouse and other gases (affecting global warming and human health), crash costs (imposed on crash partners), roadway congestion, and space consumption, among others. These five sources of external costs by vehicle make and model were estimated for the top-selling passenger cars and light-duty trucks in the US. Among these external costs, those associated with crashes and congestion are estimated to be the most practically significant. When crash costs are included, the worst offenders (in terms of highest external costs) were found to be pickups. If crash costs are removed from the comparisons, the worst offenders tend to be four pickups and a very large SUV: the Ford F-350 and F-250, Chevrolet Silverado 3500, Dodge Ram 3500, and Hummer H2, respectively. Regardless of how the costs are estimated, they are considerable in magnitude, and nearly on par with vehicle purchase prices.

1. Introduction

Vehicle ownership and use impose a variety of social costs that are not directly borne by vehicle owners. Furthermore, these external costs vary greatly depending on the size and type of vehicle. Many studies have examined such external costs. For example, Delucchi (1998) and Litman (2007)[1] sought to characterize the total costs of motor vehicle transport. Others characterize such costs across travel modes (IBI Group, 1995; Poorman, 1995; DeCorla-Souza and Jensen-Fisher, 1997). Still others (Douglass, 1995; Sansom et al., 2001; Schreyer et al., 2004; Parry et al., 2007) look at the issue from the perspective of developing pricing policies.

These studies share a common attribute: costs are examined at an aggregate level. While a few studies observe certain cost variations by vehicle class, none does so by vehicle model. In contrast, this paper examines such variations in external costs of light-duty vehicle ownership and use by vehicle make and model.[2] Though a wide array of external transportation costs have been investigated previously, some do not apply well at the level of individual vehicle makes and models. This is discussed in more detail later in the paper. Consequently, this paper focuses on four environmental cost categories as well as congestion costs. The four environmental costs include emissions of greenhouse and other gases (affecting global warming and air quality), crash costs (for partner vehicles in multi-vehicle crashes), and space consumption.

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* Corresponding author. Tel.: +1 512 471 0210; fax: +1 512 475 8744.
E-mail address: kkockelm@mail.utexas.edu (K.M. Kockelman).

[1] Litman's (2007) study is an extensive review of existing literature related to the estimation of vehicle costs. And Litman's costs represent an average of those found in others' studies.

[2] The externalities considered in this paper are all technical externalities, meaning they involve a direct effect on a third party. Of course, this is only one type of externality as pecuniary externalities have indirect effects on a third party, where consumption by one individual drives the price higher, causing others to pay more.

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These five external costs calculated in this analysis do not encompass all external costs associated with vehicle ownership and use. For example, Sansom et al. (2001) estimated external costs of passenger vehicle noise to range from \$0.005 to \$0.03 per vehicle mile, DeCorla-Souza and Jensen-Fisher (1997) and Litman (2007) suggest disposal costs (at the end of a vehicle's "life") average about \$0.002 per vehicle mile, and water contamination from hazardous material runoff of roads has been estimated anywhere from \$0.002 (DeCorla-Souza and Jensen-Fisher, 1997) to about \$0.013 (Litman, 2007) per vehicle mile traveled. Based on his review of the transport-cost literature, Litman (2007) believes that the largest external costs of automobile ownership and use relate to land use impacts (about \$0.07 per vehicle mile). These impacts include increased temperatures caused by paved surfaces (the so-called "heat island" effect), watershed degradation due to the clearing and paving of lands, loss of green space, and urban sprawl, which have a variety of negative impacts (e.g., increased pollution, increased costs of public services, and decreased accessibility of land resulting from destination dispersal and reduced travel options). Clearly, there are many other vehicle use externalities, but most of these are generally difficult to distinguish by make and model.

This paper estimates external costs for the US's best-selling year-2006 passenger vehicle models in each class. It compares these to standard operations costs, and identifies the main offenders (i.e., those vehicles with the highest external cost estimates). The purpose of this work is to highlight, for consumers and policymakers, social cost distinctions that can exist across vehicle types.

2. Methodology

The environmental externalities investigated in this study include a global warming cost, a health cost of emissions, a crash cost (as imposed on crash partners), and a land consumption cost. In addition, traffic congestion costs[3] are considered as a point of comparison to these other costs. Several parameters were used in making these calculations: fuel economy (city and highway), US Environmental Protection Agency (EPA) air pollution scores, vehicle dimensions, curb weight, and class of vehicle (e.g., passenger car, van, pickup, and sport-utility vehicle [SUV]). The methods used in making these calculations are described below.

2.1. Global warming cost estimation

It is well understood that fossil fuel combustion adds greenhouse gases to the atmosphere. Nordhaus and Boyer (2000) performed a comprehensive analysis of the cost of carbon removal from the atmosphere, and Pearce (2005) and Tol (2005) provided insightful literature reviews on this topic. Illustrating the great deal of uncertainty concerning atmospheric damage costs, these reviews reveal estimates ranging from \$10 to \$50 per ton of carbon dioxide, though some estimates are as high as \$300 or more per ton. These large disparities are seemingly due to the way costs are aggregated across countries and the assumed discount rate (Tol 2005). Similar to estimates by Fischer et al. (2007), the US Environmental Protection Agency (2008a) and Charles River Associates International (2008), this paper's global warming external cost assumption is \$50 per ton.[4] Since 26 pounds of carbon dioxide are emitted for every gallon of gasoline refined and burned in an internal combustion engine (US Environmental Protection Agency 2007a), each vehicle's global warming cost (*GWC*) on a per mile basis can be estimated as:

$$\mathrm{GWC} = \frac{26\,\frac{\mathrm{lbs}}{\mathrm{gal}}}{\mathrm{FE}} \times \frac{50\,\frac{\$}{\mathrm{ton}}}{2000\,\frac{\mathrm{lbs}}{\mathrm{ton}}}$$

where FE represents the vehicle's combined fuel economy.

2.2. Emissions cost estimation

The US Environmental Protection Agency (2008b) air pollution indices, by vehicle make and model[5] correspond to a single set of "limits" for oxides of nitrogen (NOx), volatile organic compounds (VOCs), carbon monoxide (CO), and particulate matter of 10 microns effective diameter or less (PM10) at the end of a vehicle's "full useful life" (assumed by the EPA to be 100,000 to 120,000 miles)[6]. These limits form the basis for emissions cost estimates.

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[3] It should be noted that congestion costs are quite distinctive, in that they are borne by other motorists, and could be managed by a road authority if appropriate technologies and economically efficient pricing mechanisms were employed.

[4] The US Environmental Protection Agency's (2008a) analysis relies on a suite of estimates that rise from roughly \$30 per ton in 2015 to \$70 in 2030, and over \$100 per ton by 2040. Such costs assume that international trade in carbon credits is permitted. Costs will be higher without trade permissions.

[5] For some makes and models (13 [about 14%] of those analyzed here), EPA air pollution scores were not available and so were estimated using scores of similar model types.

[6] Actual emissions standards are in fact lower for many vehicles, particular passenger cars and lower-weight LDTs and new cars.

Ozbay and Berechman (2001) give estimates of morbidity and mortality (disease and death) costs of such emissions, per ton, though these costs are rather uncertain.[7] Based on EPA's indices and these costs, emissions costs can be estimated for each vehicle model.

2.3. Space consumption cost estimation

Providing land for use by vehicles (either parked or moving) is expensive and infringes upon other possible uses of the land (e.g., greenspace and other buildings). Litman (2007) describes two different sources of external costs in the consumption of public space. Based on his review, he suggests parking costs and land value average $0.042 and $0.024 per VMT, respectively. Here, it is assumed that land is valued at $2 million per acre (on average) in the core of a large urban area;[8] this translates to $46 per sq. ft. If, in addition, it is assumed that paved land costs an additional $50 per sq. ft.,[9] the life of a vehicle is 40% that of land (e.g., the typical vehicle life is assumed to be 10 years[10] and land value is almost fully discounted within about 25 years), and a vehicle spends half of its life consuming such publicly held land, then the value of public land devoted to storing a private vehicle is about $19 per square foot over the life of the vehicle. Using the area of the vehicle, the external costs can be calculated.

Parking and roadway facilities are designed for a 'design' vehicle, with specific dimensions; thus, it seems reasonable to assume that larger vehicles contribute more toward design decisions and larger parking spaces, producing additional external costs, as compared to smaller vehicles. Of course, land rents vary over space and time-of-day, so assumptions may be modified substantially, depending on the area of interest.

2.4. Crash cost estimation

LDTs generally are more aggressive than other vehicles in crashes (White, 2004), due to their heavier mass, higher chassis, and other design distinctions. In this way, they can cause more damage to others, including loss of life. The crash severities for LDTs relative to passenger cars were estimated using Wang and Kockelman (2005) analytical results, which are virtually the only results that control for weight and vehicle type while conditioning on crash occurrence.[11] Using a heteroskedastic ordered probit specification for crash severity, they estimated the probability of certain injury types for occupants of crash "partner vehicles". These models control for the curb weights of the crash-involved vehicles, as well as vehicle type (coded as passenger car, SUV, minivan, pickup, and heavy truck). Wang and Kockelman used the KABCO injury scale,[12] which was translated to the maximum abbreviated injury scale (MAIS) for economic analysis (see, e.g., Lee et al., 2004).

Wang and Kockelman (2005) looked at the probability of injury (in each vehicle and its crash partner), given that the crash had occurred. They analyzed multi-vehicle crashes as sets of two-vehicle crashes (so some vehicles were represented more than once in the database). Using data provided by the Federal Highway Administration (FHWA, 2004) on vehicle miles traveled (VMT) in 2004 and (reported) crash data from the NHTSA for 2004, crash rates could be identified (while both data sources offer such data for passenger cars and LDTs separately, a single crash rate was identified for all vehicle types to provide consistency in the analysis[13]). Together these suggest that vehicles are involved in (police-reported) multi-vehicle crashes at a rate of about one every 314,000 VMT (3.18 per 10^6 VMT). Using the FHWA estimates of annual VMT and passenger-miles traveled, average vehicle occupancy can also be computed.

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[7] For example, Ozbay and Berechman (2001) suggest that emissions of oxides of nitrogen (NOx) cost over $10,000 per ton, while the FHWA's Surface Transportation Efficiency Analysis Model (STEAM) default values are just $3,700 per ton (FHWA, 2000).

[8] The $2 million per acre assumption for the value of land will vary greatly, by geographic location (e.g., downtown San Francisco or suburban Dallas). Based on prices of vacant land in San Francisco from the Pacific Union website (2007), the $2 million per acre estimate is rather conservative.

[9] This cost reflects the additional cost of paving land as well as its maintenance and operations costs. Litman (2007) suggests the total cost of highway construction in urban regions to range in cost from $5 – $10 million per lane-mile, which includes cost of right-of-way. If land acquisition is ignored, and one assumes highway construction to cost $3 million per lane mile, this translates to about $50 per sq ft.

[10] Davis et al. (2008) suggest the average vehicle age at scrappage is approximately 16 years. The assumption of 10-year lifespan for vehicles comes from discounting at a rate of 7% annually, which is done to adjust for declining vehicle mileage over a vehicle's lifespan. It should be noted that the other cost estimates do not rely on this 10-year lifespan assumption.

[11] Other studies have compared crash involvement to vehicle registrations, but these hide use distinctions. For example, Kockelman and Zhao (2000) have shown that SUVs are driven roughly 25% more than passenger cars, everthing else constant (including household size and income, and vehicle age). Kweon and Kockelman (2002) found that LDTs are less crash involved, per mile driven, than passenger cars, after controlling for driver age cohort and gender. It is difficult to compare crash frequency when so many unobserved variables may be impacting the results. SUVs and minivans are costlier, on average, than passenger cars, and may be driven by more highly educated, wealthy, and conservative drivers. All these impact crash involvement rates, per registered vehicle.

[12] In the KABCO scale, K = killed, A = incapacitating injury, B = non-incapacitating injury, C = possible injury, and O = no injury. The MAIS scale includes 7 levels (0, 1, 2, 3, 4, 5, and Fatal).

[13] Crash rates were assumed to be more a function of the driver than the vehicle type. On average, it was assumed that those who choose to drive pickups probably share similar driving behaviors that may cause these drivers to have higher or lower crash rates than those who choose to drive passenger cars (i.e. if a person that had always driven a pickup began driving a passenger car, it is unlikely that there would be a significant change in the rate of crashes for this person).

Blincoe et al. (2002) estimated economic and non-economic costs associated with different injury severities based on the MAIS scale.[14] These costs were used as the basis for the external crash cost calculations. In reality, there is a certain amount of risk inherent in driving and one should not be responsible for all of the costs borne by one's crash partner if one's crash partner was at fault for the crash. It was assumed that on average, a crashing vehicle is only responsible for half of the losses borne by its crash partners[15] (e.g., if vehicles A and B were in a collision, vehicle A was assumed to responsible for half of vehicle B's costs, and vice versa). It is important to recognize two items in this analysis. First, due to 3-plus vehicle collisions, there is some systematic over-counting of the blame.[16] However, the majority (about 91%) of multi-vehicle crashes do involve only two vehicles, so this manner of over-counting should be rather small. Second, the analysis only accounts for crash partners. Thus, any costs incurred by pedestrians or bicyclists in a crash are ignored. This is clearly a limitation of this work since these are significant costs (roughly 13% of all crash fatalities are non-occupants and about 4% of all non-fatal injuries are endured by non-occupants), and their inclusion would likely make the external cost differential between big, tall and small, low-riding vehicles even greater (probably on the order of 10% higher).

2.5. Congestion cost estimation

The Bureau of Public Roads (BPR) link performance formula (as commonly used for travel demand forecasting and traffic studies [Martin and McGuckin, 1998]) can predict added delay due to each vehicle. This calculation is performed by finding the marginal difference in BPR travel time estimates (when a single vehicle is added to the traffic stream). The congestion cost is assumed to be the value of that added delay, recognizing that different vehicle types have distinct passenger car equivalent (PCE) values. Kockelman and Shabih's (2000) traffic data analyses suggest that PCE values for regular SUVs, long SUVs,[17] vans, and pickups at signalized intersections equal 1.07, 1.41, 1.34, and 1.14, respectively. (In other words, these other vehicles effectively require more "green time" than the average passenger car.) Using these PCE values and several other assumptions,[18] congestion costs are estimated.

Of course, congestion costs (as computed here) cannot be considered an environmental externality, which is the focus of this work. Moreover, many assumptions are needed here to compute congestion costs, all of which would vary by context, and the congestion cost estimates only vary by vehicle type (passenger car versus van, pickup, and SUV), not by individual vehicle model. Therefore, congestion cost estimates are offered mostly as a point of comparison.

3. Comparative cost results

The methods of analysis were applied to the top-selling light-duty vehicles of 2006. Several other vehicles of special interest also were included (e.g., GM's Hummer and several hybrid vehicles). Ward's Automotive Yearbook (2007) categorizes passenger vehicles across eight classes: small/compact, mid-sized, large, and luxury cars, crossover and sport-utility vehicles (CUVs and SUVs), pickups, and vans (including minivans). Table 1 shows US sales volumes for 107 vehicles – including top sellers and other vehicles of interest. These 107 vehicles include 20 pickups (2 of which are hybrids), 3 cargo vans, 8 minivans, 4 long SUVs, 27 regular SUVs (5 of which are hybrids), 8 luxury cars, 8 large cars, 15 mid-sized cars (4 of which are hybrids), and 14 small cars (2 of which are hybrids).

Table 2 presents each of the five estimated external costs for each vehicle model. Estimated global warming costs range from $0.0134 per vehicle mile traveled (VMT) for a 48.5 mpg Honda Insight (a small, hybrid-drivetrain car) to $0.0610 per VMT for the 10.7 mpg Ford F-350, Chevrolet Silverado 3500, and Dodge Ram 3500 (all pickups). As a point of reference, Schreyer et al. (2004) and Sansom et al. (2001) estimated climate change costs at €0.0176 per passenger-km (roughly $0.022) and £0.039 per veh-km (about $0.012), respectively. The European vehicle sizes are smaller, on average, so one would expect such estimates to be low.

Other-emissions cost estimates range from $0.0018 per VMT for the Honda Civic Hybrid (a small car) and Honda Accord Hybrid (mid-sized car) to $0.0245 per VMT for the Ford F-250 and F-350 (both pickups). These per mile costs pale in comparison to global warming and other cost estimates. The light-duty vehicle fleet's emissions have been regulated for so many years, with requirements becoming increasingly stringent over time, that most vehicles are becoming quite "clean".

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[14] Blincoe et al.'s (2002) estimates of non-economic crash costs vary with injury severity. They are $0 for no-injury. crashes and then range from a low of $4,500 (about 30% of total MAIS 1-injury crash costs) to $2.4 million (about 70% of fatal-injury crash costs). Blincoe's assumed value of life is roughly $2.4 million.

[15] Litman (2007) suggests that the fraction of crash costs borne by others (i.e., external to the vehicle owner and driver) is in the range of 15–50%. Thus, this study's assumption of 50% is on the high end. However, single vehicle crashes are not considered in our analysis (which likely have some external component), and non-occupant (e.g., pedestrians and bicyclists) injuries and fatalities are not considered (which also have some external component).

[16] For example, if three vehicles, A, B, and C, are involved in a collision and vehicle B was between vehicles A and C, vehicle B is counted as being in two two-vehicle collisions. Because of this, vehicle B is assumed to be half responsible for the collision with vehicle A and half for the collision with vehicle C, while vehicles A and C would both be half responsible for their respective collisions with vehicle B.

[17] Kockelman and Shabih (2000) defined long SUVs as those with total length greater than 200 inches (16.7 feet).

[18] Here, BPR-required parameters, alpha (α) and beta (β), were assumed to be 0.84 and 5.5, respectively (Martin and McGuckin 1998). The average roadway was assumed to have a free-flow speed of 40 mph, corresponding to 1.5 min of travel time per mile traveled. Capacity was assumed to be 2000 vehicles per hour per lane (vphpl), and demand during congested conditions is assumed to lie at 95%. The portion of travel assumed to occur during congested conditions is just 0.1 (10%), with all remaining travel assumed to occur under free-flow conditions, where marginal delay costs are practically zero. Finally, the value of travel time (VOTT) is assumed to be $8 per vehicle-hour.

Table 1
Make and model characteristics

Veh. Type	Make	Model	2006 Sales	Air pollution score	Area (sq. ft.)	Curb weight (lbs)	Combined fuel economy (mpg)	Average retail price ($)
Small car	Toyota	Corolla	335,054	6.5	83.0	2605	30.4	16,053
	Honda	Civic	272,899	6.5	84.2	2776	28.7	19,795
	Chevrolet	Cobalt	211,449	6.0	85.1	2828	24.1	17,565
	Ford	Focus	177,006	7.0	80.3	2694	25.3	16,110
	Nissan	Sentra	117,922	6.5	87.9	2922	26.7	17,940
	Saturn	Ion	102,042	6.0	86.7	2849	24.6	16,620
	Hyundai	Elantra	98,853	7.0	86.1	2737	27.7	12,165
	Mazda	Mazda3	94,437	6.5	85.0	2863	25.5	17,390
	Dodge	Caliber	92,224	6.5	83.0	3137	25.0	16,985
	Toyota	ScionTC	79,125	6.5	83.5	2889	23.3	16,240
	Kia	Spectra	72,557	7.0	82.6	2935	26.0	15,045
	Toyota	Yaris	70,308	6.5	73.8	2293	31.6	12,068
	Honda	Insight (2006 Hybrid)	N/A	7.5	71.8	1975	48.5	20,430
	Honda	Civic (Hybrid)	N/A	9.0	84.6	2628	42.1	19,600
Mid-sized car	Toyota	Camry	362,961	6.5	94.2	3483	23.9	23,625
	Honda	Accord	323,079	6.5	95.0	3281	24.0	23,608
	Chevrolet	Impala	289,868	7.0	101.5	3633	20.1	25,028
	Nissan	Altima	232,457	6.5	93.2	3162	25.0	23,790
	Ford	Taurus	174,803	5.0	100.2	3322	20.6	22,820
	Ford	Mustang	166,530	5.0	96.4	3414	18.0	26,185
	Chevrolet	Malibu	163,853	6.0	91.4	3295	22.5	20,940
	Pontiac	G6	157,644	6.0	92.7	3425	21.2	24,208
	Hyundai	Sonata	149,463	6.5	94.6	3362	23.4	20,795
	Ford	Fusion	142,502	5.0	95.4	3276	21.9	21,260
	Pontiac	Grand Prix	108,634	6.0	101.6	3539	20.8	25,815
	Toyota	Prius (Hybrid)	106,971	8.0	82.5	2932	46.6	22,998
	Honda	Accord (Hybrid)	N/A	9.0	95.0	3605	27.0	25,858
	Toyota	Camry (Hybrid)	N/A	8.0	93.4	3637	33.4	26,200
	Saturn	Aura (Hybrid)	N/A	6.0	93.2	3529	27.0	23,790
Large Car	Chrysler	300 Series	143,647	6.5	102.8	4009	19.2	32,725
	Dodge	Charger	114,201	6.0	103.5	4055	19.2	29,535
	Buick	Lucerne	96,515	7.0	104.1	3889	19.0	30,780
	Toyota	Avalon	88,938	6.5	99.7	3545	23.0	31,050
	Ford	Five Hundred	84,218	5.0	103.8	3729	20.4	26,133
	Nissan	Maxima	69,763	6.5	96.8	3585	21.3	29,780
	Ford	Crown Victoria	62,976	5.0	115.3	4129	17.1	27,890
	Mercury	Grand Marquis	54,688	5.5	114.8	4135	17.1	29,093
Luxury	BMW	3-Series	120,180	6.5	88.3	3579	20.7	41,833
	Lexus	ES350	75,987	6.5	94.6	3580	21.9	33,885
	Acura	TL	71,348	6.5	95.0	3649	20.9	36,545
	Infiniti	G35	60,745	6.5	90.1	3596	18.9	33,400
	Cadillac	DTS	58,224	6.5	107.8	4009	17.5	45,675
	BMW	5-Series	56,756	6.5	96.5	3649	18.8	51,695
	Cadillac	CTS	54,846	6.0	93.3	3709	17.9	41,155
	Lexus	IS	54,267	6.5	88.7	3553	22.3	33,695
Cargo Van	Ford	Econoline	180,457	2.0	122.3	5141	***13.9***	30,963
	Chevrolet	Express	123,195	4.0	123.5	5230	14.0	26,640
	GMC	Savana	29,973	4.0	123.5	5437	14.5	26,143
Van (mini)	Dodge	Caravan	211,140	6.0	103.3	3842	19.1	21,290
	Honda	Odyssey	177,919	6.5	107.6	4534	19.1	31,865
	Toyota	Sienna	163,269	6.5	108.0	4408	18.8	31,555
	Chrysler	Town & Country	159,105	6.5	106.4	4171	19.1	29,423
	Chevrolet	Uplander	58,699	6.0	98.8	4211	17.9	24,370
	Kia	Sedona	57,018	6.5	106.1	4376	18.5	24,130
	Ford	Freestar	50,125	5.0	106.6	4233	17.7	25,418
	Nissan	Quest	31,905	6.5	110.0	4365	18.5	29,730
SUV	Ford	Explorer	179,229	5.0	103.3	4617	15.5	30,285
	Chevrolet	TrailBlazer	174,797	5.5	99.4	4573	15.5	31,480
	Honda	CRV	170,028	6.5	88.5	3461	22.1	22,920
	Ford	Escape	157,395	5.0	85.1	3466	21.6	23,955
	Honda	Pilot	152,154	6.5	101.2	5950	17.6	30,765
	Toyota	RAV4	152,047	6.5	90.9	3489	22.3	24,240
	Jeep	Grand Cherokee	139,148	5.0	111.7	4568	16.6	36,878
	Jeep	Liberty	133,557	6.0	86.7	3981	17.4	24,598

(*continued on next page*)

Table 1 (*continued*)

Veh. Type	Make	Model	2006 Sales	Air pollution score	Area (sq. ft.)	Curb weight (lbs)	Combined fuel economy (mpg)	Average retail price ($)
	Toyota	Highlander	129,794	6.0	92.2	3726	20.1	29,150
	Chrysler	PT Cruiser	126,148	6.5	78.7	3076	21.0	25,115
	Chevrolet	Equinox	113,888	6.5	93.6	3813	19.4	23,825
	Toyota	4Runner	103,086	6.5	98.8	4300	17.2	33,615
	Chevrolet	HHR	101,298	6.0	84.7	3155	23.1	17,295
	Saturn	Vue	88,581	6.5	90.0	3480	21.5	22,360
	Jeep	Commander	88,497	5.0	116.5	4944	15.2	36,640
	Nissan	Murano	81,362	6.0	96.4	3916	19.6	34,200
	Jeep	Wrangler	80,271	6.5	78.2	3932	16.7	22,758
	Chrysler	Pacifica	78,243	6.5	109.3	4529	17.6	30,548
	Lexus	RX 350	75,508	6.5	93.9	3980	19.4	38,815
	GMC	Envoy	74,452	6.0	99.4	4600	15.7	32,355
	Nissan	Pathfinder	73,120	6.5	94.8	4616	16.8	31,450
	Hummer	H3	N/A	6.0	111.8	4776	15.0	34,978
	Ford	Escape (Hybrid)	N/A	8.0	85.1	3610	29.1	24,943
	Lexus	RX400H (Hybrid)	N/A	8.0	94.4	4190	26.6	41,880
	Mercury	Mariner (Hybrid)	N/A	8.0	85.1	3787	27.5	29,225
	Saturn	Vue (Hybrid)	N/A	6.0	90.1	3466	25.4	20,488
	Toyota	Highlander (Hybrid)	N/A	8.0	92.7	4020	26.6	34,520
Large SUV	Chevrolet	Tahoe	161,491	5.0	110.8	5385	15.5	36,653
	Ford	Expedition	87,203	4.5	116.7	5816	14.1	36,695
	Chevrolet	Suburban	77,211	5.0	122.2	5679	15.5	41,725
	Hummer	H2	N/A	3.0	114.8	6614	***11.2***	59,615
Pickup	Ford	F-150	744,996	4.0	125.9	5232	14.7	29,368
	Ford	F-250		0.5	135.4	6000	***11.2***	33,603
	Ford	F-350		0.5	148.7	6399	***10.7***	34,778
	Chevrolet	Silverado 1500	636,069	4.0	126.2	4819	15.9	27,630
	Chevrolet	Silverado 2500		1.0	133.2	5656	***11.2***	36,150
	Chevrolet	Silverado 3500		1.0	146.7	5747	***10.7***	36,445
	Dodge	Ram 1500	364,177	4.5	126.3	4982	14.7	30,120
	Dodge	Ram 2500		1.5	132.2	6468	***11.2***	41,770
	Dodge	Ram 3500		1.0	146.1	6573	***10.7***	40,208
	GMC	Sierra	210,736	4.5	125.2	4819	15.7	27,778
	Toyota	Tacoma	178,351	6.0	104.9	3620	20.6	20,603
	Toyota	Tundra	124,508	6.5	125.5	6600	15.4	32,715
	Chevrolet	Colorado	93,876	6.0	94.5	3666	18.2	19,510
	Ford	Ranger	92,420	5.5	92.5	3409	20.0	19,688
	Nissan	Frontier	77,510	6.5	107.4	4746	18.3	22,425
	Dodge	Dakota	76,098	6.0	108.9	4457	15.9	25,560
	Nissan	Titan	72,192	6.0	122.7	4987	13.2	30,685
	Chevrolet	Avalanche	57,076	5.0	121.6	5562	15.5	35,825
	Chevy	Silverado 15 (Hybrid)	N/A	3.0	125.5	5198	17.2	25,325
	GMC	Sierra 15 (Hybrid)	N/A	3.0	125.5	5198	17.2	27,483

Note: Model year for each vehicle is 2007 (except Honda Insight, 2006). Fuel economy is EPA's harmonically weighted average of highway and city driving fuel economies. Area, curb weight, fuel economy, and price values represent the midpoint in range given by Ward's (2007). Combined Fuel Economies shown in **bold** and *italics* are based on assumed values since no air pollution score was available for these models. These values were taken from other models with similar attributes. For some models, Ward's offers a range in values (e.g., length, width, weight, fuel economy). For such models, simple averages were taken using the minimum and maximum values offered by Ward's.

However, the EPA's air pollution indices are probably biased low, since actual vehicle operation may differ greatly from a chassis test on a rather gentle run cycle (Samuel et al., 2002; Pelkmans and Debal, 2006), and some vehicles' emissions equipment are poorly maintained.

The methodology for space consumption costs relies on the vehicle's discounted life – assumed to be 10 years – which comes from discounting the average light-duty vehicle's age of 16 years (Davis et al., 2008) at 7% – and is computed as a single vehicle lifetime cost. For consistency with other estimates, these costs are presented in Table 2 on a per mile basis (by dividing the cost by 120,000 lifetime miles). The findings suggest space consumption costs range from $0.0115 per VMT for the Honda Insight Hybrid (a small hybrid car) to $0.0238 per VMT for the Ford F-350 (a pickup). In comparison to Litman's (2007) summary of several cost estimates for external parking and roadway land values (about $0.072 per VMT), our estimates appear low.

The crash costs presented in Table 2 range from $0.0660 per VMT for the Chrysler PT Cruiser (SUV) to $0.2304 per VMT for the Toyota Tundra (pickup). The sales weighted average value over all vehicles is $0.1056 per VMT. Clearly, crash costs are the greatest single externality evaluated here. Interestingly, external crash cost estimates of Sansom et al. (2001), Schreyer et al. (2004), and Parry and Small (2005) are all in the range of $0.03–0.04 per VMT. And Parry (2004) estimated low, middle,

Table 2
External cost estimates by vehicle make and model, per mile driven (ranked from highest total cost to lowest)

Vehicle type	Make and model	Global warming cost	Crash cost	Health cost of emissions	Congestion cost	Land consumption cost	Total cost	Total cost (w/out crash cost)
Pickup	Dodge Ram 3500	***0.0610***	0.2295	0.0198	0.0796	0.0233	***0.4132***	***0.1837***
Pickup	Ford F-350	***0.0610***	0.2239	0.0245	0.0796	0.0238	***0.4128***	***0.1889***
Pickup	Dodge Ram 2500	***0.0583***	0.2261	0.0165	0.0796	0.0211	***0.4015***	***0.1754***
Pickup	Ford F-250	***0.0583***	0.2113	0.0245	0.0796	0.0217	***0.3953***	***0.1840***
Pickup	Chevrolet Silverado 3500	***0.0610***	0.2036	0.0198	0.0796	0.0235	***0.3874***	***0.1838***
Pickup	Chevrolet Silverado 2500	***0.0583***	0.2008	0.0198	0.0796	0.0213	***0.3797***	***0.1789***
Pickup	Toyota Tundra	0.0423	0.2304	0.0025	0.0796	0.0201	0.3748	0.1444
Pickup	Chevrolet Avalanche	0.0419	0.1981	0.0031	0.0796	0.0194	0.3420	0.1440
Pickup	Ford F-150	0.0442	0.1885	0.0051	0.0796	0.0201	0.3376	0.1490
Pickup	Nissan Titan	0.0494	0.1817	0.0028	0.0796	0.0196	0.3330	0.1513
Pickup	Chevy Silverado 15 (Hybrid)	0.0377	0.1876	0.0060	0.0796	0.0201	0.3310	0.1434
Pickup	GMC Sierra 15 (Hybrid)	0.0377	0.1876	0.0060	0.0796	0.0201	0.3310	0.1434
Pickup	Dodge Ram 1500	0.0442	0.1816	0.0041	0.0796	0.0202	0.3297	0.1481
Pickup	Chevrolet Silverado 1500	0.0409	0.1771	0.0051	0.0796	0.0202	0.3229	0.1458
Pickup	GMC Sierra	0.0413	0.1771	0.0041	0.0796	0.0200	0.3222	0.1450
Pickup	Nissan Frontier	0.0356	0.1752	0.0025	0.0796	0.0172	0.3100	0.1349
Pickup	Dodge Dakota	0.0409	0.1676	0.0028	0.0796	0.0174	0.3083	0.1407
Long SUV	Hummer H2	***0.0583***	0.1097	0.0060	0.0984	0.0183	***0.2907***	***0.1811***
Van (cargo)	Ford Econoline	***0.0469***	0.1107	0.0131	0.0935	0.0195	***0.2838***	***0.1731***
Pickup	Chevrolet Colorado	0.0356	0.1484	0.0028	0.0796	0.0151	0.2815	0.1331
Van (cargo)	GMC Savanna	0.0447	0.1153	0.0051	0.0935	0.0197	0.2785	0.1631
Pickup	Toyota Tacoma	0.0315	0.1474	0.0028	0.0796	0.0168	0.2780	0.1306
Van (cargo)	Chevrolet Express	0.0463	0.1121	0.0051	0.0935	0.0197	0.2768	0.1647
Pickup	Ford Ranger	0.0326	0.1427	0.0029	0.0796	0.0148	0.2725	0.1299
Long SUV	Ford Expedition	0.0460	0.0983	0.0041	0.0984	0.0187	0.2655	0.1673
Long SUV	Chevrolet Suburban	0.0419	0.0964	0.0031	0.0984	0.0195	0.2594	0.1629
Long SUV	Chevrolet Tahoe	0.0419	0.0925	0.0031	0.0984	0.0177	0.2537	0.1611
Van (mini)	Honda Odyssey	0.0341	0.1016	0.0025	0.0935	0.0172	0.2490	0.1474
Van (mini)	Nissan Quest	0.0351	0.0992	0.0025	0.0935	0.0176	0.2479	0.1487
Van (mini)	Toyota Sienna	0.0347	0.0998	0.0025	0.0935	0.0173	0.2478	0.1480
Van (mini)	Ford Freestar	0.0367	0.0973	0.0031	0.0935	0.0170	0.2477	0.1504
Van (mini)	Kia Sedona	0.0351	0.0993	0.0025	0.0935	0.0170	0.2474	0.1481
Van (mini)	Chevrolet Uplander	0.0364	0.0970	0.0028	0.0935	0.0158	0.2454	0.1484
Van (mini)	Chrysler Town & Country	0.0341	0.0964	0.0025	0.0935	0.0170	0.2436	0.1472
Van (mini)	Dodge Caravan	0.0341	0.0919	0.0028	0.0935	0.0165	0.2389	0.1469
Regular SUV	Honda Pilot	0.0370	0.1001	0.0025	0.0747	0.0162	0.2305	0.1304
Regular SUV	Jeep Commander	0.0427	0.0869	0.0031	0.0747	0.0186	0.2260	0.1391
Regular SUV	Hummer H3	0.0432	0.0848	0.0025	0.0747	0.0179	0.2231	0.1383
Large car	Mercury Grand Marquis	0.0380	0.0923	0.0031	0.0698	0.0183	0.2215	0.1292
Large car	Ford Crown Victoria	0.0380	0.0922	0.0031	0.0698	0.0184	0.2215	0.1293
Regular SUV	Ford Explorer	0.0419	0.0829	0.0031	0.0747	0.0165	0.2190	0.1362
Regular SUV	Chevrolet TrailBlazer	0.0419	0.0823	0.0029	0.0747	0.0159	0.2177	0.1354

(*continued on next page*)

Table 2 (*continued*)

Vehicle type	Make and model	Global warming cost	Crash cost	Health cost of emissions	Congestion cost	Land consumption cost	Total cost	Total cost (w/out crash cost)
Regular SUV	GMC Envoy	0.0415	0.0827	0.0028	0.0747	0.0159	0.2175	0.1348
Luxury car	Cadillac DTS	0.0371	0.0905	0.0025	0.0698	0.0172	0.2172	0.1267
Regular SUV	Jeep Grand Cherokee	0.0392	0.0823	0.0031	0.0747	0.0179	0.2171	0.1349
Large car	Dodge Charger	0.0339	0.0912	0.0025	0.0698	0.0165	0.2139	0.1227
Regular SUV	Nissan Pathfinder	0.0386	0.0829	0.0025	0.0747	0.0152	0.2138	0.1309
Regular SUV	Chrysler Pacifica	0.0368	0.0818	0.0025	0.0747	0.0175	0.2133	0.1315
Large car	Chrysler 300 Series	0.0339	0.0905	0.0025	0.0698	0.0164	0.2131	0.1226
Large car	Buick Lucerne	0.0343	0.0889	0.0023	0.0698	0.0166	0.2119	0.1230
Luxury car	Cadillac CTS	0.0363	0.0864	0.0028	0.0698	0.0149	0.2102	0.1237
Regular SUV	Toyota 4Runner	0.0377	0.0791	0.0025	0.0747	0.0158	0.2098	0.1307
Large car	Ford 500	0.0318	0.0867	0.0031	0.0698	0.0166	0.2080	0.1213
Luxury car	BMW 5-Series	0.0345	0.0856	0.0025	0.0698	0.0154	0.2079	0.1223
Mid-sized car	Ford Mustang	0.0361	0.0826	0.0031	0.0698	0.0154	0.2069	0.1244
Luxury car	Infiniti G35	0.0344	0.0849	0.0028	0.0698	0.0144	0.2063	0.1213
Mid-sized car	Chevrolet Impala	0.0323	0.0854	0.0025	0.0698	0.0162	0.2062	0.1208
Luxury car	Acura TL	0.0311	0.0856	0.0025	0.0698	0.0152	0.2042	0.1186
Regular SUV	Jeep Liberty	0.0373	0.0755	0.0028	0.0747	0.0139	0.2041	0.1286
Mid-sized car	Pontiac Grand Prix	0.0313	0.0842	0.0025	0.0698	0.0162	0.2040	0.1198
Regular SUV	Jeep Wrangler	0.0388	0.0750	0.0025	0.0747	0.0125	0.2035	0.1285
Large car	Nissan Maxima	0.0305	0.0848	0.0025	0.0698	0.0155	0.2031	0.1183
Luxury car	BMW 3-Series	0.0315	0.0847	0.0023	0.0698	0.0141	0.2024	0.1176
Mid-sized car	Ford Taurus	0.0316	0.0814	0.0031	0.0698	0.0160	0.2019	0.1205
Luxury car	Lexus ES350	0.0296	0.0847	0.0025	0.0698	0.0151	0.2018	0.1171
Regular SUV	Lexus RX 350	0.0334	0.0755	0.0025	0.0747	0.0150	0.2011	0.1256
Large car	Toyota Avalon	0.0283	0.0843	0.0025	0.0698	0.0159	0.2008	0.1166
Mid-sized car	Pontiac G6	0.0307	0.0827	0.0028	0.0698	0.0148	0.2008	0.1180
Regular SUV	Nissan Murano	0.0331	0.0748	0.0028	0.0747	0.0154	0.2008	0.1260
Luxury car	Lexus IS	0.0292	0.0844	0.0025	0.0698	0.0142	0.2000	0.1156
Regular SUV	Chevrolet Equinox	0.0335	0.0737	0.0025	0.0747	0.0150	0.1993	0.1256
Mid-sized car	Ford Fusion	0.0296	0.0808	0.0031	0.0698	0.0152	0.1986	0.1178
Mid-sized car	Toyota Camry	0.0272	0.0835	0.0023	0.0698	0.0151	0.1978	0.1143
Regular SUV	Toyota Highlander	0.0323	0.0727	0.0028	0.0747	0.0147	0.1972	0.1245
Mid-sized car	Hyundai Sonata	0.0278	0.0819	0.0025	0.0698	0.0151	0.1971	0.1152
Mid-sized car	Chevrolet Malibu	0.0289	0.0811	0.0028	0.0698	0.0146	0.1971	0.1161
Mid-sized car	Honda Accord (Hybrid)	0.0240	0.0851	0.0018	0.0698	0.0152	0.1958	0.1108
Mid-sized car	Saturn Aura (Hybrid)	0.0240	0.0841	0.0028	0.0698	0.0149	0.1955	0.1115
Mid-sized car	Honda Accord	0.0271	0.0809	0.0025	0.0698	0.0152	0.1955	0.1146

Table 2 (*continued*)

Vehicle type	Make and model	Global warming cost	Crash cost	Health cost of emissions	Congestion cost	Land consumption cost	Total cost	Total cost (w/out crash cost)
Regular SUV	Lexus RX400H (Hybrid)	0.0245	0.0779	0.0021	0.0747	0.0151	0.1942	0.1163
Mid-sized car	Nissan Altima	0.0260	0.0794	0.0023	0.0698	0.0149	0.1924	0.1130
Regular SUV	Toyota Highlander (Hybrid)	0.0245	0.0759	0.0021	0.0747	0.0148	0.1920	0.1161
Regular SUV	Saturn Vue	0.0303	0.0701	0.0025	0.0747	0.0144	0.1920	0.1219
Mid-sized car	Toyota Camry (Hybrid)	0.0194	0.0855	0.0021	0.0698	0.0149	0.1917	0.1062
Regular SUV	Ford Escape	0.0300	0.0700	0.0031	0.0747	0.0136	0.1914	0.1214
Regular SUV	Toyota RAV4	0.0291	0.0702	0.0025	0.0747	0.0145	0.1910	0.1208
Small car	Dodge Caliber	0.0260	0.0791	0.0025	0.0698	0.0133	0.1907	0.1116
Regular SUV	Honda CRV	0.0294	0.0699	0.0025	0.0747	0.0141	0.1906	0.1207
Small car	Toyota ScionTC	0.0279	0.0762	0.0025	0.0698	0.0133	0.1897	0.1135
Small car	Chevrolet Cobalt	0.0269	0.0755	0.0025	0.0698	0.0136	0.1883	0.1128
Small car	Saturn Ion	0.0264	0.0757	0.0025	0.0698	0.0139	0.1883	0.1125
Regular SUV	Saturn Vue (Hybrid)	0.0256	0.0700	0.0028	0.0747	0.0144	0.1874	0.1175
Regular SUV	Mercury Mariner (Hybrid)	0.0236	0.0734	0.0021	0.0747	0.0136	0.1874	0.1140
Small car	Nissan Sentra	0.0243	0.0766	0.0025	0.0698	0.0141	0.1873	0.1107
Small car	Mazda Mazda3	0.0255	0.0759	0.0022	0.0698	0.0136	0.1869	0.1110
Small car	Kia Spectra	0.0250	0.0767	0.0022	0.0698	0.0132	0.1869	0.1102
Regular SUV	Chrysler PT Cruiser	0.0310	0.0660	0.0025	0.0747	0.0126	0.1868	0.1208
Regular SUV	Chevrolet HHR	0.0281	0.0668	0.0028	0.0747	0.0135	0.1859	0.1191
Small car	Ford Focus	0.0257	0.0740	0.0028	0.0698	0.0128	0.1850	0.1111
Regular SUV	Ford Escape (Hybrid)	0.0224	0.0715	0.0021	0.0747	0.0136	0.1842	0.1127
Small car	Hyundai Elantra	0.0235	0.0745	0.0022	0.0698	0.0138	0.1836	0.1092
Small car	Honda Civic	0.0227	0.0749	0.0023	0.0698	0.0135	0.1831	0.1082
Small car	Toyota Corolla	0.0214	0.0730	0.0025	0.0698	0.0133	0.1799	0.1069
Mid-sized car	Toyota Prius (Hybrid)	0.0139	0.0767	0.0019	0.0698	0.0132	0.1756	0.0989
Small car	Toyota Yaris	0.0206	0.0696	0.0025	0.0698	0.0118	0.1743	0.1047
Small car	Honda Civic (Hybrid)	0.0154	0.0732	0.0018	0.0698	0.0135	0.1737	0.1005
Small car	Honda Insight (Hybrid)	0.0134	0.0664	0.0022	0.0698	0.0115	0.1633	0.0969

Note: Total costs/global warming costs shown in **bold** and *italics* are based on assumed values for combined fuel economy since EPA does not measure fuel economy for these models. These values were taken from other models with similar attributes. Totals do not include the gas guzzler or CAFE fuel economy taxes. Vehicle life is assumed to be 10 years with an assumed annual mileage of 12,000.

and high crash costs at \$0.022, \$0.044, and \$0.066 per VMT, respectively. Litman's (2007) review of the literature suggests external crash costs average about \$0.035 per VMT but may range from \$0.01 to \$0.10. Of course, once these estimates are corrected for inflation and certain differences in value of life assumptions, they will be higher. Nevertheless, our crash cost estimates appear rather high, in comparison. This may be due to higher crash frequency assumptions and a rather high external cost assignment (50% of two-vehicle collision costs). However, Litman (2007) suggests external crash cost shares that are reasonably coincident with our assumptions: his range from 15% to 50% of crash costs (including single-vehicle crashes, which are roughly half of all crashes and result in no external cost assignment here). And Edlin and Karaca-Mandic (2006) estimate that external crash costs represent over 65% of crash costs (in part by recognizing all uninsured motorist costs as external). Regardless, results and rankings of vehicles types are shown with and without crash costs, reflecting the uncertainty in these estimates.

Results for the marginal social costs of congestion by vehicle type are \$0.0698, \$0.0747, \$0.0984, \$0.0935, and \$0.0796 per VMT for passenger cars, regular SUVs, long SUVs, vans, and pickups, respectively. If these results are averaged using 2006 sales figures as weights, the average social cost of added congestion is \$0.076 per VMT. As points of reference, Litman's (2007) summary of others' results suggests average congestion costs in urban areas to be about \$0.07 per VMT, similar to Fischer et al.'s (2007) findings of \$0.065 per VMT. In some contrast, Sansom et al. (2001) estimated UK congestion costs to be much higher at about \$0.306 per VMT (9.71 UK pence per veh-km), and Parry and Small (2005) assumed average congestion costs to be just $0.035 per VMT, after considering a range from $0.015 to $0.09 per VMT. Of course, as noted earlier, much variation can be tied to context: external delay costs will be much higher in highly congested regions and probably negligible in uncongested locations.

3.1. Analysis of external costs

The results of the analysis indicate that the largest external costs are associated with pickups. This is largely a result of the significant crash impacts that pickups tend to impose on others. Wang and Kockelman's (2005) analysis indicates that occupants in vehicles involved in a crash where the crash partner is a pickup are over twice as likely to suffer fatal injury as compared to those where the crash partner is a passenger car. Occupants in vehicles where the crash partner is an SUV or van are slightly less likely to incur fatal injury relative to those where the crash partner is a passenger car. The associated monetary costs with fatal crashes are very high, causing the external costs of pickups to be high, relative to those of other vehicle models. Investigation of the 25 worst models in terms of their associated external costs (including congestion costs) shows that

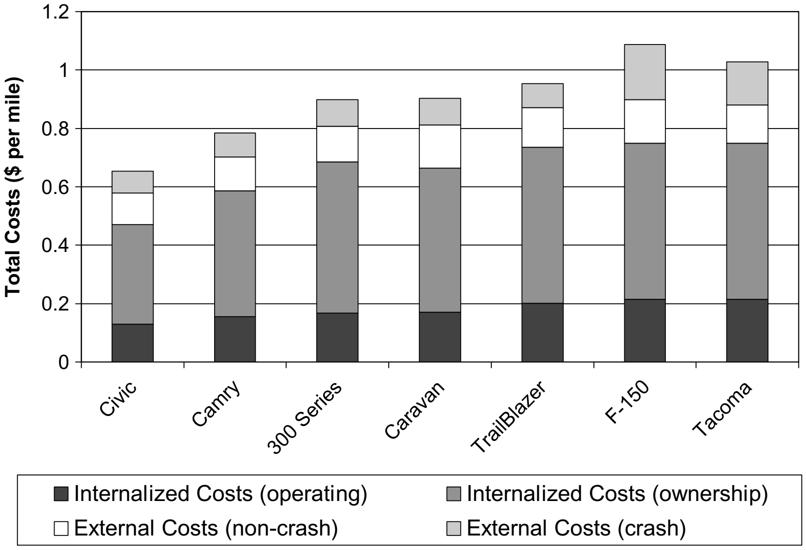

Fig. 1. Costs of driving per VMT (internal [from AAA, 2006 estimates] vs. external).

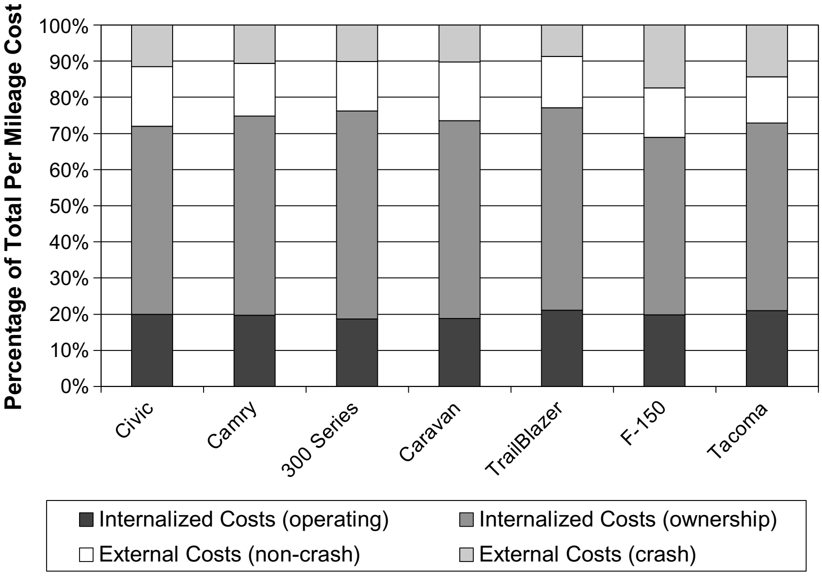

Fig. 2. Costs of driving per VMT as percentage of total.

20 are pickups (these represent all of the pickups analyzed), two are long SUVs, and three are cargo vans (only three cargo vans were analyzed).

Because some variables, such as driver aggressiveness, were not controlled for in this crash analysis and because crash costs dominate the totals (as shown in Figs. 1 and 2), external cost totals without crash costs also were computed. Using these totals, the 25 worst models in terms of the associated external costs are quite different. Many of the pickup models fall out of the top 25 while large SUV models and vans rise to the top. Based on these totals, the four worst offenders are still pickups (the Ford F-250 and F-350, Chevrolet Silverado 3500, and Dodge Ram 3500), but a total of 10 pickup models are no longer found in the list of 25 worst models, and the list is instead composed of 4 large SUVs, 3 cargo vans, and 8 minivans, along with the 10 pickups.

The highest congestion costs are associated with large SUVs and van models due to their higher passenger car equivalents. If congestion costs are ignored, the worst offenders will be even more heavily weighted toward pickups. The ordering of such an analysis would show close similarities to the 25 worst offenders with all external costs recognized here, with no regular SUVs or passenger cars appearing among the worst 25. But if crash costs and congestion costs are removed from the analysis, the 25 worst offenders are comprised of 15 pickups, 3 cargo vans, 4 large SUVs, and 3 regular SUVs. Noticeably absent in both lists are any type of cars – even luxury cars. The market shift toward LDTs over the past 30 years (rising from 17% of LDV sales in 1980 to 49% in 2007 (US Environmental Protection Agency 2007b)) is taking a toll, in terms of external cost imposition. Of course, with the recent rise in fuel prices, shifts are occurring, at least in the near term, as a passenger car model (the Honda Civic) recently topped the US monthly vehicle sales chart, edging out the Ford F-series or another non-car model for the first time in 16 years (Associated Press 2008). In fact, the top-four-selling models in May 2008 were passenger cars, and included Toyota's Corolla and Camry and Honda's Accord.

Land consumption costs are highest for pickup models, in general, but the variation in this external cost across models is relatively small. (For example, the difference between the biggest offender [a Ford F-350] and the least offensive [a Honda Insight hybrid] is only $0.012 per VMT.) Therefore, without land consumption costs the worst offenders would look quite similar to the 25 worst when all external costs are included.

In any case, there are 15 vehicle models that appear in the 25 worst offenders when all costs are considered and when any one of the three costs discussed above is not included. These include 2 long SUVs (the Hummer H2 and Ford Expedition), 10 pickups (Chevrolet's Silverado 1500, 2500, and 3500; Ford's F-150, F-250, and F-350; Dodge's Ram 1500, 2500, and 3500; and Nissan's Titan), and 3 cargo vans (the Chevrolet Express, Ford Econoline, and GMC Savanna). Not surprisingly, these are some of the largest vehicles included in our analysis, and all but one (the Nissan Titan) come from US manufacturers. These 15 regular "top offenders" do not include any passenger cars, minivans, or regular-size SUVs.

3.2. *Analysis of LDTs*

Cost calculations of LDT models were compared to the top-selling passenger car model of 2006, the Toyota Camry. While the ordering of the "worst" offenders in the LDT class of vehicles does not change, it is important to recognize the difference in magnitudes. For many of the LDT models, the external costs are more than 50% greater than those of the Camry (when crash costs are included in the comparison), including all three top-selling models of 2006 (the Dodge Ram, Chevrolet Silverado, and Ford F-Series [all pickups]). This suggests that if LDT models were all (costlessly) traded in for Camrys or comparable passenger car models, the potential benefits to the greater US community would be enormous (on the order of $100 billion[19]).

3.3. *Analysis of hybrids*

Calculated external costs of hybrid models can be compared to the top-selling in-class vehicle for 2006. All hybrids analyzed here perform better, in terms of external costs, than their top-selling in-class vehicle counterparts. In general, external costs of vehicle ownership and use could be reduced a fair amount via a within-class shift to hybrids, at least in the SUV and car classes. For example, when shifting from the top-selling vehicles to their within-class hybrids, reductions in external costs are in the range of 2.0% for pickups, 11.3–15.9% for regular SUVs, 1.0–11.2% for mid-sized cars, and 3.4–9.2% for small cars. These reductions are even greater if crash costs are ignored (3.8% for pickups, 13.7–17.2% for regular SUVs, 2.5–13.5% for mid-sized cars, and 6.0–9.4% for small cars). As expected, the greenhouse-gas-emissions benefits of a shift to hybrids are sizable.

3.4. *Sensitivity analysis*

The cost calculations depend on many assumptions, and all are simply point estimates. As these estimates change (by location, driving styles, route choices, etc.), differences in results arise. Here, we investigate such variations, as parameter and input values are adjusted.

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[19] Of course, the Toyota Camry is not designed to go off-road, tow a trailer, or haul large, heavy equipment, and the like. So some losses would be incurred, particularly the subset of owners who really need such qualities in their vehicles.

In the case of the global warming costs, the main assumption is the cost of carbon removal from the atmosphere (assumed to be $50 per ton), which is directly proportional to the global warming external cost estimates; at $25 and $100/ton, the external cost of a Ford F-150 pickup will be $0.022 and $0.088/mi. In the case of crash costs, a key assumption is the fraction of multi-vehicle-crash costs that are endured by crash partners. Fifty percent was assumed here, but this assumption may be reduced to 40% or 30%, reducing external crash costs by 20% or 40%, respectively. Of course, the calculations used here ignore crashes with cyclists and pedestrians, which also carry heavy crash costs, and may well raise the cost per mile back up, beyond our starting assumptions.

In computing external space consumption costs, several assumptions are made. Land is valued at $2M per acre ($46 per sq. ft.), paving costs at $50 per sq. ft., vehicle life is 10 years, land value is fully discounted over 25 years, and 50% of a vehicle's life is assumed to occupy public space. Based on these assumptions, the external space consumption cost for a vehicle is about $19 per sq. ft. of vehicle footprint over the vehicle's lifetime. As the ratio of vehicle life to land's discounting period increases, the space consumption cost increases. If land is fully discounted over 35 years (instead of 25 years), the cost estimate will fall to $13.70/sf. In addition, as the portion of a vehicle's life spent occupying public land rises, external costs rise. If a vehicle is housed 80% of the time on privately held land, the social cost estimate would fall to $7.60/sf. And the actual average life of most vehicles is closer to 16 years (Davis et al., 2008), though the time it spends on publicly held land probably falls as vehicles are driven less in their later years. However, if it is assumed that vehicles consume publicly held land for 50% of their lives over the entire 16 years, space consumption cost estimates rise to about $30/sf.

Finally, congestion costs are rather sensitive to the various assumptions used, but these are not environmental in nature and so do not merit much discussion here.

3.5. Aggregate external cost analysis

Although only five particular cost categories are analyzed in this paper, it is important to appreciate the relative magnitudes of other external costs associated with vehicle ownership and use. Verhoef (1994) identified and characterized nine different sources of vehicle externalities, but did not estimate values of each. In the literature, there is really only one study that characterizes what could be considered a comprehensive analysis of all external costs: Litman (2007) reviewed the cost literature and summarized 14 distinct external cost categories of vehicle ownership and use (most of which are similar to those identified by Verhoef, 1994), of which five equate to the five cost categories analyzed here. Litman's (2007) average estimates for these five external costs are about $0.189 per VMT. Using a sales weighted average over vehicle makes and models, our estimates for these five costs are about $0.236 per VMT. When one ignores congestion costs, Litman's (2007) estimates of the remaining four external costs are about $0.147 per VMT, very close to ours, at roughly $0.160 per VMT. One important distinction between the two estimates is that Litman's costs are an average – over all vehicle miles, while land and congestion parameters used here assume urban travel, resulting in higher costs. The total for Litman's (2007) remaining external cost categories is about $0.140 per VMT, for an overall external cost of about $0.329 per VMT.

3.6. Internal cost comparison

To better understand the magnitudes of the external costs associated with vehicle ownership and use, the magnitudes of internalized costs must be recognized. The American Automobile Association (AAA) estimates such costs annually. (These costs include gas, maintenance, and tire costs, full coverage insurance, license and registration costs, taxes, depreciation, and an average finance charge[20] for vehicle ownership.) American Automobile Association (AAA) (2006) offers driving costs for five vehicle classes: small cars, mid-sized cars, large cars, SUVs, and minivans. It uses several vehicle models in each class to estimate average user costs for 10,000, 15,000, and 20,000 driving miles per year. For consistency in our analysis, linear interpolation of costs was performed to find average user costs for 12,000 annual VMT. AAA cost estimates range from about $0.47 per mile driven (for small cars) to about $0.74 per mile (for large SUVs). Figs. 1 and 2 show absolute and percentage-based results of the AAA (2006) internal (user) costs, as compared to our calculated external costs for top-selling vehicle models in each of the five AAA vehicle classes. costs (internal plus external [including crash costs]) range from $0.65 per VMT for the Honda Civic (a small car) to $1.09 per VMT for the Ford F-150 (pickup). External costs as a percentage of the cost range from 22.9% (for the Ford Explorer, a regular SUV) to 31.1% (for the Ford F-150 pickup). It should be noted that AAA does not estimate the (direct) costs of pickup truck use, so these were assumed to be the same as for SUVs, except in the category of gasoline costs, which were adjusted upward to reflect the lower average fuel economy of pickups.

4. Conclusions

This study has presented a variety of external cost estimates for vehicle ownership and use, highlighting great disparities in social costs by vehicle type, make and model. While some uncertainty exists in all external cost estimates, and these costs do vary by location (e.g., a congested urban area with high land costs and low travel speeds versus a rural location), it seems

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[20] American Automobile Association (AAA) (2006) assumes a 10% down payment and interest rate of 6% on the unpaid balance over 5 years.

clear that the true costs of travel are not borne directly by road users, and economic efficiency is not being realized in the vehicle market.

The total of the five external costs examined here averages \$0.236 per mile, which translates to almost \$22,000 over the life of the average vehicle (assuming 12,000 miles per year over ten years and discounting at 5%). Such estimates vary substantially across vehicle models: for example, the Dodge Ram 3500's external costs are 2.1 times greater than the Toyota Camry's \$0.198 per mile. External costs and their variations can rival vehicle purchase prices, suggesting the potential for dramatic vehicle ownership shifts if such costs were internalized.

The great cost variations existing across vehicle models is important to recognize, both direct and indirect, internalized and external. This work illuminates the variation in external costs by recognizing the costs arising from emissions, global warming, crashes, congestion delays, and land consumption. It suggests that many light-duty trucks impose dramatically far more costs on the larger community than their passenger car counterparts. Ideally, policy should require that markets reflect external costs, so that vehicle users bear them directly (through, for example, parking fees and emissions- and distance-based taxes or purchase taxes), and pay the true price of their vehicle use decisions. If distance-based taxes were instituted, which, for example, resulted in a doubling of operating cost, US vehicle usage levels may drop by 6–10%, in the short run, to as much as 10–29% in the long run, based on estimates of the elasticity of vehicle use with respect to operating costs suggested by Mannering and Winston (1985), and Goodwin et al. (2004). Mannering and Winston (1985), and Goodwin et al. (2004) also estimated elasticities of vehicle ownership with respect to purchase prices of −0.3 and −0.24 in the short run and −0.6 and −0.49 in the long run. Thus, if purchase taxes were introduced, large shifts in the types (and number) of vehicles people purchase (from vehicles with high external costs to those with low costs) would likely result, and older vehicles would probably be retained longer. Revenues from such policies could be used to encourage provision and design of lower-cost substitutes (including hybrids, bicycles, walk paths, and safer vehicle bodies). In markets that internalize such costs, motorists may be expected to drive significantly less, purchase different vehicles, and, along with their communities, be much better off.

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