Journal of Transport Economics and Policy, Volume 50, Part 2, May 2016

Is Vehicle Depreciation a Component of Marginal Travel Cost?

A Literature Review and Empirical Analysis

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We are grateful to BP for funding this research. We thank Prof. Joan Walker for useful comments at the planning stage of our analysis.

Abstract

A review of 116 travel cost models finds that, of the studies that report their practice, about half include depreciation in their calculation of vehicle costs and half do not, with none giving a justification for either approach. We examine empirically whether depreciation is related to households' decisions of how much to drive. Using a sample of over 200,000 US households, we find that, relative to fuel costs, depreciation has a small effect on the amount that households drive. This finding is consistent with households' considering depreciation as primarily a fixed rather than marginal cost.

Final version: October 2015

1.0 Introduction

The marginal cost of driving an automobile enters practically all aspects of transportation demand, including the fundamental triumvirate of trip generation, mode choice, and destination choice. Fuel costs per mile and the value of time are routinely included in the calculation of travel costs. However, as we describe below, there seems to be no consensus on whether to include vehicle depreciation. To our knowledge, no evidence has been presented on whether depreciation is an appropriate element of marginal travel costs. This situation is problematic because the estimates that a study obtains for welfare measures, such as the value of time and the welfare impacts of policies, differ greatly depending on whether or not depreciation is included in the calculation of travel costs.[1] Differences across studies in estimates of travellers' monetised values can depend on differences in the researchers' treatment of vehicle depreciation rather than differences in the preferences of travellers.

In the current paper, we review how researchers have calculated vehicle costs in previous studies, to determine whether there is a common practice with respect to vehicle depreciation. We then examine empirically the relation of annual depreciation costs to the amount that households drive their vehicles annually, based on the 2009 National Highway Transportation Survey.

Reviewing all of the transportation demand literature with respect to depreciation is too vast an undertaking, and in any case is probably not needed to obtain a sense of common practice. Instead, we reviewed papers within one subfield of transportation demand, namely, travel cost models of recreational demand. These models are used extensively to assess the value of destination attributes such as campsites and parking facilities, and the welfare impacts of, for example, new infrastructure and park closures.[2]

Our review indicates that the issue of depreciation is generally not addressed. Most studies do not report whether travel costs include depreciation, even though the omission prevents meaningful comparison of results across studies. Of those that provide the information, about half include depreciation and half do not. No study to our knowledge has provided evidence for one approach or the other.

In our empirical analysis, we relate the annual miles travelled on a vehicle to its fuel costs, depreciation, and other factors. We used two measures of depreciation: year-to-year change in market value of the vehicle, and the current market value of the vehicle amortised over its remaining years of life. Fuel cost per mile is found, as expected, to be negatively and significantly related to vehicle miles travelled (VMT). Depreciation is also negatively and significantly related to VMT using either measure. However, the estimated coefficient on depreciation is very small in magnitude relative to the fuel cost coefficient, such that the contribution of depreciation to households' implicit travel costs is found to

[1]Consumer surplus in travel costs models is inversely proportional to the travel cost coefficient (see, for example, Small and Rosen, 1981), whose estimated value is itself inversely related to the magnitude of measured costs. As a result, for example, a proportional change in the measured costs changes all welfare measures derived from the estimated model by the same proportion.

[2]See Bockstael (1995), Herriges and Kling (1999), and Parsons (2003, 2012) for general descriptions of these models' forms and functions.

be very small: $0.002 per mile on average under the first measure of depreciation and $0.003 per mile under the second. This result is consistent with rational consumers viewing depreciation primarily as a fixed cost.

2.0 Review of Travel Cost Studies of Recreational Demand

We reviewed 116 travel cost studies of recreational demand, listed in Table 1, to determine how each of them calculated the per-mile vehicle cost component of travel costs. The first column of the table indicates the article or report. The second column gives the per-mile cost that was used in the study, if the value was reported.[3] When the reported value was in a non-US currency or for kilometres instead of miles, we converted to dollars per mile using the exchange rate applicable at the time. An entry of 'V' indicates that the cost per mile varied over respondents. If a value was not reported, then the entry is blank. The third column states the source that the study cites for its cost per mile, if such a source was given. The fourth column lists how travel costs were described for the study. The words are in quotes because they are taken directly from the article/report. If no description was given, or the only description was 'travel costs' or 'transportation costs', then the column is blank. The last column states whether the study included vehicle depreciation in its travel costs, with the entry left blank if we could not make a determination from the reported information.

Several interesting observations are evident. A third of the papers (thirty-eight of the 116) do not report the per-mile cost they used or, when using respondents' self-reported costs, do not give the average per-mile cost implied by respondents' answers.[4] Not knowing the costs used in studies makes comparison of estimated travel cost coefficients and welfare measures difficult, since differences in estimates across studies, especially for welfare measures, can reflect differences in the unreported per-mile cost that is used in the studies rather than differences in the behaviour or values of travellers.

Forty-three studies stated their per-mile costs but gave no explanation of the cost basis or source. Hagerty and Moeltner (2005) said that 'virtually all [past travel cost studies] impose arbitrarily chosen vehicle cost per mile' and that $0.30 per mile was the most popular choice. The most popular choice in our review is also $0.30 per mile, followed closely by $0.25 per mile.[5]

Twenty-one studies obtained their cost per mile from the American Automobile Association (AAA) or its equivalent in other countries. The AAA publication *Your*

[3]Cost per mile in nominal dollars is given in the table, as reported in the studies. Comparison of these costs across studies at different times is not generally feasible. Converting to real dollars using the CPI does not account for the fact that fuel and car prices change at different rates than the general price index. The studies also do not provide the individual costs components that are needed to convert each component for its own price changes.

[4]Twenty-three papers use a fixed cost per mile but do not report it, and fifteen studies use respondents' self-reported costs but do not give the average per mile cost, perhaps because the self-reported costs cannot be broken down into a per-mile component.

[5]Hagerty and Moeltner's stating that the values were 'arbitrarily chosen' is in part justified by the fact that the popular $0.30 per mile was used in studies dating from 1999 to 2009 and $0.25 was used in studies dating from 1991 to 2011, despite changes in nominal fuel prices and other costs over these periods.

Table 1

Description of Per-mile Costs in Recreation Demand Models

Citation	*Cost per Mile (in nominal dollars)*	*Source*	*Description*	*Depreciation*
Adamowicz and Graham-Tomasi (1991)			'expenditures on travel'	
Adamowicz *et al*. (1997)	$0.43		'out-of-pocket cost'	
Alvarez *et al*. (2012)	$0.55	Internal Revenue Services (2009)	'IRS mileage rate'	Yes
Awondo *et al*. (2011)	$0.33	American Automobile Association (2008)	AAA 'vehicle operating cost' and 'a portion of the depreciation cost'	Yes
Baerenklau and Provencher (2005)			'driving costs'	
Bell and Leeworthy (1990)	$0.08	U.S. Federal Highway Administration (1984)	'gasoline and taxes'	No
Bell and Strand (2003)	$0.15			
Berman *et al*. (1997)			'sum of fuel cost, vehicle depreciation cost'	Yes
Bhat (2003)	$0.14	Leeworthy and Bowker (1997)		
Bin *et al*. (2005)	$0.35		'fuel and vehicle maintenance costs'	No
Bockstael *et al*. (1987)				
Bockstael *et al*. (1989)	$0.10			
Carson *et al*. (2009)	V	Respondent self-report	'respondent's reported motor vehicle cost per mile'	
Caulkins *et al*. (1986)			'transportation costs'	
Chapman and Hanemann (2001)	$0.21		'cost reported by respondents'	
Criddle *et al*. (2003)	V	Respondent self-report	'vehicle fuel expenditures'	No
Cullinan (2011)	$0.32	AAIreland (2006)	'average petrol cost per mile'	No
Cutter *et al*. (2007)				
Desvousges *et al*. (2000)	$0.12, $0.25	American Automobile Association (1998)	'sum of operating costs, depreciation'	Yes
Edwards *et al*. (2011)	$0.20	American Automobile Association (2008)	'gas plus half of the AAA depreciation costs'	Yes
Egan and Herriges (2006)	$0.25			
Englin and Mendelsohn (1991)	$0.25			
Englin and Moeltner (2004)				
Englin and Shonkwiler (1995)	$0.25		'out-of-pocket travel costs'	
Englin *et al*. (2006)	$0.25			
Englin *et al*. (1997)	$0.25			
Eom and Larson (2006)	V	Respondent self-report		
Feather (1994)	$0.31	American Automobile Association (1989)	'average cost of driving'	Yes

Greene *et al*. (1997)	$0.37		'cost of fuel and maintenance'	No
Grijalva *et al*. (2002)	$0.33	Internal Revenue Service (1998)	'standard mileage rate' 'including depreciation, maintenance and repairs, gasoline, insurance, and vehicle registration fees'	Yes
Haab (2003)	$0.20			
Haab *et al*. (2009)	$0.30		'explicit travel cost'	
Haab *et al*. (2008)	V	Respondent self-report		
Haab *et al*. (2006)	$0.30		'explicit travel costs'	
Haab *et al*. (2000)	$0.30			
Haener *et al*. (2004)	$0.77		'out-of-pocket expenses'	
Haener *et al*. (2001)	$0.45		'out-of-pocket expenses'	
Hagerty and Moeltner (2005)	$0.30, V	American Automobile Association (2003)	'gas and oil, tires, and maintenance'	No
Hanley *et al*. (2003)	$0.07	Royal Automobile Club (2000)	'marginal cost of motoring'	No
Hanley *et al*. (2002)	$0.06	Royal Automobile Club	'Marginal cost of motoring'	No
Herriges *et al*. (2004)	$0.21			
Herriges and Phaneuf (2002)	$0.21			
Hesseln *et al*. (2003)	V	Respondent self-report	'gas cost'	No
Hindsley *et al*. (2011)	$0.35		'explicit costs of travel'	
Huhtala and Pouta (2009)	V	Respondent self-report	respondents self-reported 'travel expenses'	
Hunt *et al*. (2007)	$0.88	Canadian Automobile Association (2004)	'out-of-pocket expenses' as CAA's 'average operating expense'	Yes
Hynes *et al*. (2007)	$0.31	Hynes, Hanley, and O'Donoghue (2004)	'petrol for the trip, operating cost of the vehicle, etc.'	
Hynes *et al*. (2009)	$0.31		'marginal vehicle operating cost'	
Hynes *et al*. (2008)	V	Respondent self-report		
Jeon and Herriges (2010)	$0.25			
Kaoru *et al*. (1995)	$0.20		'operating cost'	
Kim *et al*. (2010)	$0.14	Internal Revenue Services (2004), charitable rate	'reimbursement rate for charitable organisations'	No
Kuriyama *et al*. (2010)	$0.15		'cost of vehicle operation'	
Landry and Liu (2009)	$0.37			
Landry *et al*. (2010)	$0.54	American Automobile Association (2009)		Yes
Larson *et al*. (2004)	V	Respondent self-report		
Leeworthy and Bowker (1997)	$0.14	Respondent self-report		
Lew and Larson (2005)	V	Respondent self-report		
Lew and Larson (2008)	$0.15	American Automobile Association (2001)	'gas and oil, maintenance, and tires'	No

Table 1
Continued

Citation	*Cost per Mile (in nominal dollars)*	*Source*	*Description*	*Depreciation*
Loomis (1988)		U.S. Department of Transportation	'variable costs'	Yes
Marvasti (2013)			'gasoline cost'	No
McConnell and Strand (1994)	$0.20	American Automobile Association (1988)	'average variable mileage costs'	Yes
McConnell *et al.* (1995)			'explicit cost'	
Milon (1988)			'cost …. of fuel'	No
Moeltner (2003)	$0.25	U.S. Department of Transportation	'a compromise between $0.41 for total and $0.1 for variable cost'	Yes
Moeltner and Shonkwiler (2005)	$0.30			
Montgomery and Needelman (1997)	$0.25		'direct cost'	
Morey (1981)	$0.06	U.S. Department of Commerce (1968)	'cost of operating an automobile'	
Morey and Breffle (2006)			'vehicle operating cost'	
Morey *et al.* (2001)	V	Respondent self-report		
Morey *et al.* (1993)				
Morey *et al.* (1991)				
Morey and Waldman (1998)				
Morgan and Huth (2011)	$0.48	American Automobile Association (2006)		Yes
Murdock (2006)	$0.11	American Automobile Association (1998)	'gas, oil, maintenance, and tires'	No
Myers *et al.* (2010)				
Parsons and Kang (2010)	$0.37			
Parsons and Kealy (1992)	$0.10			
Parsons *et al.* (2009)	$0.37	U.S. General Services Administration		Yes
Parsons *et al.* (1999)	$0.30		'out-of-pocket' costs	
Phaneuf and Siderelis (2003)	$0.14		'out-of-pocket travel costs'	
Provencher *et al.* (2002)	$0.13	American Automobile Association (2005)	'gasoline, oil, and tire wear'	No
Provencher and Bishop (1997)		American Automobile Association (1995)	'fuel and oil costs, and wear-and-tear on tires'	No
Provencher and Bishop (2004)	$0.13	American Automobile Association (1996–1997)	'gasoline, oil, tire wear, and depreciation'	Yes
Samples and Bishop (1985)	$0.14			

Scarpa and Theine (2005)				
Scarpa *et al*. (2007)				
Scarpa *et al*. (2008)	\$0.57		'car running cost'	
Schuhmann (1998)	\$0.41	U.S. Bureau of the Census (1991)	'fixed and variable costs'	Yes
Schuhmann and Schwabe (2004)	\$0.30		'explicit travel costs'	
Schwabe *et al*. (2001)	\$0.30		'explicit travel costs'	
Scrogin *et al*. (2004)	V	Respondent self-report		
Shaw and Jakus (1996)	V	Respondent self-report		
Shonkwiler and Hanley (2003)	\$0.06		'marginal (petrol) cost'	No
Signorello *et al*. (2009)	\$1.06	Italian Automobile Association (2003)	'vehicle operating cost'	Yes
Smith and Kaoru (1986)	\$0.08			
Starbuck *et al*. (2004)	\$0.31	U.S. Government Services Administration (1996)	'standard mileage reimbursement rate'	Yes
Starbuck *et al*. (2006)	\$0.33	General Services Administration (2001)	'standard mileage reimbursement rate'	Yes
Swait *et al*. (2004)			'fuel cost'	No
Thiene and Scarpa (2009)	\$0.57		'car running cost'	
Thomas and Stratis (2002)	\$0.25	American Automobile Association (1998)	'variable cost'	Yes
Timmins and Murdock (2007)	\$0.15	Murdock (2002), which was published as Murdock (2006)		
Train (1998)			'gas, maintenance, tires, and oil'	No
Vaughan and Russell (1982)	\$0.08	American Automobile Association (1975)	'out-of-pocket cost' 'AAA for variable cost per mile'	Yes
Violette (1985)	V	Respondent self-report	'gas and oil'	No
von Haefen (2003)	\$0.30			
von Haefen (2007)	\$0.35		'out-of-pocket cost'	
von Haefen *et al*. (2005)				
von Haefen and Phaneuf (2003)	\$0.21			
von Haefen and Phaneuf (2008)				
Whitehead and Haab (2000)	\$0.20			
Whitehead *et al*. (2008)	\$0.37	American Automobile Association (2005)	'variable cost and no fixed costs'	
Williams and Bettoli (2003)	\$0.35	U.S. Department of Revenue (2001)		Yes
Woodward *et al*. (2001)	V	Respondent self-report		
Yeh *et al*. (2006)	\$0.30			
Zawacki *et al*. (2000)	V	Respondent self-report		

Driving Costs[6] gives operating costs and ownership costs separately and in combination, which allows us to determine whether or not the study included depreciation. For example, for its composite average over three sizes of sedans, the 2012 publication gives \$0.196 as the operating cost per mile and states that, if the vehicle is driven 15,000 miles per year, its annual ownership cost of \$6,000[7] translates to \$0.40 per mile such that the combined operating and ownership cost per mile is \$0.596. We can infer, therefore, that a study that uses \$0.196 per mile with the 2012 AAA publication as its source did not include depreciation, while a study that uses \$0.596 with the same source included depreciation.[8,9]

Three studies used the government reimbursement rate from the General Services Administration (GSA)[10] which allows a similar distinction. There are two government reimbursement rates, one that is applicable when a government vehicle is available but the driver chose to use their own vehicle, and another rate when a government vehicle is not available. The former rate is lower than the latter (\$0.23 and \$0.555 per mile, respectively, in 2012). The rationale for the different rates is not explained, but it seems reasonable that the difference is due to depreciation. A person who has a government vehicle available and chooses to use their own vehicle did not need to buy a vehicle for government work, and so does not need to be reimbursed for the ownership costs. But a person who does not have a government vehicle available might have needed to buy a vehicle for government work, and would need to be reimbursed to some degree for the capital cost. While we cannot be sure that this is indeed the rationale, it seems reasonable to assume that a study that used the first reimbursement rate did not include depreciation and one that used the second rate did. The three studies citing the GSA rate used the second one and so are categorised as including depreciation.

Grijalva *et al.* (2002) and Alvarez *et al.* (2012) used the standard IRS mileage rate for business miles driven, and Kim *et al.* (2010) used the IRS rate for charitable organisations. The IRS rate for business travel is the same as the second GSA reimbursement rate and includes 'the fixed and variable costs of operating an automobile'.[11] We therefore categorise Grijalva *et al.* and Alvarez *et al.* as including depreciation in their travel costs. The IRS rate for 'rendering gratuitous services to a charitable organisation' is even lower (\$0.14 in 2012)

[6] Available, for example, at http://westerncentralny.aaa.com/files/news-room/aaa_yourdrivingcosts_2012.pdf.

[7] Ownership cost includes full coverage insurance, license, registration, taxes, finance charge, and depreciation at 15,000 miles.

[8] Whitehead *et al.* (2008) cite 'AAA (2005) personal communication' as their source for \$0.37 per mile and states that it represents variable costs and no fixed costs. This figure is higher than the amount listed in AAA's *Your Driving Cost* for operating costs (fuel, maintenance, and tyres) and lower than the amount obtained by adding the amount listed for depreciation. We therefore categorise his paper as 'unknown' regarding whether depreciation is included.

[9] The AAA figures are calculated for new vehicles rather than for the fleet of new and used vehicles. This distinction is especially important for its ownership component, since the depreciation rate is considerably higher for new vehicles than older ones. It also explains why the AAA ownership cost, on a per-mile basis, is so large relative to the operating cost.

[10] Available at www.gsa.gov/portal/content/103969.

[11] Available at www.irs.gov/uac/2013-Standard-Mileage-Rates-Up-1-Cent-per-Mile-for-Business,-Medical-and-Moving. Also, www.irs.gov/Tax-Professionals/Standard-Mileage-Rates. The IRS rate for medical and moving travel was \$0.23 cents per mile in 2012, which is the same as the first GSA rate discussed above.

than the first GSA reimbursement rate. We therefore categorise Kim *et al.* as not including depreciation.[12]

Of the forty-two studies that can be categorised, twenty-two include depreciation while twenty do not. That is, somewhat more than half of the assignable studies include depreciation, while somewhat fewer than half do not. However, these shares might not be indicative of the practice, since most studies cannot be categorised. Of the 116 studies that we reviewed, 19 per cent can be categorised as including depreciation, 17 per cent can be categorised as not including depreciation, and 64 per cent cannot be categorised.

3.0 Data and Measures of Depreciation

The National Highway Transportation Survey (NHTS) is a comprehensive survey sponsored by the U.S. Department of Transportation and conducted on a periodic basis, the most recent being in 2009.[13] Its vehicle file contains information on 309,163 vehicles, and the linked household file provides demographics of the principal driver of each vehicle and the location of the household at the zip code level. We utilised the following data fields for each vehicle: make, model, vintage, and the fuel cost per mile (calculated by the survey agency on the basis of the vehicle's efficiency level and the price of fuel in the location of the household that owns it). The survey asked the sampled households to state the amount that each of their vehicles was driven in the past year. The survey agency used this information, along with other information about the household, to develop a 'best estimate' of the annual mileage of each vehicle. For our analysis reported below, we used this 'best estimate'; however, results are essentially the same with the respondent's stated VMT. Golf carts and vehicles with unspecified type were omitted from the analysis, as well as vehicles whose 'best estimate' of annual mileage was missing. Vehicles with missing data for fuel cost per mile were assigned a value of 0, and a dummy variable identifying these vehicles was included in the analysis to capture their average fuel cost.

We calculated two measures of depreciation

1. *Annual change in market value*: This measure embodies the most common concept of depreciation, namely, how much the vehicle's market price changes from one year to the next. We used the 2009 and 2010 Kelley Blue Book's used car and truck guides for private party sales. Based on the year, make, and model of each vehicle, we recorded the Kelley Blue Book valuations in 2009 and 2010. The Blue Books differentiate valuations of each make, model, and year by the condition and style of the vehicle, which the NHTS data set does not contain. We specified the condition of each vehicle as 'good', which is the middle level of condition. Since style has no obvious mid-level, we selected the style of each vehicle randomly from the available styles for that vehicle, and we used

[12] Loomis (1988) cites the U.S. Department of Transportation's 'Cost of Owning and Operating a Vehicle — 1984'. The earliest edition of this citation that we could find was for 2001 at www.fhwa.dot.gov/ohim/onh00/chart1.htm, which states that the per-mile costs represent 'Total costs over five years, based on 70,000 miles' and 'includes depreciation, financing, registration fees, taxes, fuel, maintenance, and repairs'. We therefore categorise Loomis as including depreciation.

[13] Available at http://nhts.ornl.gov/introduction.shtml.

the same style for its 2009 and 2010 valuations. The 2010 value was adjusted to 2009 dollars using the CPI and then subtracted from the 2009 value to obtain the change in value over the year.

2. *Current market value amortised over remaining life*: If the household plans to keep the vehicle for its remaining life, rather than sell it, then the change in market price is not necessarily relevant. An alternative measure of depreciation is the current value of the vehicle amortised over the remaining years of its life. We calculated this figure by assuming that vehicles live for twelve years. (For our sensitivity testing, we also assumed a fifteen-year-life, as stated in Section 4.) For example, a five-year-old vehicle was assumed to have seven years of remaining life; its depreciation cost by this measure was calculated as its current market value (from the 2009 Blue Book) divided by seven. For vehicles that were already twelve or more years old, the current value of the vehicle was amortised over one year — that is, its annual depreciation was assumed to be its current value.

4.0 Estimation Results

The VMT on vehicle n is specified to depend on its fuel cost per mile g_n, its annual depreciation cost d_n, other observed factors x_n including location, and an error ε_n:

$$\mathrm{VMT}_n = \alpha g_n + \omega d_n + \beta x_n + \varepsilon_n \tag{1}$$

The implicit value of depreciation relative to fuel costs in households' driving decisions is

$$\theta = \left(\frac{\partial g_n}{\partial d_n}\right)_{\overline{\mathrm{VMT}}} = \frac{\omega}{\alpha}.$$

We call θ the translation parameter, since it translates annual depreciation costs into the driving-equivalent fuel costs per mile.

After the eliminations described above (missing VMT, golf carts, and unspecified vehicle types), 223,234 vehicles remained for analysis. Table 2 gives the estimation results for both measures of depreciation. To control for other factors that affect VMT, the models included: the age of the vehicle; the age group and gender of the principal driver; the household's income, size, and number of other vehicles owned; and the location in which the household resides. Controlling for location is important because driving opportunities and needs are location-specific. Fixed effects are included for each Core Based Statistical Area (CBSA), which is the finest definition of location that is available in the survey. Due to the large number of CBSAs, the estimated coefficients of their dummies are not shown in the table (available from the authors on request).

Fuel cost per mile enters with a negative coefficient, as expected: higher cost of driving is associated with less driving. VMT is estimated to rise with the income and size of the household, as expected. The age of the principal driver also has the expected effect: vehicles whose principal driver is twenty-five to thirty-four years old are driven more than those whose principal driver is younger or older. And vehicles whose principal driver is a woman are driven less per year than vehicles whose principal driver is a man. The age of the vehicle (as opposed to its principal driver) enters with a negative coefficient, indicating that older vehicles are driven less than newer ones. Households with more vehicles drive each

Table 2
Regression of VMT

Explanatory Variable	*Estimated coefficients (t-tatistics in parentheses)* — *Depreciation Measure 1: Change in Market Value*	*Depreciation Measure 2: Current Value Amortised over Remaining Life*
Fuel cost, in $ per mile	**−56,460** (117.6)	**−50,714** (112.6)
Depreciation, in $	**−0.8720** (35.90)	**−0.09647** (5.47)
Missing fuel cost	**−18,272** (124.7)	**−17,275** (118.9)
Missing depreciation	**−665.1** (13.54)	**−778.0** (11.77)
Vehicle age, in years	**−184.3** (35.85)	**−184.7** (33.71)
Principal driver is 25–34 years old	**1,504** (11.10)	**1,662** (12.23)
Principal driver is 35+ years old	**681.7** (6.31)	**829.0** (7.65)
Principal driver is female	**−825.6** (20.35)	**−843.3** (20.67)
Log of household income	**720.3** (19.48)	**767.0** (20.59)
Missing income	**2,175** (13.45)	**2,334.8** (14.32)
Log of household size	**2,668** (53.01)	**2,816** (55.93)
Number of other vehicles owned	**−225.0** (11.83)	**−233.2** (12.26)

vehicle less than households with fewer other vehicles. Though not shown in the table, the CBSA coefficients are highly significant collectively, confirming that location plays an important role in vehicle usage.

We now turn to the measures of depreciation, which is the primary focus of our analysis. The year-to-year change in market value obtains an estimated coefficient that is negative and statistically significant. The translation parameter θ is estimated to be 0.000015 (=−0.8720/−56460). This estimate is consistent with the following behaviours: (i) households divide their annual depreciation costs over 10,000 miles per year and treat each $1.00 per mile of depreciation to be equivalent to $0.15 per mile of fuel cost when making driving decisions (since $0.15/10000 = 0.000015 = \hat{\theta}$); (ii) households divide by 15,000 miles per year and treat each $1.00 per mile of depreciation as equivalent to $0.23 per mile of fuel costs ($0.23/15000 = 0.000015$); or (iii) any other combination of mileage and equivalence whose ratio equals $\hat{\theta}$. For any reasonable mileage, households are estimated to discount their depreciation costs considerably in their driving decisions, relative to fuel costs. This result is consistent with rational behaviour, with depreciation treated by households as primarily a fixed cost.

The sample mean of the annual change in market value is \$113. This value is smaller than expected (or at least than we expected). However, a similar mean was found by Desvousges *et al.* (2000) as the change in sales price for vehicles in Wisconsin. The small value is due to several factors (though these factors do not seem to be able to explain it completely). First, the sample mean is over the fleet of existing vehicles, as given by the NHTS, rather than over new vehicles, as in most published depreciation calculations. For example, AAA's 2009 *Your Driving Costs*, discussed above, gives a depreciation cost of \$3,461 for an average of new sedans. The average depreciation over all vintages of existing vehicles is substantially lower than for new vehicles. Second, the price of used vehicles rose generally in real terms from 2009 to 2010,[14] such that vehicles of a given age (for example, a 2006 vehicle in 2009 compared to a 2007 vehicle in 2010, both of which were three years old) experienced a price increase. As a result, the price of a given vintage dropped less over time (for example, a 2006 vehicle in 2010 compared to the same vehicle in 2009) than would have occurred if the used vehicle market had not changed. Third, our measure from Kelley Blue Books is the difference in market values, while other concepts for the change in value are used in some other sources. The AAA figures, for example, are calculated as the difference between the new-vehicle purchase price and the estimated trade-in value after five years. Trade-in value is lower than market value, and the purchase price is higher than the market value once the vehicle leaves the showroom. The difference between purchase price and trade-in value, which is AAA's calculation, therefore exceeds the difference in market values, which is the calculation from Kelley Blue Books.

The mean depreciation under this first measure (\$113) times its estimated value relative to fuel cost in households' driving choices ($\hat{\theta} = 0.000015$) gives \$0.002 per mile. The sample average fuel cost is \$0.158 per mile, and so their sum is \$0.160 per mile. The inclusion of depreciation, as measured by the change in market value, apparently has a negligible effect on travel costs.

The second measure of depreciation is the market value of the vehicle amortised over its remaining life. Its estimated coefficient is negative and significant but considerably smaller than that of the first depreciation measure. The value of depreciation costs by this measure relative to fuel cost is estimated to be only 0.0000019 (0.09647/50714), such that \$1.00 per mile of depreciation has the same effect on VMT as \$0.019 per mile of fuel costs if households divide the annual depreciation by 10,000 miles.

The sample mean of this measure of depreciation is \$1,424, which is considerably larger than that for the first measure. The difference is partly due to the fact that this second measure does not reflect the rise in market prices for used vehicles, discussed above. Also, it is based on current value and remaining life, rather than the difference in market value over time. Used-vehicle markets might consider the life of a vehicle to be longer

[14]See, for example, *New York Times*, 18 October 2013, article by Jaclyn Trop, at www.nytimes.com/2013/10/19/business/after-running-hot-market-for-used-cars-is-cooling.html?_r = 0.

than twelve years and therefore discount them less as they get a year older. Numerous vehicles in the data set (15.7 per cent) are more than twelve years old. As discussed below, we re-estimated the model assuming a fifteen-year life and found that the conclusions did not change.

The estimated contribution to travel costs from this second measure of depreciation is essentially the same as that for the first measure: \$0.003 per mile (0.0000019 × \$1,424). The higher depreciation cost under this second measure translates into a proportionately lower estimated coefficient (even though the two measures are not calculated in a way that makes them proportional). As a result, the average impact on VMT is essentially the same with the two measures.

We investigated whether the results are sensitive to specification and other issues. In particular, we re-estimated the model with these changes (each change implemented separately): (i) using only observations without missing data, instead of using all observations and including dummies for missing data; (ii) with fixed effects for each vintage of vehicle, instead of the variable for vehicle age; (iii) with fixed effects for each age of the principal driver, instead of age groups; (iv) income and household size entering linearly, instead of in logs; (v) with the second measure of depreciation calculated for a fifteen-year life instead of twelve years; and (vi) the dependent variable expressed in logs, instead of linearly. The results were similar, with no qualitative difference in findings.

5.0 Limitations and Directions for Further Research

Our analysis is limited in several important ways. First, we used cross-sectional data. However, changes over time can also be useful for understanding households' response to various cost components. For example, temporal shifts in the used-vehicle market create variation in depreciation (under both of our measures) for each make, model, and age of vehicle. Interest rates change over time and can affect the perceived cost of holding capital assets, including vehicles. And fuel price movements create variation in fuel costs per mile that can assist in identifying the impact of this cost relative to other components. The analysis that we performed on the 2009 NHTS could perhaps be fruitfully expanded to include the next NHTS survey, when it becomes available, thereby allowing for some temporal variation.

We estimated the relation of depreciation to households' annual VMT, rather than to their choice of mode or destination. The advantage of our approach is that VMT and depreciation are measured on the same basis (that is, annually), such that the relation between the two can be observed directly without mediation through other variables. In contrast, the cost-per-mile in destination choice models, for example, is interacted with the distance to each location; the impact of depreciation, if explored, would be estimated by determining whether the choice of destination is related to the product of depreciation and distance to each location, which is a less direct relation. The exploration on destination and mode choice models would nevertheless be useful, especially if depreciation enters differently for different types of travel (for example, recreational versus work-related).

We are particularly concerned about the possibility of endogeneity. The fuel costs and both of our depreciation measures depend on the make, model, and vintage of vehicle. However, the household's choice of which vehicle to own can depend on unobserved factors that also affect their VMT. The NHTS contains no variables that seem appropriate as instruments for fuel and depreciation costs, since the variables that might relate to these costs would also be likely to relate to VMT. An important direction for future work is the development of data that can be used to address endogeneity while estimating the impact of cost components on households' driving decisions.

6.0 Conclusions

Several conclusions are suggested by our literature review and empirical analysis. First, it is important that researchers (including ourselves, the authors) make a practice of reporting the cost-per-mile that is used in each of our studies, and whether the costs include depreciation. Our review of travel cost studies indicates that the vast majority of previous studies have not provided this information. However, meaningful comparison of results over studies, especially welfare measures, requires knowledge of the costs used in each study.

Second, researchers need to consider more closely, and provide a rationale for, our decisions of whether to include depreciation as a component of cost. Many of the studies that we reviewed used cost figures from the IRS, GSA, or AAA. Each of these sources gives per-mile costs with and without depreciation, which means that the researcher needs to decide which to use. However, no studies explained the basis for their decision, and we found no empirical evidence that addressed the question. Given the large impact that including or excluding depreciation has on estimation results, greater attention is clearly warranted.

Third, our empirical analysis indicates that depreciation costs have very little effect on the amount that people drive. The practical conclusion from our findings is that depreciation should either (i) not be included as a component for per-mile vehicle costs in models of travel demand, or (ii) be included at a value of only $0.002 to $0.003 per mile.

Fourth, more work is needed on this important issue. Our analysis is a first attempt at investigating the relation of depreciation to driving behaviour and, as we enumerate above, entails several limitations. These limitations can provide direction for future work. More generally, our call for further research reflects the importance of this issue in the practical application of travel demand models.

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