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The many reasons your mileage may vary: Toward a unifying typology of eco-driving behaviors

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ABSTRACT

The role of vehicle driver behavior has been ignored in prior energy and environmental policy making. Laboratory procedures that produce the fuel economy estimates posted on every new car sold in the US are designed to preclude the effects of differences between drivers. Yet, every vehicle states the caveat, "Actual results will vary for many reasons, including driving conditions and how you drive and maintain your vehicle." Eco-driving as means of strategically taking advantage of this variability has been inconsistently defined in conceptual analyses and variously operationalized in empirical analyses. The present research clarifies, synthesizes, and expands on prior definitions of eco-driving to develop a comprehensive and precise definition and typology of eco-driving behaviors. The resultant typology includes six mutually exclusive classes of behavior: *driving, cabin comfort, trip planning, load management, fueling*, and *maintenance.* This typology establishes a basis for systematic research to determine energy and climate impacts and develop effective policies and interventions for different types of eco-driving.

1. Introduction

Driver behavior has been treated as random error in models of motor vehicle fuel economy and related policy making. An early exception was research prompted by the spikes in oil prices in the late 1970s (Greene, 1986). Fuel-efficient driving behavior fell back under the radar in the 1980s, perhaps because technical changes in vehicle drivetrain technology prompted by the then new Corporate Average Fuel Economy (CAFE) standards and downward shifts in vehicle mass and size produced large improvements in on-road fuel economy. Recent concern about the depletion of fossil fuels and contribution of vehicle carbon emissions to climate change, as well as the critical role of driver behavior in achieving the fuel economy benefits of new hybrid and electric vehicles, has renewed interest in what is now most frequently called *eco-driving* (see CIECA, 2007, for other terms).

Eco-driving is part of what Dietz et al. (2009) call a *behavioral wedge*, referring to "the adoption and use of available technologies in US homes and nonbusiness travel by means of behaviorally oriented policies and interventions" in order to "appreciably reduce energy consumption… with low or zero cost or attractive returns on investment, and without appreciable changes in lifestyle" (p. 18452–18453). Dietz et al. identified five behaviors related to personal vehicular transportation that would reduce US household sector emissions by 9% in ten years if implemented on a national scale: purchase of fuel-efficient vehicles; low rolling resistance tires; routine auto maintenance; driving behavior; and carpooling

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and trip-chaining. Of these behaviors, purchase of fuel-efficient vehicles can have the most profound effect; however, given the selection of a vehicle, lack of attention to maintenance practices, route selection, and managing vehicle load, in addition to inefficient driving styles, can diminish fuel economy up to 45% (Sivak and Schoettle, 2012). Clearly, there are suites of behaviors available to drivers to reduce the energy and emissions intensities and totals of their vehicle travel.

2. What is Eco-driving?

From a behavioral perspective, this is the most important question. The answer is (or should be) foundational to questions regarding the savings potential of eco-driving and how best to promote it. One can only effectively understand any behavior once it is operationally defined so that it can be measured consistently and analyzed systematically. In the field of behavior analysis, two main ways of defining behavior are acknowledged; behavior may be defined in terms of its topography (its observable form/what it looks like) or in terms of its function (its effect/what it does; Cooper et al., 2013).

2.1. Topography

Topographical definitions of eco-driving specify what a driver should do, and therefore are useful in developing interventions. A satisfactory topographical definition of eco-driving should be precise and consistent in order to avoid confusion and develop a parsimonious and reliable account of the behaviors that constitute eco-driving. It should be comprehensive so that the full potential of eco-driving is understood. Current definitions of eco-driving do not sufficiently meet these criteria.

2.1.1. Consistent

Definitions of eco-driving in academic and popular sources vary widely in terms of the behaviors included; they are typically restricted to a driver's operation of the vehicle (Barkenbus, 2010), but sometimes inclusive of vehicle purchase and maintenance decisions (e.g., Sivak and Schoettle, 2012). Even eco-driving behaviors related to vehicle operations (i.e., driving) that are widely agreed-upon are defined inconsistently. In some cases, definitions seem to contradict each other; for example, sources recommend accelerating gently (AA, 2014), accelerating moderately (Barkenbus, 2010; Dogan et al., 2011), and accelerating to quickly reach cruising speed (Birrell et al., 2014; Wahlberg, 2007). Similarly, evenness of speed has been treated as having both a positive and a negative effect on fuel savings (Beusen et al., 2009; Wahlberg, 2007, respectively).

Some of the confusion about what constitutes eco-driving, topographically, is likely because the answer varies from one vehicle to another. For example, Energy and Environmental Analysis, Inc. (2001) discussed how the relationship between "aggressive" driving and fuel economy is dependent on a given vehicle's horsepower/curb weight (HP/WT) ratio—the more powerful the vehicle the less it is penalized in terms of fuel economy for driving styles characterized by high rates of acceleration and braking and high maximum speed relative to average speed. In vehicles with low fuel economy, there is little room for improvement gained from widely promoted eco-driving behaviors. Sivak and Schoettle (2012) pointed out that driving a vehicle rated as achieving on average 11 mpg (21 L/100 km) in accordance with all eco-driving practices would result in no fuel savings.

2.1.2. Comprehensive

Regardless of whether the scope is narrowly restricted to vehicle operations or more inclusive, existing definitions of eco-driving are not comprehensive, i.e., they do not include all the possibilities within a given category of eco-driving behavior, such as vehicle operations. Sivak and Schoettle (2012) offer a broad conceptualization of eco-driving that ranges from vehicle operations to route selection to vehicle selection, yet leave out important behaviors such as trip-chaining (visiting multiple destinations sequentially instead of making multiple separate trips) and do not consider eco-driving in the context of hybrids (HEVs), plug-in hybrids (PHEV) and electric vehicles (EVs)—the latter two together referred to as 'PEVs'. This focus on internal combustion engine vehicles (ICEVs) is typical of eco-driving research despite the fact that many driver behaviors have a relatively greater influence on efficiency outcomes for PEVs (e.g., AA, 2014, October 9).

HEVs and PEVs are exceptions to some eco-driving rules that apply generally to ICEVs. For example, repeating a cycle of heavy acceleration to top speed then coasting ('pulse and glide') can allow a HEV to run on battery power for longer periods without engaging the engine (MetroMPG, 2006, January 15), amounting to greater fuel savings compared to moderate acceleration and even speed which are widely promoted as eco-driving for ICEVs (e.g., Barkenbus, 2010). Regenerative braking systems in PEVs present a unique opportunity for re-capturing some energy lost in braking, a behavior not available to ICEV drivers.

2.1.3. Precise

"Aggressive driving" is sometimes used as a catch-all for vehicle operations that are not eco-driving; e.g., "aggressive driving behavior such as hard acceleration and braking, excessive speed, open windows, etc." (Alam and McNabola, 2014). Conversely, eco-driving proponents often recommend accelerating "moderately" without further operationalization (e.g., Barkenbus, 2010). In terms of research, imprecise definitions preclude accurate and reliable measurement, which is required to understand the relationships between interventions, behaviors, and impact. Complementary to this assessment,