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A market systems analysis of the U.S. Sport Utility Vehicle market considering frontal crash safety technology and policy

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ABSTRACT

Active safety features and adjustments to the New Car Assessment Program (NCAP) consumer-information crash tests have the potential to decrease the number of serious traffic injuries each year, according to previous studies. However, literature suggests that risk reductions, particularly in the automotive market, are often accompanied by adjusted consumer risk tolerance, and so these potential safety benefits may not be fully realized due to changes in consumer purchasing or driving behavior. This article approaches safety in the new vehicle market, particularly in the Sport Utility Vehicle and Crossover Utility Vehicle segments, from a market systems perspective. Crash statistics and simulations are used to predict the effects of design and policy changes on occupant crash safety, and discrete choice experiments are conducted to estimate the values consumers place on vehicle attributes. These models are combined in a market simulation that forecasts how consumers respond to the available vehicle alternatives, resulting in predictions of the market share of each vehicle and how the change in fleet mixture influences societal outcomes including injuries, fuel consumption, and firm profits. The model is tested for a scenario where active safety features are implemented across the new vehicle fleet and a scenario where the U.S. frontal NCAP test speed is modified. While results exhibit evidence of consumer risk adjustment, they support adding active safety features and lowering the NCAP frontal test speed, as these changes are predicted to improve the welfare of both firms and society.

1. Introduction

Automotive crash safety in developed nations has improved considerably in recent decades, due in large part to advanced vehicle structure and restraint system designs, innovative active safety features, and more stringent regulatory standards. These advances are often modeled computationally to estimate their impacts on occupant injuries, fatalities, and other vehicle-related outcomes that are of interest to society like fuel consumption, costs, and travel time. Actual safety improvements often fall short of model-based estimates due to the complex ways that vehicle users react to changes in designs, prices, and policies. Previous research suggests that when design improvements reduce a user's risk of injury, that user will make a behavioral adjustment in a way that typically increases his or her risk, thereby diminishing some of the expected safety improvement (Peltzman, 1975; Graham and Garber, 1984). Some researchers argue that this behavioral adjustment, known as "risk compensation," completely offsets any anticipated safety benefit (Wilde, 1998), a widely contested phenomenon known as "risk homeostasis" (O'Neill and Williams, 1998).

This article discusses the development of a market systems modeling framework that incorporates safety considerations in both engineering attributes and consumer choice within the Sport Utility and Crossover Utility Vehicle (SUV/CUV) market in the United States. The paper links engineering analyses and estimation of consumer demand for vehicles. This approach lays a foundation for understanding how vehicle attributes, including safety, attract consumer demand and thereby influence the composition of the consumer vehicle fleet. Vehicle frontal crashworthiness modeling is used to link observed vehicle attributes with on-road injury probabilities. A discrete choice experiment (Louviere et al., 2000) is conducted to understand heterogeneous consumer preferences for new SUV and CUV models. The crashworthiness model and the consumer choice model are combined to project expected safety outcomes by simulating the behavior of utility-maximizing consumers as they choose new vehicles from the available options in the market. Results are examined for the business-as-usual case and compared with posited scenarios in which (1) implementation of new active safety measures changes the distribution of speeds at which crashes occur on the roadways, and (2) modifications to the U.S. NCAP consumer-information frontal crash test speed influence

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manufacturer-optimized designs and therefore crash outcomes. Simulation results reveal trends in consumer purchasing patterns that quantify the amount of the expected safety benefit that is diminished by changing consumer preferences. These injury predictions are presented alongside the associated effects on fleet fuel consumption and firm profitability in order to show the relationships among these public and private objectives.

1.1. Consumer valuation of safety

Regardless of the extent to which people compensate for safety improvements, economists typically agree that rational people make decisions that maximize their perceived utility (von Neumann and Morgenstern, 1944). Safety considerations as well as other attributes may contribute to utility in different ways. The present study uses utility-based demand estimation along with physics-based crash modeling in a market systems framework to simulate the impact of a changing market on consumers, firms, and society.

One common way to estimate demand for particular vehicles and the importance of various product features is through analyzing vehicle buyers' choices along with the specifications of the available vehicles while assuming that consumers made rational choices to maximize their utility among the set of available vehicles. This process is referred to as discrete choice analysis (Train, 2003). The resulting discrete choice model produces probabilistic estimates of a vehicle buyer's choice given a finite set of vehicle alternatives. Data for estimating discrete choice models are typically of two types, either stated-choice data generated from surveys of prospective or recent car buyers, or revealed-choice data, which involves analyzing actual purchases. One recent study was conducted using stated-choice data from surveys of Spanish and Swedish new vehicle buyers (Koppel et al., 2008), revealing safety as the most important vehicle attribute in the purchase process. The results show that consumers look for safety features more than crashworthiness or crash test results when evaluating a vehicle for safety, though how respondents valued different attributes varied by country. The study revealed a strong stated-choice preference for safety features and safety in general, but the interpretability of the results rests on correspondence of the stated choices to market choices, as in any stated-choice experiment. The generalizability of the results also can be affected by cultural differences between countries. Another stated-choice study was conducted using hypothetical scenarios that forced a choice between vehicle price and different safety levels (McDaniels, 1992). The study found that more people state a willingness to pay for a feature that is standard in other vehicles on the road, and consumers expect a higher discount for reduced safety than they expect a markup for improved safety by the same amount. While the data in this study provide information on how price trades off with safety in the purchasing decision, they do not consider tradeoffs with other vehicle attributes such as performance and efficiency that are likely to play a role in actual purchasing decisions, and the focus on safety invites bias towards a higher stated preference for safety.

Revealed-choice studies have their own limitations, especially with respect to studying the role of safety in vehicle buyer choice. These studies may make assumptions such as consumers having perfect information about injury and mortality rates for vehicles when they purchase them, which typically is neither available at the time of purchase nor widely distributed to the public. Several researchers have constructed vehicle demand models with data from household surveys of vehicle purchasers, and among other vehicle attributes they accounted for safety with metrics such as vehicle mass, size, passive safety feature availability, whether the vehicle received top safety accolades, average costs related to occupant injury in a crash, and average costs of vehicle repair (Winston and Mannering, 1984; McCarthy and Tay, 1989; McCarthy, 1990). These have been used to discuss implications on policy and market shares within the new vehicle market. Other authors including Dreyfus and Viscusi (1995) and Lave and Weber (1970) used purchase data to estimate the ways that consumers trade off price with safety, without considering other vehicle attributes. While these models provide insights into how consumers may have made choices in the late 1980s and early 1990s, they are limited in that (1) they do not account for modern safety features and lower costs of today's airbags, and (2) safety was less transparent to consumers than it is today, e.g., fewer crash tests were conducted and their results were not posted on window stickers.

1.2. Vehicle design and safety

When designing vehicles for safety, it is not enough to interpret how consumers perceive and value safety, but also to understand how the design of the vehicle itself affects occupant safety. Vehicle safety features can be classified into two main categories: passive features such as seat belts and crumple zones that seek to reduce injuries in the event of a crash, and active features such as anti-lock braking systems (ABS) and electronic stability control (ESC) that seek to avoid crashes altogether (Wenzel and Ross, 2005). Many automakers and researchers have optimized vehicle structures and restraint systems for crashworthiness using computer simulations to find designs that improve occupant injury criteria in specific crash scenarios (White et al., 1985; Hou et al., 1995; Kent, 2006; Kamel et al., 2008). Others have used empirical data and physics-based modeling to show how various vehicle design characteristics influence safety in the diverse crashes that occur on the road rather than in specified scenarios (Evans, 1985, 2004; Wood, 1997; Ross and Wenzel, 2001). A key finding of these studies is that increased mass, size, and price correspond with improved on-road safety for occupants of that vehicle. The mass-safety correlation is explained by the laws of conservation of momentum, which show that in multiple-vehicle collisions a heavier vehicle will undergo a smaller change in velocity than a lighter vehicle. Thus, while a heavier vehicle may be safer for its occupants, it is more aggressive and often poses increased dangers to occupants of other vehicles, cyclists, and pedestrians (Tay, 2002). This change in velocity was plotted against a driver's probability of death by Joksch (1993), who developed a "rule of thumb" stating that probability of driver death is closely modeled by a power function of vehicle change in velocity.

Various active safety features have emerged in recent decades to enhance vehicle crash avoidance capabilities, the most widespread being anti-lock braking systems (ABS) and electronic stability control (ESC). Additional advanced features are currently available in some of the latest models, including forward collision warning, emergency brake assistance, lane departure warning, and blind spot detection (IIHS, 2008). These features have the potential to decrease the speed at which crashes occur as well as the frequency of crashes altogether, and they are expected to save thousands of lives in the U.S. each year if widely implemented (Schewel, 2008). However, the previously discussed consumer risk compensation and trading off with other vehicle attributes are likely to attenuate these safety benefits to some extent.

To promote better design for crashworthiness, government agencies specify a number of dynamic whole-vehicle crash test standards that manufacturers must satisfy using a self-certification process. In addition, New Car Assessment Programs (NCAPs) have been established in several countries to give consumers more information about how vehicles compare in specific crashworthiness scenarios. In the U.S., NCAP scores are posted on window stickers of new cars with a five-star rating system and are therefore the most transparent way that consumers can compare crashworthiness. Since frontal crashes account for approximately 70% of all crashes,