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Forecasting Americans' long-term adoption of connected and autonomous vehicle technologies

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ABSTRACT

Automobile manufacturers, transportation researchers, and policymakers are interested in knowing the future of connected and autonomous vehicles (CAVs). To this end, this study proposes a new simulation-based fleet evolution framework to forecast Americans' long-term (year 2015–2045) adoption levels of CAV technologies under eight different scenarios based on 5% and 10% annual drops in technology prices; 0%, 5%, and 10% annual increments in Americans' willingness to pay (WTP); and changes in government regulations (e.g., mandatory adoption of connectivity on new vehicles). This simulation was calibrated with data obtained from a survey of 2167 Americans, regarding their preferences for CAV technologies (e.g., WTP) and their household's annual vehicle transaction decisions.

Long-term fleet evolution suggests that the privately held light-duty-vehicle fleet will have 24.8% Level 4 AV penetration by 2045 if one assumes an annual 5% price drop and constant WTP values (from 2015 forward). This share jumps to 87.2% if one uses a 10% annual rate of decline in prices and a 10% annual rise in WTP values. Overall, simulations suggest that, without a rise in most people's WTP, or policies that promote or require technologies, or unusually rapid reductions in technology costs, it is unlikely that the U.S. light-duty vehicle fleet's technology mix will be anywhere near homogeneous by the year 2045.

1. Introduction

There is a lot of excitement surrounding the future of car travel. Hybrid-electric vehicles, plug-in electric vehicles, car-sharing services, and on-demand taxis are all examples of recent technological and strategic advances in the automobile and transportation sectors. However, the real vehicle-market revolution is associated with the introduction of autonomous vehicles (AVs), connected vehicles (CVs), and connected-autonomous vehicles (CAVs). CAVs introduce all sorts of different benefits, from dramatic reduction of crash rates and congestion to concerns about security, safety and privacy, and negative economic consequences associated with transition to vehicle automation (Schoettle and Sivak, 2014; Fagnant and Kockelman, 2015; National Highway Traffic Safety Administration [NHTSA] 2013). Despite the excitement about CAVs, there is much uncertainty regarding their future.

Policymakers, industry professionals, and researchers would like to ensure that their coming decisions will provide support for a future roll-out of CAVs. NHTSA's (2013) preliminary AV policy guidelines indicate that policymakers need to understand the future of AVs in order to adjust current policies. NHTSA also expects to require connectivity on all vehicles

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produced after year 2020 (Automotive Digest, 2014). Automobile manufacturers and investment banks need to know what technologies will be in demand and which corresponding industries have the greatest potential for rapid growth.

Forecasting long-term CAV technologies' adoption is not easy: many demand-side factors (e.g., willingness to pay [WTP]) and supply-side factors (e.g., technology prices) must be taken into account. Several researchers (Litman, 2015), private enterprises (e.g., Mosquet et al., 2015; Laslau et al., 2014), and industry enthusiasts (e.g., Rowe, 2015; Hars, 2014) have made different predictions about upcoming adoption rates. However, these predictions are based on the extrapolation of trends associated with previous vehicle technologies, expert opinions, or forecasts of supply-side variables, with very little emphasis on the underlined assumptions behind these predictions. In contrast to prior studies, this work uses a simulation-based fleet-evolution framework to forecast Americans' long-term (year 2015–2045) adoption of CAV technologies. This framework considers not only supply-side factors, like technology costs and their evolution over time, but also demand-side factors, like WTP for these technologies, vehicle transaction decisions, and government regulations on vehicle production.[1] This framework incorporates a formal mechanism to anticipate Level 1 and Level 2 automation adoption rates[2] (including lane-centering assistance and adaptive cruise control, for example) and/or vehicle connectivity (using dedicated short-range communications [DSRC] technologies), which are not reflected in prior studies. This study forecasts the adoption of CAV technologies under eight different scenarios, based on 5% and 10% annual drops in technology prices and 0%, 5%, and 10% annual increments in Americans' WTP, as well as NHTSA's current and coming requirements for electronic stability control (ESC) and vehicle connectivity on all new vehicles sold in the U.S. These simulations predict the proportion of vehicles with specific technology at the end of each year under these scenarios.

A survey was designed and disseminated to obtain 2167 Americans' preferences (e.g., WTP for CAV technologies and vehicle transaction decisions), and those data were used in a simulation model. To incorporate the impact of demographics and built-environment variables on vehicle transaction decisions, logit choice models were calibrated and are included in the model. The following sections describe related studies, the survey and simulations design, summary statistics, modeling specifications, key findings, and conclusions.

2. Literature review

Forecasting long-term adoption of CAV technologies is a fairly new topic. Existing literature has only a few such forecasting studies by academic researchers, with most studies conducted by consulting firms, investment banks, and other private enterprises. Table 1 summarizes three types of studies that have forecasted: (a) future-year shares of self-driving vehicles, (b) future sales of AVs, and (c) vehicle-miles traveled by self-driving cars. The private enterprises generally do not focus on forecasting methods in their reports and therefore, such details are not provided in the Table 1.

One of the most cited studies about CAV adoption is by Litman (2015). Based on deployment and adoption of previous vehicle technologies (like automatic transmission, airbags, vehicle navigation systems, and hybrid-electric drive), Litman forecasted that AVs will constitute around 50% of vehicle fleet, 90% of vehicle sales, and 65% of all vehicle travel by 2050. He argues that faster implementation will require "low- and middle-income motorists, who normally purchase used vehicles or cheaper new models to spend significantly more in order to purchase a new automobile with self-driving capability."

Most of other recent studies (e.g., Schoettle and Sivak, 2014; Haboucha et al., 2015; Krueger et al., 2016) are focused on understanding respondents' currently perceived benefits and concerns about CAV technologies and WTP for these technologies, among many other opinion-based attributes. Interested readers are referred to Bansal et al. (2016) and Bansal and Kockelman (2016) for detailed literature reviews of opinion-based studies. To the best of the authors' knowledge, this study is the first to forecast long-term evolution of a nation's fleet toward CAVs while considering demand-side (consumers' WTP) and supply-side (technology prices) variables, as well as NHTSA's regulations on ESC and vehicle connectivity. A few vehicle simulation frameworks have been developed for forecasting market shares of alternative-fuel vehicles in Austin (Musti and Kockelman, 2011) and the U.S. (Paul et al., 2011). Garikapati et al. (2016) recently proposed a simulation-based model using a multiple discrete continuous extreme value (MDCEV) specification to predict a household's own fleet mix. Such models are not directly applicable to forecasting the long-term adoption of CAV technologies, but provide a basis for this new framework.

3. Survey design and data processing

A U.S.-wide survey was designed and disseminated in June 2015 using Qualtrics, a web-based survey tool. The Survey Sampling International's (SSI, an internationally recognized and highly professional survey firm) continuous panel served as the respondents for this survey. The Office of Research Support at The University of Texas at Austin processed this study and determined it as "Exempt" from Institutional Review Board (IRB) review (protocol number: 2014-09-0078).

[1] ESC has been mandated on all new passenger vehicles in the US since 2012 model year (NHTSA, 2012). NHTSA is expected to require connectivity on all vehicles produced after year 2020 (Automotive Digest, 2014).

[2] NHTSA (2013) defined five levels of automation. To state briefly, automation Levels 0, Level 1, Level 2, Level 3, and Level 4 imply no automation, function-specific automation, combined function automation, limited self-driving automation, and full self-driving automation, respectively.