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Perspective

Sustainability implications of connected and autonomous vehicles for the food supply chain

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ABSTRACT

Connected and autonomous vehicles are anticipated to transform food distribution systems. The food distribution industry is a likely early-adopter of this technology, with resulting changes affecting the environmental and economic profiles of the food supply chain. Considerations for a truly sustainable adoption of this technology are discussed.

1. Introduction

Connected and autonomous vehicles (CAVs) will fundamentally change many industries, including shipping and delivery. CAVs provide the opportunity for environmental improvements in transportation, however, the economic effects of adoption for workers are likely to be quite negative.

Connectivity in autonomous vehicles provides the basis for vehicle communications and allows for traffic flow optimization. CAVs can reduce accident rates and improve environmental outcomes through decreased transportation emissions, particularly from improved efficiency and/or light-weighting, and when the potential for increases in vehicle-miles-traveled (VMT) are limited (Miller and Heard, 2016).

The food product distribution industry is a likely early-adopter of CAVs, delivering often-perishable products on constrained timetables. For example, it is estimated that in 2015, there was an almost 8% difference in primary weight of fresh vegetables between their primary availability and retail availability (United States Department of Agriculture Economic Research Service, 2017). Losses such as these could be reduced by improvements in transportation logistics and technologies, including automation. While automated transportation has the potential to impact many economic sectors, food distribution is particularly pertinent given the interplay between transportation logistics, food perishability, and cost. CAVs have the potential to change food distribution systems by relaxing existing economic constraints that govern how and where perishable food may be shipped.

CAV adoption will be motivated by potential increases in profit, with this technology providing 24/7 service for trucks at higher efficiencies, and without driver wages (Wadud, 2017). CAVs could provide these continuing benefits for a food distribution firm after a one-time capital investment.

This industry provides a valuable case-study where the sustainability performance of autonomous trucking can be evaluated. For food consumed in the United States, trucking provides 28% of supply chain transportation and is responsible for 71% of total food supply chain transportation emissions (Weber and Matthews, 2008). Previous research has demonstrated the potential benefits of automated technology, with "intelligent" shipping containers and autonomous logistics simulated to decrease food losses in banana distribution (Haass et al., 2015), and the use of distribution optimizations and algorithms providing notable reductions in perishable food losses (Osvald and Zadnik, 2008; Rong et al., 2011).

Autonomous trucking will transform two key areas of the food system: environmental and economic. Both must be studied to ensure a truly sustainable adoption of this technology.

2. Environmental effects

2.1. Emissions reductions through efficiency gains

Recent research has reported the fuel economy and emissions benefits from of CAVs. Higher efficiency can be achieved through mechanisms including an optimal driving cycle, optimal routing and dynamic eco-routing, less idling, reducing cold starts, trip smoothing,

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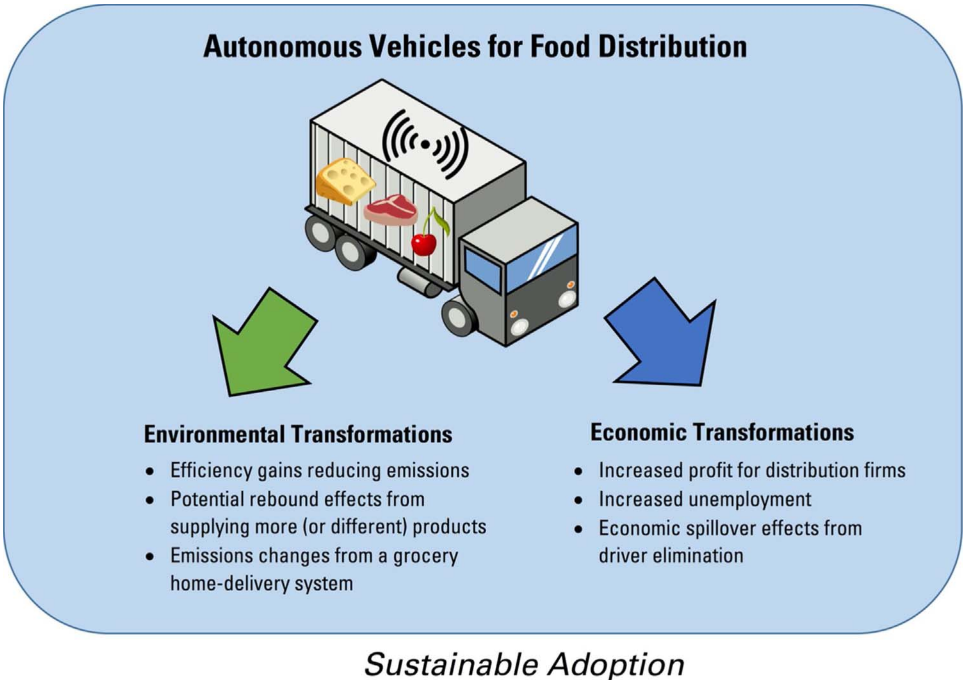

Fig. 1. The key anticipated environmental and economic transformations from autonomous vehicle adoption in the food supply chain.

speed harmonization, and vehicle light-weighting. These environmental savings compound for refrigerated food transportation, decreasing the quantity of energy and refrigerants used in distribution.

CAV platooning provides additional potential for higher fuel economy and emissions reductions by reducing aerodynamic drag. Since the large majority of truck travel occurs on the highway, platooning can facilitate significant emissions decreases with Wadud et al. estimating a 10–25% reduction in energy intensity from platooning autonomous heavy trucks (Wadud et al., 2016). On the other hand, improved safety of CAVs may enable traveling at higher speeds. While this might be of interest for faster and more optimized scheduling of deliveries, it will increase fuel consumption and GHG emissions in autonomous trucks. Therefore, the trade-off between energy savings and increased energy consumption through higher travel speeds is uncertain.

2.2. Potential transformations in food distribution patterns

For a traditionally-structured trucking firm, CAVs present a lower marginal cost of transportation from decreased fuel use and not paying a driver wage. If there is suppressed demand for a food product, these savings present the ability to increase supply in a way which may not have been previously profitable. Additionally, CAVs provide the potential for semi-perishable food to be shipped longer distances from in-season agricultural zones to out-of-season markets, and could even displace some ship or air distribution for certain products. Lower costs and increased capacity for transportation could present an emissions rebound effect through increased VMT and fuel consumption, which may erase some of the emissions savings from efficiency gains.

More notably, CAVs could fundamentally transform the current post-processing food distribution model. Enabled by logistics innovations and e-commerce platforms, autonomous vehicles could displace grocery stores, delivering ordered foods directly to consumers instead. The consumer convenience brought by this new delivery mode would accelerate adoption. A shift to this model of distribution presents a number of changes affecting the system's sustainability.

First, home-delivery of food products presents a last mile problem in delivery optimization, whose relative emissions outcome is unknown. There may be increased emissions from CAV home-delivery displacing a larger truck with multiple smaller vehicles. However, this substitution can be contrasted with the avoided emissions from a consumer round-trip to the grocery store as well as emissions and waste associated with grocery store retailing practices, including operating refrigerated display cases and waste from over-stocking. A consumer may also choose to order a grocery shopping trip's worth of food in smaller quantities delivered separately, which could increase transportation emissions associated with delivering groceries, but decrease food waste from over-estimating food requirements during one shopping trip.

The extent to which these potential changes in food distribution will be realized cannot currently be predicted. However, observing changes in distribution choices and resulting emissions is critical for evaluating the environmental performance of this technology.

3. Economic effects

Examining a technology's sustainability requires assessing its economic and social implications in addition to its engineering performance. The economic effects associated with CAVs in food distribution are shared with other industries adopting autonomous vehicle technology, and as such, are discussed more broadly.

Through increased efficiency and greater flexibility in vehicle deployment, CAVs present the potential for increased profits in the food distribution industry. However, a substantially negative economic effect of autonomous vehicle technology will be the potential for increased unemployment. Heavy and tractor-trailer truck driving employs 1.7 million Americans, with grocery and related product merchant wholesalers being the third-largest employer in this category, with over 63,000 jobs (Bureau of Labor Statistics, 2016). Autonomous vehicles present the potential to displace these workers.

Trucking also provides economic activity through facilitating demand for purchases at truck rest stops as well as for lodging and food in towns close to the highway system. While there may be shorter-term opportunities for job retention, such as drivers riding along and "supervising" an autonomous truck, it is difficult to imagine companies continuing to pay former drivers to do so into the future, particularly when CAV technology is more established and trusted.

Emissions changes cannot be the only metric used to evaluate the sustainability of CAVs. If a technology decreases emissions but also creates economic instability, then it does not result in a sustainable system. Active labor market policies such as job search assistance and worker re-training have the potential to mitigate the negative effects of unemployment (Card et al., 2017; Council of Economic Advisers, 2016), and must be evaluated in the context of CAV introduction to ensure a sustainable adoption.

4. Research and policy considerations

A summary of the transformations presented by CAVs in food distribution is presented in Fig. 1. CAV adoption is likely to occur early for this industry due to potential increases in profits, and may fundamentally change many aspects of the food distribution system.

Since there is currently no overarching framework or policy for CAV introduction in nations such as the US, demonstrations of sustainable and successful adoption by an industry such as food distribution will likely serve as the blueprint which others will follow. This presents a time-sensitive element: the earlier a successful, sustainable industry adoption of CAVs for an application can be presented, the more industries will be able to use these results to inform their strategies, facilitating a more sustainable adoption of CAVs overall.

The timeline for how and when full automation will be available in trucks is still uncertain. This situation presents unique research and policy evaluation opportunities. The environmental performance of CAVs can be monitored and evaluated, providing insights into the emissions outcomes of different configurations and optimizations of these distribution fleets. Some potential technological and logistic challenges, such as loading and unloading at origin and delivery location, need to be addressed prior to realizing the market transformation of food delivery via CAVs. Assessing changes in firm profitability and the effectiveness of active labor market policies for mitigating unemployment also provide opportunities for applied economics research.

CAVs are a transformative technology whose adoption will bring about a number of substantial changes. The deployment of CAVs in industries with incentives to adopt early, such as food distribution, will likely influence how they are used in other applications. For a truly sustainable adoption of this technology, positive environmental outcomes must be attained while also mitigating the negative effects of unemployment.

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