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How Autonomous Vehicles Will Drive Our Budgets

AN ANALYSIS OF THE ECONOMIC AND FISCAL IMPACTS OF SELF-DRIVING CARS ON THE COMMONWEALTH OF MASSACHUSETTS

By Rafael Mares, Chris Stix, and Sara Dewey

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Executive Summary

Big changes are underway that will affect how Massachusetts residents get around. Companies are racing to bring autonomous vehicles to the market as quickly as possible. Self-driving vehicles are already on the streets in Boston's Seaport District for testing purposes. We can expect them in more regular use as early as 2020 and widely available by 2023. With this new technology just around the corner, we must prepare to ensure that Massachusetts realizes the benefits of this new technology, while minimizing its potential downsides.

As self-driving vehicles arrive in the Commonwealth, we can expect changes to more than just the way we get to work and run errands. Self-driving vehicles will have enormous impacts on state and local budgets and on the economic outlook in the Commonwealth. Self-driving cars will affect the considerable state and local revenues related to motor vehicles, including motor fuels taxes, excise taxes, and parking fees. In addition, the shift to self-driving vehicles will lead to economic impacts, including congestion and air pollution costs. There still is enough time for us to determine the future of autonomous vehicles and our transportation system, but the opportunity to do so is now.

This report assesses the economic and fiscal impacts of the transition to self-driving vehicles on Massachusetts, its cities and towns, and its households. It also identifies policy options to mitigate certain budget and economic impacts and allow the Commonwealth to reap the full benefits of this transition. It is the first such analysis for the Commonwealth of Massachusetts, and it is critical as self-driving vehicles start to become a reality in our communities.

This report models the various ways that self-driving vehicles could be deployed in Massachusetts. These vehicles could be offered to consumers in several ways: as private vehicles for individual or family use; as public transit; or as a ride-sharing service, including ride-hailing vehicles that serve an individual or group on demand, like traditional taxis, Lyft, or Uber, and ride-pooling vehicles that offer shared rides to more than one individual or group traveling in the same direction, like Lyft Line, UberPool, or Waze Carpool. For any of these approaches, a petroleum-fueled internal combustion engine, a battery, or another technology can power the self-driving vehicle. Our analysis considers the various ways these vehicles and technologies can be deployed over time.

MAJOR TRENDS

As autonomous vehicles deploy in Massachusetts, two key trends will drive economic and fiscal impacts: increased vehicle miles traveled and decreased demand for parking. These top-level trends are largely responsible for the anticipated economic and fiscal effects of the transition to driverless vehicles.

First, in the short term, self-driving vehicles will cause significant increases in congestion on highways, major roads, and streets, even at early stages when relatively few autonomous vehicles are on the road.[1] Currently, drivers in the Commonwealth travel more than 50 billion miles per year.[2] With a vehicle fleet that is made up of just 20% self-driving vehicles and 80% conventional vehicles, our analysis anticipates an increase of almost 6 billion miles traveled annually in Massachusetts alone. At full deployment of self-driving cars, this could increase to 35 billion additional miles annually in Massachusetts. The many factors in this predicted increase in vehicle miles traveled include lower per-mile vehicle costs, greater access to cars for people who cannot drive, a willingness to travel longer distances, and the ability of self-driving vehicles to travel without passengers.

[1] See Fagnant, D. and Kockleman, K. (2015). Preparing a nation for autonomous vehicles: opportunities, barriers and policy recommendations. *Transportation Research Part A: Policy and Practice* 77: 167-181. http://www.caee.utexas.edu/prof/kockelman/public_html/TRB14EnoAVs.pdf; Wadud, Z. MacKenzie, D., and Leiby, P. (2016). Help or hindrance? The travel, energy and carbon impacts of highly automated vehicles. *Transportation Research Part A: Policy and Practice.* 86: 1-18; International Transport Forum. (2015). *Urban Mobility System Upgrade: How shared self-driving cars could change city traffic.* https://www.itf-oecd.org/sites/default/files/docs/15cpb_self-drivingcars.pdf.

[2] Number of total vehicles (passenger and commercial) registered in the Commonwealth (2014) and annualized mileage (Fourth Quarter 2014) is from the Metropolitan Area Planning Council Vehicle Census. See Metropolitan Area Planning Council. (2017). *Massachusetts Vehicle Census 2009-2014.* trans_mavc_public_summary_ma.zip. The U.S. Department of Transportation estimated Massachusetts Vehicle Miles Traveled to be 54.4 billion in 2010. *See* U.S. Department of Transportation Federal Highway Administration (2005, 2010). *Highway Statistics.* Table VM-2. http://www.fhwa.dot.gov/policyinformation/statistics.cfm.

Second, the demand for parking will decrease as autonomous vehicles park more efficiently or do not need parking at all. This change will have a particular bearing on cities, as up to 60% of their budgets' motor vehicle-related revenues come from parking. This municipal revenue stream will face sharp declines in the short term. In the longer term, cities and towns should be able to stem the loss in revenues by redeveloping current parking structures and reaping the benefits of additional property taxes. Smaller towns could also face budget impacts, primarily from reductions in the excise tax, rather than parking, if ride sharing, particularly ride pooling, increases.

ECONOMIC IMPACTS

The transition to self-driving vehicles can yield major economic benefits that outweigh revenue declines, but only if the fleet is primarily electric and largely deployed through ride pooling. Increased vehicle miles traveled and the types of vehicle technologies the Commonwealth incentivizes will drive the economic impacts.

Congestion: Increased vehicle miles and worsened congestion will drive the economic impacts of autonomous vehicle deployment. At 20% autonomous vehicle deployment, congestion costs could be $984 million annually. At 100% deployment, congestion costs could be as high as $5.4 billion per year. However, if ride-pooling vehicles become a large portion of the fleet, the Commonwealth could realize economic benefits from relatively lower congestion.

Safety: Driverless cars will cause fewer accidents, allowing for increased productivity, improved health, and other economic benefits generated from increased safety. The safety benefits will lead to annual economic benefits of $810 million at 20% autonomous vehicle deployment and $3.3 billion at full deployment.

Greenhouse gases: Greenhouse gas emissions from autonomous vehicles with internal combustion engines will increase due to higher vehicle miles traveled, which could result in annual economic costs of as much as $51 million at 20% deployment and $381 million at 100% deployment. A rise in the number of electric vehicles and increased ride pooling in the autonomous fleet will drive reductions in greenhouse gas emissions. For example, a 100% electric fleet that is a mix of ride pooling and ride hailing could lead to economic benefits of $988 million annually.

Air pollution: Increases in mileage will also lead to increased local and regional air pollution to the extent that the fleet includes vehicles with internal combustion engines. At 20% deployment, air pollution costs could be as high as $60 million per year, and at 100% deployment, these costs could be as high as $300 million per year. Ride-pooling and electric vehicles will both drive benefits, including air pollution-related economic benefits as high as $845 million per year with a 100% electric fleet.

FISCAL IMPACTS

With the arrival of autonomous vehicles, the Commonwealth and its cities and towns will need to fill the budgetary gaps from potential revenue reductions. Overall, if effective policies are put in place, the economic benefits are likely to outweigh these revenue shortfalls. However, without intervention, such gains do not directly address budget deficits. The state and municipalities will need to take steps to make up anticipated revenue gaps. In this context, it is important for decision makers to plan ahead for each of these potential impacts and to develop policies that maximize the benefits of the transition to autonomous vehicles, avoid economic and environmental costs, and steer clear of budget reductions.

State Fiscal Impacts

Motor fuels taxes: As self-driving vehicles increase vehicle miles traveled, gas tax revenue is projected to increase unless or until the fleet is largely electric. With an internal combustion-powered fleet, annual tax revenues could be $42 million higher at 20% deployment and $191 million higher at 100% deployment.

Sales and use taxes: Sales and use taxes will increase with private autonomous vehicle ownership: At 20% private autonomous vehicle deployment, these taxes could be $142 million annually, and at full deployment, they could be $777 million per year. With more ride pooling, these revenues will decline, but shorter vehicle life in years will partially mitigate the impact of fewer vehicles as cars wear out more rapidly.

Executive Summary

Toll receipts: As vehicle miles traveled increase with driverless car deployment, revenue from existing toll roads will rise. We anticipate a 16% increase in toll revenue at 20% deployment, and a 60% increase at full deployment.

Moving violations: Self-driving cars will reduce and then nearly eliminate moving violation revenue for the state.

License, title, and registration fees: Motor vehicle license, title, and registration fees for a largely private ownership approach will increase in the short term and then fall at higher levels of self-driving vehicle deployment. For a ride-sharing fleet with a mix of ride-hailing and ride-pooling vehicles, fees will begin to decrease sooner.

Road maintenance: The cost of road maintenance for state highways and roads from incremental miles traveled by self-driving cars is likely to increase slightly.

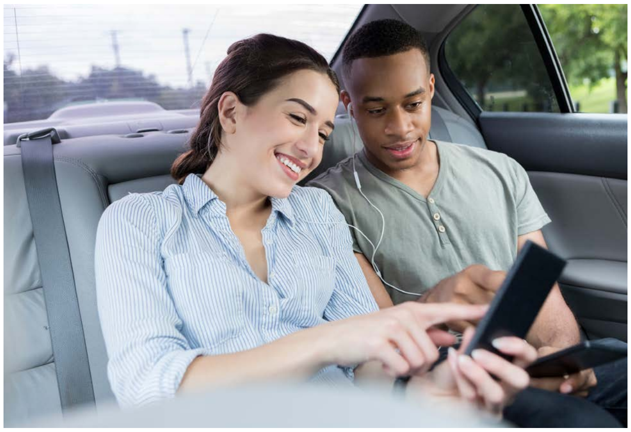
Municipal Fiscal Impacts

Parking-related revenues: These revenues, including paying to park, permit fees, and violations, will fall in the short term, with cities expected to make up those losses in parking-area redevelopment in the longer term.

Excise taxes: Excise tax revenue can be expected to increase with a largely private fleet, primarily due to increased vehicle miles. However, if most vehicles are shared, excise taxes will drop with fewer vehicle purchases.

Moving violations: Self-driving cars will reduce—and then nearly eliminate—moving violation revenue for municipalities.

Road maintenance: The cost of road maintenance on local roads from incremental miles traveled by self-driving cars is likely to increase.[3]



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BENEFITS OF ELECTRIC AND RIDE-POOLING VEHICLES

Most of the economic benefits of the transition to autonomous vehicles can be realized only if the autonomous fleet is primarily made up of electric and ride-pooling (rather than ride-hailing) vehicles. When companies developing autonomous vehicles tout the benefits of self-driving technology, they are generally claiming the advantages of a largely electric, ride-pooling vehicle fleet. However, the autonomous vehicle fleet will not necessarily be electric and ride-pooling unless smart policies push the Commonwealth in this direction. Our analysis suggests that some of these benefits occur only if self-driving vehicles that are both electric and ride-pooling become pervasive and at autonomous vehicle penetration levels of 80% of the fleet. While the economic benefits of electric, ride-pooling self-driving vehicles likely will far outweigh costs to local and state government, municipalities and the Commonwealth will have to make a number of significant adjustments in order to adapt to the budget impacts of the new technology and realize the economic benefits.

[3] This report assumes continued use of existing roadway infrastructure. New investments in infrastructure to improve the roadways for self-driving vehicles would increase these costs, but they are not part of this analysis.

POLICY RECOMMENDATIONS

Zero emissions vehicles: Incentivize or phase in requirements for including electric vehicles in the self-driving vehicle fleet, building on the Commonwealth's existing Zero Emissions Vehicle policies.

Ride pooling: Provide incentives for ride pooling over ride hailing and private ownership.

Supplementing the gas tax: Introduce other revenue streams such as mileage-based or other user fees.

Limits on zero-occupancy vehicles: De-incentivize or restrict the distance that vehicles can travel while empty, without passengers.

Municipal budget planning: Plan now to deal with projected shortfalls in individual cities and towns.

Public transit investments: Maintain and improve public transit options for everyone in the Commonwealth.

Job training: Develop large-scale programs to retrain professional drivers.[4]

VISIONS OF THE FUTURE: ECONOMIC IMPACTS OF OUR AUTONOMOUS VEHICLE FLEET

Economic Impacts of Private Internal Combustion Engine Autonomous Vehicle Fleet vs. Ride-Sharing Electric Autonomous Vehicle Fleet at 20% and 100% Penetration*

PROJECTED IMPACT	Congestion	Collisions	Greenhouse Gas Emissions	Local and Regional Air Pollution
20% Private Internal Combustion Engine Vehicles	Increases with more vehicle miles	Improve moderately	Increase with more vehicle miles	Increases with more vehicle miles
100% Private Internal Combustion Engine Vehicles	Increases with more vehicle miles	Improve significantly	Increase with more vehicle miles	Increases with more vehicle miles
20% Ride-Sharing* Electric Vehicles	Increases with more vehicle miles, somewhat offset by ride pooling	Improve moderately	Decrease with EV technology and ride pooling	Decreases with EV technology and ride pooling
100% Ride-Sharing* Electric Vehicles	Increases with more vehicle miles, more offset by ride pooling	Improve significantly	Decrease with EV technology and ride pooling	Decreases with EV technology and ride pooling

High levels of ride-sharing and electric vehicles will drive better outcomes.

ECONOMIC IMPACTS Large Economic Benefit · Moderate Economic Benefit · Large Economic Cost · Moderate Economic Cost

** Ride-sharing mix assumes 40% ride pooling and 60% ride hailing*

[4] While employment impacts will be significant under any self-driving vehicle scenario, they are beyond the scope of this analysis.

I. Introduction

THE CHALLENGES AND OPPORTUNITIES FOR THE COMMONWEALTH

The transition to an autonomous vehicle fleet is a key moment of opportunity for the Commonwealth to invest in electric and ride-pooling vehicles. Electric vehicles can help reduce air pollution, while ride pooling can decrease congestion, and both can drive economic benefits. However, these outcomes are not inevitable: If the autonomous vehicle fleet is primarily made up of private or ride-hailing vehicles with petroleum-fueled internal combustion engines,[5] the Commonwealth will be unable to realize these economic and other benefits. It is crucial to put forward-thinking policies in place to realize the economic benefits of this transition, while mitigating potential significant negative budget and economic impacts.

With the arrival of autonomous vehicles, we must prepare for changes not only to how residents get around but also to the revenue streams that support state and local governments. Without dependable revenue, state and local governments cannot provide the schools, services, and infrastructure on which residents and businesses depend. Self-driving cars will affect the significant state and local revenues related to motor vehicles, such as motor fuels taxes and parking fees. Along with state and local fiscal impact, self-driving vehicles will also have important economic implications for the state and its residents, including congestion and air pollution costs.

This report seeks to assess the economic and fiscal impacts of driverless vehicles so Massachusetts can put policies in place to reap the potential benefits of this new technology without jeopardizing local and state budgets, miring the state in more traffic congestion, or leading to more air pollution.

Photo credit: nuTonomy Press Kit

OUR APPROACH

Based on rigorous modeling, this report lays out a number of possible economic and fiscal scenarios depending on the rate of adoption of autonomous vehicles, as well as what percentage of those vehicles are electric or ride-sharing. We examine the following impacts of autonomous vehicle deployment: (1) economic impacts, including congestion and air pollution costs; (2) state budget impacts, including gas tax and other motor vehicle-related revenues; and (3) municipal budget impacts, including parking fees, excise taxes, and other motor vehicle-related revenues. The economic impacts of changes in employment as a result of autonomous vehicle deployment are beyond the scope of this analysis, though they will be extremely important for decision makers to consider.

There are several ways in which self-driving vehicles could serve consumers, and multiple technology options for powering them, all of which have important economic and fiscal impacts. In this report, we assume that self-driving vehicles can be provided as (1) "private"—vehicles for individual or family use; and two types of "ride-sharing" vehicles, including (2) "ride hailing"—vehicles

[5] For example, Boston-based nuTonomy is using a Peugeot SUV hybrid for its autonomous vehicle development. Companies including Waymo and Uber, in collaboration with Chrysler and Volvo, are working on self-driving internal combustion engine vehicles.

that serve an individual or group on-demand, like a traditional taxi, Lyft, or Uber ; or (3) "ride pooling"—vehicles that offer shared rides to more than one individual or group traveling in the same direction, like Lyft Line, UberPool, or Waze Carpool.[6] In some of our analysis, we assess a mix of ride hailing and ride pooling ("ride-sharing mix"). Regardless of delivery method, the self-driving vehicle, itself, can have a petroleum-fueled internal combustion engine or can be an electric vehicle. For the purposes of this report, "electric vehicles" includes battery-powered electric vehicles, which are fully electric, zero-emission vehicles with an electric battery that can be recharged from an external electricity source.

While many uncertainties remain about the deployment of self-driving vehicles, this analysis maps a range of potential deployment outcomes for policymakers to consider. To model this range of possible deployment scenarios, our analysis includes 20%, 50%, 80%, and 100% levels of self-driving car penetration. The report also considers the impact of different mixes of private, ride-hailing, and ride-pooling self-driving cars in the fleet, using petroleum-fueled internal combustion engines or electric-vehicle technology.

The automobile fleet is continuing to evolve due to policy choices, consumer demand, and technological improvements. These ongoing vehicle innovations include electric vehicles, ride pooling, safety improvements, and increased fuel efficiency. These improvements, which can confer substantial benefits, are often conflated with the expected benefits of self-driving cars. However, our analysis controls for these factors that are evolving independently of and in parallel with autonomous vehicle development.

It may be tempting to read the top-line findings of this report and consider net impacts of the transition to autonomous vehicles, especially given the enormous economic benefits of electric and ride-pooling self-driving vehicles. However, we encourage our readers to consider each type of economic and fiscal impact individually. By weighing each impact rather than the net effects of driverless vehicles, the Commonwealth can put sensible policies in place to mitigate specific harms (such as congestion and greenhouse gas emissions) and maximize benefits (such as an increase in safety). This is necessary so we can start planning now to account for the range of anticipated impacts.

Preparing for this change will require governmental entities to look beyond incentives created by avoiding changes to specific revenue streams and, instead, consider the broad impacts of autonomous vehicle deployment. For example, for state agencies, incentivizing electric vehicle use in the autonomous vehicle fleet could lead to decreased revenues from the gas tax; however, electric vehicles will lead to massive economic and environmental benefits. For municipal governments, more privately owned autonomous vehicles could lead to higher excise tax revenue, but that revenue will likely be distributed unevenly across municipalities, depending on where those vehicles are registered, and the economic and environmental benefits of shared vehicles, especially ride pooling, far outweigh private ownership. The report's findings highlight the need for the policy interventions in Section VI to ensure that Massachusetts gains economically from the rollout of the autonomous vehicle fleet.

The report provides top-level findings in Section II. The sections that follow provide the economic and fiscal context and underlying analysis. Section III contains a snapshot of the Commonwealth's current economic and fiscal picture related to motor vehicles. Section IV reviews the key metrics in our analysis. Section V lays out the autonomous vehicle deployment scenarios modeled in the report. Section VI offers some high-level policy recommendations based on our analysis. Appendix A provides full tables of our modeling results and Appendix B provides a detailed methodology.

[6] Autonomous vehicles can also serve consumers as public transit, but that is not the focus of this analysis.

II. Findings

Key Takeaways

- Vehicle miles traveled will increase and result in greater congestion as well as increased air pollution. Reducing vehicle miles traveled and associated congestion will be possible only if a significant percentage of trips use ride pooling.
- Massachusetts is committed by law to achieving reductions in greenhouse gas emissions over time. Unless self-driving vehicles are incentivized to be electric and ride pooling, it will be difficult for the Commonwealth to achieve its goals due to anticipated increases in vehicle miles traveled.
- Generally, to the extent that the transition to autonomous vehicles incentivizes or mandates vehicles that are both ride-pooling and electric, economic costs will fall (for example, from minimizing congestion or emissions) and benefits will increase. State and local revenue sources, such as vehicle taxes and fees, will likely be lower. On the other hand, without the use of electric vehicles and ride pooling, congestion and air pollution impacts will be high. A deployment scenario with 100% ride-pooling electric vehicles could drive net economic benefits of over $3 billion annually, while 100% private petroleum-fueled internal combustion engine vehicles would lead to economic costs of $3.5 billion annually (see Figure 1).
- Autonomous vehicles have the potential to decrease collisions, but an increase in vehicle miles traveled will moderate that reduction.
- There is likely to be a time lag between budget reduction at the state and local level and opportunities to mitigate those decreases, so municipalities should plan accordingly.
- Tradeoffs between negative fiscal impacts and positive economic benefits can be avoided with forward-thinking policies.

TRENDS DRIVING ECONOMIC AND FISCAL IMPACTS

Despite the challenge of predicting precisely how autonomous vehicle deployment will unfold in Massachusetts, two top-level trends will drive economic and fiscal impacts: increased vehicle miles traveled and decreased parking demand. These two factors are largely responsible for the economic and fiscal impacts of the transition to driverless vehicles in the Commonwealth and municipalities. In addition, the research anticipates that the introduction of autonomous vehicles that are electric or ride-pooling will lag without additional policies driving these options.

ECONOMIC IMPACTS ON MASSACHUSETTS

As the Commonwealth and municipal governments prepare for the transition to driverless vehicles, it is important to consider the major economic impacts of autonomous vehicles, including congestion, safety, greenhouse gas emissions, and local and regional air pollution. Based on our modeling, we anticipate the following impacts:

Congestion: Congestion is expected to be the most significant impact in the short term. Increased vehicle miles and worsened congestion will drive the economic impacts of autonomous vehicles, particularly at early stages of deployment. The economic cost of increased congestion to consumers, businesses, and state and local governments could total $984 million annually at just 20% self-driving car penetration, with

TREND 1:

INCREASE IN VEHICLE MILES TRAVELED

- Expect a large increase in vehicle miles traveled and a significant increase in empty driving time.
- At 100% autonomous vehicles in the fleet, annual mileage driven could increase by 35 billion miles (a 60% increase).

IMPACTS

- ✗ Increased congestion
- ✓ Increased toll revenue and motor fuels taxes (unless approximately 70% are electric vehicles)

TREND 2:

DECREASE IN PARKING DEMAND

- Expect lower parking demand as autonomous vehicles park more efficiently and less frequently.
- Vehicles will be able to self-park and park together more tightly, without room for passengers to exit.
- Vehicles can circulate when empty or return home.

IMPACTS

- ✗ Reduced revenue from parking

private ownership or ride hailing. Even at these levels of low autonomous vehicle penetration, congestion in the Boston area could increase by as much as 17%. Once all vehicles are self-driving, vehicle miles traveled could increase by as much as 85%. At full autonomous vehicle adoption, these costs could be as high as $5.4 billion per year. However, if electric and ride-pooling vehicles make up a greater portion of the fleet, the Commonwealth will realize economic benefits from relatively lower congestion and greenhouse gas emissions and air pollution reductions (see Figure 1). However, even at 80% ride pooling, our model still shows an increase in traffic. To address congestion in the long term, we will need a solution that includes public transit, as well as high levels of ride pooling.

Safety: The safety benefits of the transition to driverless vehicles will be considerable. The economic benefits of reduced collisions could total approximately $810 million annually at 20% autonomous vehicle penetration. While human error may account for 90% or more of collisions, the period when both human drivers and self-driving vehicles share the road—as well as the software in autonomous vehicles—likely will introduce some new errors and collisions. At full deployment of autonomous vehicles, the potential conflicts between human drivers and self-driving vehicles will go away. At this later stage, the economic benefits of collision reduction could total approximately $3.4 billion annually.[7]

Greenhouse gases: Greenhouse gas emissions from autonomous vehicles with internal combustion engines will likely increase due to higher vehicle miles traveled. The higher the percentage of electric vehicles in the driverless fleet, the lower these greenhouse gas emissions. In the short term, we expect the cost of greenhouse gas pollution[8] to increase to $51 million annually absent strong incentives for electric-vehicle deployment. In the longer term, if the entire autonomous fleet is private or ride-hailing conventional internal combustion engine vehicles, greenhouse gas emissions could cost as much as $381 million per year. Alternatively, electric and ride-pooling vehicles will reduce greenhouse gas emissions, with benefits of $988 million with 100% ride-sharing electric vehicle deployment.

[7] While the safety benefits of autonomous vehicles are often touted, some studies do cast doubt on these claims. A preliminary safety assessment in 2015 suggested that self-driving vehicles had a higher crash rare per million miles than conventional vehicles at the time of the study. See Schoettle, B. and Sivak, M. (2015). *A Preliminary Analysis of Real-World Crashes Involving Self-Driving Vehicles*. University of Michigan Transportation Research Institute. http://umich.edu/~umtriswt/PDF/UMTRI-2015-34.pdf. Some experts argue that human intervention will always be required due to safety shortcomings of autonomous vehicles. See Nunes, A., Reimer, B., and Coughlin, J. (2018). People must retain control of autonomous vehicles. *Nature*. https://www.nature.com/articles/d41586-018-04158-5.

[8] The cost of greenhouse gas emissions is based on the social cost of carbon, a widely used metric to quantify the impact of greenhouse gas pollution. It is a dollar amount that represents the damage of a ton of carbon dioxide or the benefit of a marginal reduction in carbon dioxide emissions. Developed by an intergovernmental panel and revised in 2016, it reflects a wide range of harms caused by greenhouse gas pollution, including human health, agricultural impacts, energy system costs, and more. See https://www.epa.gov/sites/production/files/2016-12/documents/sc_co2_tsd_august_2016.pdf.

Findings

Air pollution: Increases in mileage will also lead to more local and regional air pollution to the extent that the fleet is made up of petroleum-fueled internal combustion engine vehicles. In the near term, a 20% deployment of private, internal combustion engine vehicles will lead to costs of up to $60 million per year. At 100% penetration of self-driving cars, the economic costs of air pollution may be as high as $300 million for private vehicles.[9] However, electric and ride-pooling vehicles will both drive savings. For example, a fleet of entirely ride-pooling internal combustion engine vehicles could lead to a savings of $16 million. A 20% rollout of electric self-driving vehicles could lead to $169 million in economic benefits for the Commonwealth, thanks to lower air pollution. A 100% self-driving electric fleet may lead to benefits from reduced air pollution of as much as $845 million.

FISCAL IMPACTS ON MASSACHUSETTS

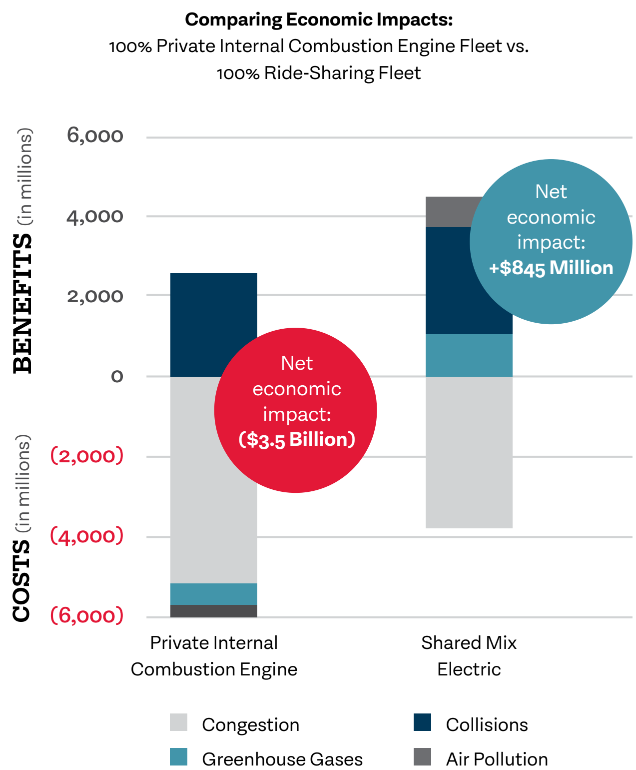
The state generated approximately $2.5 billion, or 7% of state spending, from motor vehicle-related revenues in 2015, as discussed in Section III. Based on our modeling, we anticipate the following possible budgetary effects of autonomous vehicle deployment on state revenue:[10]

Motor fuels taxes: As self-driving vehicles increase miles traveled, gas tax revenue is projected to increase by $42 million at 20% deployment and $191 million per year with a 100% autonomous vehicle fleet made up of either private vehicles, ride hailing, or a mix. While an increase in the portion of electric vehicles is enormously beneficial from an economic and environmental perspective, it reduces gas tax revenue. The larger the share of electric vehicles, the more this revenue will decline. However, a transition to electric vehicles will result in significantly larger economic benefits than fiscal revenue reductions, including fewer greenhouse gas emissions and reduced air pollution, and the state is already committed to exploring direct revenue replacement models.[11]

FIGURE 1.

Economic Impacts of Private Internal Combustion Engine vs. Ride-Sharing Electric Autonomous Vehicle Fleet

A deployment scenario with 100% ride-sharing, electric vehicles could drive net economic benefits of $845 million annually. The ride-sharing mix assumes 40% ride pooling and 60% ride hailing. These economic benefits far outweigh any state or local fiscal impacts. On the other hand, a deployment scenario with 100% private petroleum-fueled internal combustion engine vehicles would lead to economic costs of $3.5 billion annually.



[9] Based on the Addendum to the Federal Highway Cost Allocation Study Final Report (1997), Table 13. We estimate the economic cost of air pollution for motor vehicles, adjusted to 2015 dollars, at $0.021 per mile.

[10] Our analysis assumes that self-driving vehicles will deploy in our existing roadway infrastructure without major redevelopment to create driverless vehicle-friendly "smart roads," which is consistent with the way autonomous vehicles are currently being developed.

[11] See Transportation and Climate Initiative. (Nov. 2017). Joint Statement of Northeast and Mid-Atlantic States.

Sales and use tax: Sales and use taxes will increase in the short term by $142 million annually and increase over time, to as much as $777 million per year at full autonomous vehicle penetration of private vehicles. With higher levels of ride pooling and ride hailing and, as a result, lower levels of private car ownership, sales and use tax will decline. However, the shorter vehicle life in years of ride-sharing vehicles will somewhat mitigate the impact of fewer vehicles as they wear out more rapidly.

Toll receipts: As vehicle miles traveled increase with driverless car deployment, revenue from tolls will rise to $68 million per year, representing a 16% increase at 20% deployment, and $300 million, or 60%, annually at full deployment. Higher levels of ride pooling will dampen this increase, especially in urban areas where ride pooling likely will be more prevalent.

License, title, and registration fees: Overall, motor vehicle license, title, and registration fees will fall. Since drivers' licenses may not be necessary when vehicles are fully self-driving, license fees may drop significantly once 80% of vehicles are autonomous. Title fees and registration fees are dependent on the vehicle sales volume: They may go up if more cars are purchased as a result of increased demand for private driverless vehicles. However, these fees will fall if fewer private cars are purchased and riders choose ride-sharing.

Moving violations: Self-driving cars will reduce moving violation revenue as autonomous vehicles, unlike humans, likely will be programmed to obey the rules of the road. Even at early stages of autonomous vehicle deployment, moving violation revenue will drop by as much as $5 million per year, or 20%. At full penetration, self-driving cars will nearly eliminate moving violations, bringing revenues to close to $0.

Road maintenance: The economic cost of road maintenance from incremental miles traveled by self-driving cars is likely to increase. While the state and its municipalities spend well over $1 billion per year on road maintenance, a significant portion of that is caused by weather and age. A smaller amount is a result of incremental miles traveled. Our analysis estimates a range of $15 to $59 million in additional costs per year statewide upon the complete conversion to self-driving cars.[12]

FISCAL IMPACTS ON MUNICIPALITIES

The transition to autonomous vehicles will affect parking fees and excise tax revenue among other municipal revenue sources. In cities, our analysis suggests short-term losses from reduced parking fees as a result of autonomous vehicle deployment. In rural areas, our findings indicate a possible modest decrease in excise tax revenue.

It is important to note the potential for uneven fiscal impacts on different towns and cities. For example, if a company buys a fleet of autonomous vehicles to use for ride hailing, those vehicles may all be registered in one municipality, which will enjoy the benefit of the excise tax payment at the expense of other localities. These uneven distributional impacts are hard to predict but likely to occur.

Parking-related revenues: Our analysis suggests short-term losses from reduced parking fees, particularly in cities where such income can account for more than half of motor vehicle revenues. In Boston, for example, that will mean a loss of up to $17 million, or 12% of city motor vehicle revenues, at 20% self-driving penetration. Over a longer timeframe, cities likely will establish replacement revenue streams through redevelopment of parking areas.

In urban areas, 52% to 60% of motor vehicle-related revenues come from parking and parking violations. If self-driving cars circulate or return home rather than park, these parking-related revenues may disappear. After these revenues diminish, some parking garages could be redeveloped into larger office or residential towers. However, there will likely be a delay between the time when parking revenues diminish and redevelopment occurs.[13]

[12] Based on the Addendum to the Federal Highway Cost Allocation Study Final Report (1997), Table 13, Rate for autos on urban highways, adjusted to 2015 dollars we estimate the economic cost of road maintenance from incremental miles driven totals $0.0014 per mile.

[13] For example, there are currently proposals to redevelop garages in Dewey Square, Government Center, and other areas of Boston. However, the redevelopment process is slow and likely to lag behind the loss of parking revenues. In addition to the delay, there may be a budgetary mismatch: funds from higher property values may not be directed to the same budgetary needs as parking revenues were, especially in cities like Cambridge, where much of the parking revenue is directed specifically to the Traffic, Parking, and Transportation Department. Thus, even if city revenue grows over time with reinvestment, it will not provide one-to-one replacement, and there may still be specific budgetary gaps.

Findings

In suburban areas, parking revenues could potentially increase if commuters traveling in their self-driving vehicles from outlying communities into cities choose to have their vehicles park in lower-cost suburban parking lots during the work day instead of parking in costly downtown lots or returning all the way home. For rural areas and smaller cities, the fiscal impact will likely be lower because parking is a smaller revenue source, roughly 3% to 15% of motor vehicle-related revenues.

Excise taxes: For suburban and rural communities, the vehicle excise tax is a more significant source of revenue. The excise tax revenue may decline with changes in the vehicle fleet over time. Autonomous vehicles are expected to be about 15% more expensive than regular vehicles when widely deployed. As a result, excise tax revenue can be expected to get a slight lift. However, over a longer period, the additional cost of the self-driving feature is expected to decline significantly, nearly eliminating any price differential. At the same time, the percentage of self-driving vehicles used for ride pooling may increase, which is desirable from an economic and environmental perspective, but would lower excise tax revenue for municipalities by as much as 50% over time. The impact may be uneven across municipalities depending on where shared-vehicle fleets choose to register.

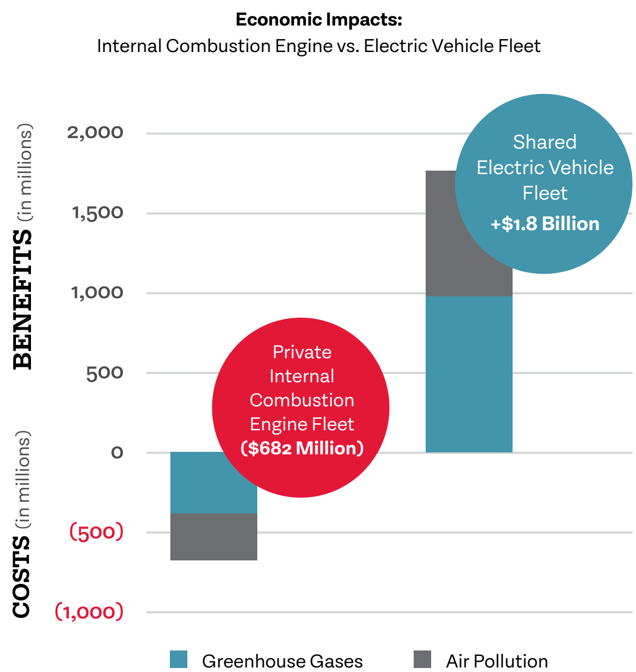
Moving violations: Even at early stages of autonomous vehicle deployment, moving violation revenue, which is shared between the state and municipalities, will go down by as much as $5 million per year at 20% penetration and largely disappear at 100% penetration.

Road maintenance: Municipalities will have to bear some minimally higher expenses from a portion of the increased road maintenance costs that come with increased vehicle miles traveled.

FIGURE 2.

Benefits of Electric Vehicles

Electric vehicles drive major economic benefits in the form of reduced greenhouse gas emissions and reduced local and regional air pollution. By contrast, internal combustion engines lead to significant economic costs. This figure reflects a 100% private self-driving fleet that is all internal combustion engines vs. a 100% ride-sharing self-driving fleet that is entirely electric vehicles (40% ride pooling and 60% ride hailing).



IMPACTS OF ELECTRIC AND RIDE-POOLING VEHICLES ON THE SELF-DRIVING VEHICLE FLEET

To leverage the most benefit from the transition to self-driving vehicles, the vehicles must be both ride pooling and electric.[14] Indeed, one without the other fails to comprehensively address the challenges of this new technology. If self-driving vehicles are electric but not ride-pooling, we reap some benefits of reduced pollution, but drivers will be mired in gridlock. If self-driving cars are ride-pooling but not electric, then pollution will rise dramatically.

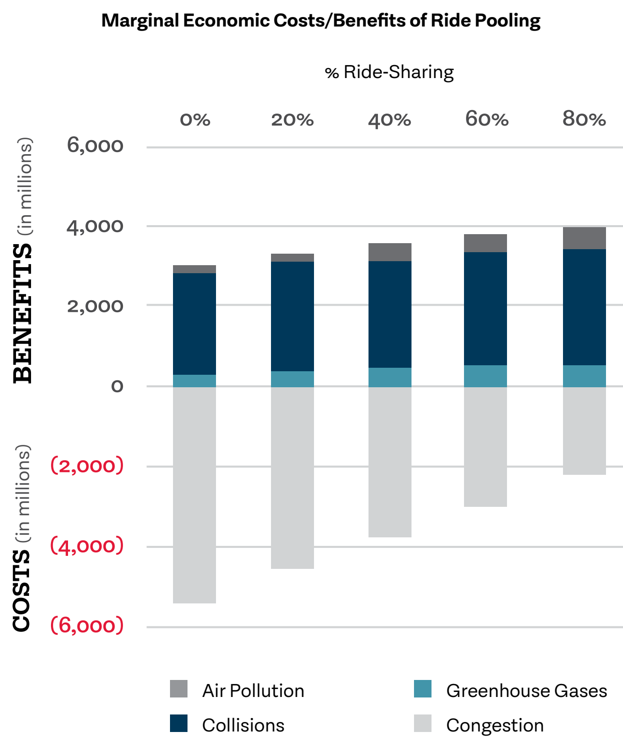
The economic benefits of electric vehicles outweigh their costs to state and local governments at all levels of deployment. Electric vehicles will drive enormous greenhouse gas reductions, avoiding almost a half-pound of carbon dioxide emissions per mile along with other air pollutants (see Figure 2). An all-electric autonomous vehicle fleet at 100% penetration likely will drive savings of $1.1 billion in reduced greenhouse gas emissions and $845 million in air pollution reductions. At the same time, since the vehicles do not require gasoline, electric vehicles will lower the state's gas tax revenue, which could be replaced with another revenue source. However, electric vehicles' purchase price may be somewhat higher, at least in early years of autonomous vehicle adoption, thereby increasing revenues from the sales and use tax and the excise tax.[15]

Higher levels of ride pooling will mitigate the mileage increase anticipated from autonomous vehicles. A fully ride-pooling vehicle fleet likely will add up to 15% to vehicle miles traveled, while an entirely private fleet is expected to lead to a 60% increase in vehicle miles, with associated economic costs of up to $3.5 billion annually.[16] Indeed, if the fleet is 100% ride-pooling vehicles, the savings are likely to total approximately 26 billion miles compared with a fully private vehicle fleet. High levels of sharing will also reduce the demand for parking.

FIGURE 3.

Economic Impact of Ride Pooling

This figure shows economic impact of an increasing percentage of ride pooling in a fully self-driving fleet. This scenario assumes 100% autonomous vehicle penetration with a 50% electric vehicle fleet. The relative costs of congestion will fall and the benefits in greenhouse gas, local and regional air pollution, and collisions will grow as ride pooling increases as a percent of the self-driving fleet.



[14] *See* Chase, R. (2014). Will a World of Driverless Cars be Heaven or Hell? *CityLab.* https://www.citylab.com/transportation/2014/04/will-world-driverless-cars-be-heaven-or-hell/8784/.

[15] While the purchase price of electric vehicles may be higher for now, price parity of cost of ownership is approaching rapidly. The purchase price is expected to reach parity in the coming years. See Fitzgerald, Garrett and Chris Nedler. (2017). *From Gas to Grid: Building Charging Infrastructure to Power Electric Vehicle Demand.* Rocky Mountain Institute. https://www.rmi.org/wp-content/uploads/2017/10/RMI-From-Gas-To-Grid.pdf

[16] For a fully ride-pooling fleet, the estimate of 15% additional miles includes the following factors: 12% latent demand, 24% induced demand, 25% empty miles, 34% fewer miles as a result of ride-sharing, and a 30% discount on mileage growth. For a fully ride-hailing fleet, we estimate 60% additional miles based on following factors: 12% latent demand, 24% induced demand, 25% empty miles, and a 30% discount on mileage growth. For a fully private vehicle fleet, we estimate 60% in additional miles based on: 12% latent demand, 24% induced demand, 25% empty miles, and a 30% discount on mileage growth. For more on our approach to modeling vehicle miles, including for ride-pooling vehicles, see Appendix B.

Findings

Even at high levels of ride pooling, the Commonwealth will experience negative congestion costs as a result of increased vehicle miles. Indeed, in a fully ride-pooling fleet, the congestion costs could still be high.[17] Given these challenging congestion impacts, the Commonwealth will need to take additional measures in conjunction with pooling to increase efficiency. This may require strict limits on empty vehicle miles without passengers,[18] incentivizing technological improvements in ride-sharing delivery, and investments in public transit options.

A ride-pooling fleet may also have important benefits for social equity, since shared services may allow lower-cost access to vehicles.[19] Ride pooling could, for example, integrate with public transit to facilitate transportation for people who cannot afford private vehicles.

To leverage the most benefit from the transition to self-driving vehicles, the vehicles must be both ride-pooling and electric. One without the other fails to comprehensively address the challenges of this new technology.

[17] For example, a fleet with 80% ride-pooling vehicles could still face congestion costs of $2 billion each year. See Appendix A.

[18] If ride-pooling vehicles run empty only 10% of the time, then mileage would not increase. As a result, there would be a positive economic impact from congestion.

[19] *See, e.g.,* Hahn, R. and Metcalfe, R. (2017). The Ridesharing Revolution: Economic Survey and Synthesis. *More Equal by Design: Economic Design Responses to Inequality*. Washington, DC: Brookings. https://www.brookings.edu/wp-content/uploads/2017/01/ridesharing-oup-1117-v6-brookings1.pdf; DeGood, K. and Schwartz, A. (2016). *Can New Transportation Technology Improve Equity and Access to Opportunity?* Center for American Progress. https://www.scribd.com/document/309877442/Can-New-Transportation-Technologi-Improve-Equity-and-Access-to-Opportunity.

III. The Current Economic and Fiscal Picture

ECONOMIC BASELINE

To assess the economic impacts of autonomous vehicle deployment, our analysis establishes the incremental costs of congestion, greenhouse gas emissions, local and regional air pollution, and collisions using data from the U.S. Department of Transportation and other government sources.[20]

In 2014, drivers on Massachusetts roads traveled more than 50 billion miles.[21] According to the 2015 Mobility Scorecard, Greater Boston is the sixth most congested region in the country, based on the number of extra hours of driving due to congestion.[22] The incremental cost of this congestion is $0.13 per mile. These miles driven contribute about 21 million tons of greenhouse gas emissions each year, which result in $740 million in costs.[23] It also results in approximately $1 billion in local and regional air pollution costs annually.[24]

At 50 billion miles driven per year, collisions have an economic cost for the Commonwealth of approximately $6.3 billion annually.[25] These economic costs include medical and emergency services costs, property damage, legal costs, productivity losses, and congestion costs.[26] As vehicle safety features improve over time, even without autonomous vehicle deployment, collision costs will fall to $4.4 billion in total expected costs by 2035.

[20] For incremental costs of congestion and air pollution, see Federal Highway Administration. (2000). Addendum to 1997 Federal Highway Cost Allocation Study Final Report, Table 13, updated to 2015 using the Consumer Price Index. The congestion costs were adjusted upwards for the median income in Massachusetts relative to the median income in the U.S. using the U.S. Census Bureau's Current Population Survey, Annual Social and Economic Supplements, Table H8, Median Household Income by State. The incremental cost of carbon was calculated from the following sources. For light vehicle fuel efficiency data, see EIA. (2017). *Annual Energy Outlook 2017,* Tested new vehicle fuel efficiency, revised for on road performance. For the social cost of carbon, see Interagency Working Group on Social Cost of Greenhouse Cases. (2016, August). *Technical Support Document: Technical Update on the Social Cost of Carbon for Regulatory Analysis under Executive Order 12866,* using 2045 value and a 3% discount rate for a cost of $64 per ton. Carbon dioxide emissions per gallon of gasoline equals 18.9 pounds per gallon (adjusted for ethanol content). Air pollution impacts were adjusted downward for the improvement in fuel efficiency from New On-Road Light Duty Vehicles, from 25 MPG in 2015 to 35.5 MPG after 2035. Estimated future emissions from electric vehicles equals 0.28 kWh per mile. Carbon intensity of the ISO New England system in 2030 comes from ISO New England's Planning Advisory Committee and represents the Average of Scenario 1 and 3 from 2016 Economic Studies. See Henderson, M. (2016). *2016 Economic Studies Executive Summary Supplement.* ISO New England Planning Advisory Committee. 10. https://www.iso-ne.com/static-assets/documents/2016/12/a9_1_2016_economic_study_executive_summary_and_metrics_update.pdf.

[21] Annualized mileage from Metropolitan Area Planning Council (MAPC). (2017). *Massachusetts Vehicle Census 2009-2014.* trans_mavc_public_summary_ma.zip. The U.S. Department of Transportation estimated Massachusetts Vehicle Miles Traveled of 54.4 billion in 2010. U.S. Department of Transportation Federal Highway Administration (2005, 2010). *Highway Statistics,* VM-2. http://www.fhwa.dot.gov/policyinformation/statistics.cfm.

[22] *See* Schrank, D., Eisele, B., Lomax, T., and Bak, J. (2015). *2015 Urban Mobility Scorecard.* Texas A&M Transportation Institute. https://static.tti.tamu.edu/tti.tamu.edu/documents/mobility-scorecard-2015.pdf.

[23] As noted above, the social cost of carbon is a widely used metric to quantify the impact of greenhouse gas pollution. See https://www.epa.gov/sites/production/files/2016-12/documents/sc_co2_tsd_august_2016.pdf. Here, the cost of carbon is generated using Federal Highway Administration data on mileage and carbon emissions and the Technical Update on the Social Cost of Carbon, using 2015 value and a 3% discount rate for a cost of $36 per ton. The miles driven and fuel efficiency data come from the MAPC Vehicle Census, Fourth Quarter 2014. See https://www.mapc.org/learn/data; see also Interagency Working Group on Social Cost of Greenhouse Cases. (2016, August). Technical Support Document: Technical Update on the Social Cost of Carbon for Regulatory Analysis under Executive Order 12866.

[24] We assume that the air pollution impact per base mile is equal to the air pollution impact per marginal mile. U.S. Department of Transportation Federal Highway Administration. (2000, May). *Addendum to the 1997 Federal Highway Cost Allocation Study Final Report.* Table 13, updated to 2015 using the Consumer Price Index.

[25] Blincoe, L. J., Miller, T. R., Zaloshnja, E., & Lawrence, B. A. (2015). *The Economic and Societal Impact of Crashes, 2010.* National Highway Traffic Safety Administration Report No. DOT HS 812 013, 145, adjusted for the Consumer Price Index increase from 2010 to 2015.

[26] This does not include impacts on the quality of life of crash victims.

FISCAL BASELINE

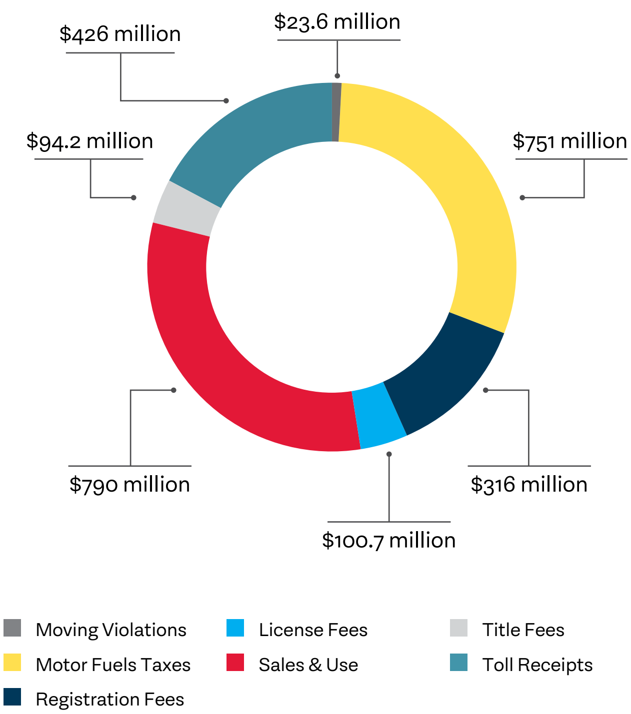
Massachusetts and its local governments will confront changes in revenues as self-driving vehicles arrive. The Commonwealth's motor vehicle-related revenues—approximately $2.5 billion annually—faces disruption, as discussed in Section II. Cities and towns will see changes to revenues of $784 million in excise taxes alone, in addition to changes in parking fees and other motor vehicle revenues.

To assess the fiscal impacts of the advent of autonomous vehicles on the Commonwealth, this report analyzes the key sources of state and municipal funding related to motor vehicles (see Figure 4). State motor vehicle-related revenues amounted to $2.5 billion in 2015, just under 7% of the state's spending.[27] These revenues include funds from moving violations, motor fuels taxes, registration fees, license fees, sales and use taxes, title fees, and toll receipts.[28]

At the municipal level, motor vehicle-related revenues largely come from parking and excise tax revenues. Across the Commonwealth, excise taxes alone totaled $784 million in 2015.[29] To establish a baseline for municipal motor vehicle-related revenues, our analysis reviews revenue in the 10 following cities and towns: Boston, Cambridge, Fitchburg, New Bedford, Pittsfield, Plymouth, Sherborn, Somerville, Springfield, and Worcester. These municipalities represent a mix of rural, suburban, and urban communities; a range in population size from 4,000 to 673,000; and different regions of the Commonwealth. For a map of the municipalities, see Appendix B.

Local motor vehicle revenues range from $129 million in Boston, mostly from parking fees and fines, to approximately $1 million in Sherborn, primarily from excise taxes. In Boston, Cambridge, and Somerville, the local motor vehicle-related revenues range from 3% to 8% of city revenues. In smaller municipalities, motor vehicle-related revenues range from 1.5% to 5% of town revenues, with the vast majority coming from the excise tax (see Table 1).

FIGURE 4.
State Revenues from Motor Vehicles in FY 2015



[27] We excluded some minor revenue sources, which represent about 5% of state revenues from vehicles, or roughly 0.35% of the annual state budget, because we could not easily estimate the impact of autonomous vehicles on these revenues. The following minimal motor vehicle-related revenue sources are excluded: parking ticket surcharges, Motor Vehicles Inspection Trust Fund revenue, motor vehicle inspection fees paid to the state, and citable motor vehicle inspection collections and registry fees. Registration fees are included. Collectively, these excluded fees totaled $113 million in fiscal 2015. Massachusetts Bay Transportation Authority (MBTA) and Massport parking revenues were also excluded.

[28] For state gas tax, see Schoenberg, S. (2016, July 30). How much does Massachusetts get from the state gas tax? *Mass Live.* http://www.masslive.com/politics/index.ssf/2016/07/massachusetts_motor_fuels_tax.html. For toll revenues and moving violations, see Massachusetts Department of Transportation. (2017). Financial Information. https://www.massdot.state.ma.us/InformationCenter/Financials/FinancialInformation.aspx. For parking ticket surcharges, see Baxandall, P. (2017). *What Does Massachusetts Transportation Funding Support and What Are the Revenue Sources.* Massachusetts Budget and Policy Center. http://www.massbudget.org/report_window.php?loc=What-Does-MA-Transportation-Funding-Support.html. For Motor Vehicle Trust Fund revenue, see Transportation Finance Research Collaborative. (2013). *Transportation Revenue Options Handbook.* http://www.northeastern.edu/dukakiscenter/wp-content/uploads/2015/06/Vehicle-Inspection-Fee.pdf. For excise taxes, see Massachusetts Department of Revenue. (2016). *FY2015 Annual Report.* http://www.mass.gov/dor/docs/dor/publ/annualreport15/i-ar2015.pdf.

[29] Please note that "2015" refers to Fiscal Year 2015 throughout the report.

TABLE 1.

Municipal Revenues from Motor Vehicles

Municipal motor vehicle-related revenues, which make up roughly 1.5% to 8% of total local budgets, come largely from excise tax revenue.

Municipality	Motor Vehicle-related Revenues $ Millions (% of Municipal Budgets)	% of Revenues from Excise Taxes
Boston	$129 (4.8%)	41%
Cambridge	$28 (3.2%)	25%
Fitchburg	$4 (3.5%)	91%
New Bedford	$9 (3%)	85%
Pittsfield	$5 (3.3%)	94%
Plymouth	$9 (5.1%)	84%
Sherborn	$1 (2.8%)	82%
Somerville	$15 (8%)	40%
Springfield	$13 (1.5%)	79%
Worcester	$15 (2.5%)	97%

Excise tax revenues make up **1.2% – 4%** of total local budgets

IV. Key Metrics

Our analysis relies on a set of metrics to determine the economic and fiscal impacts of self-driving vehicles. The metrics include the size of the self-driving car population, the increases in miles traveled by self-driving cars, the age and value of cars, the structure of fees and taxes on vehicles, the economic cost of congestion, air pollution, and the social cost of carbon generated, and the impact of fuel efficiency and electric cars on motor fuels taxes. A detailed description of the methodology is available in Appendix B.

Timing of autonomous vehicle deployment. There is some uncertainty about how quickly the fleet will transition to autonomous vehicles. The most aggressive expert estimates expect self-driving cars to fully deploy by 2030, while more conservative estimates assume that complete conversion will take until the 2050s to 2060s.[30] The pace of penetration will depend on how quickly the current fleet of non-self-driving cars retires. In this analysis, we expect fully featured self-driving cars[31] to be available by the mid-2020s.

Increase in vehicle miles traveled. The number of miles driven will heavily affect both revenues and economic costs. Based on the following factors, including empty vehicle miles, latent and induced demand, and efficiency improvements, we anticipate an 11% increase in vehicle miles traveled at 20% driverless vehicle penetration with an entirely private fleet, and a 60% increase in vehicle miles traveled at 100% driverless penetration with a private fleet.[32]

Photo credit: Pgiam, istockphoto.com

- ***Empty vehicle miles:*** Self-driving cars are likely to drive a significant portion of their miles empty, without passengers. The reasons for these empty miles include private self-driving cars that may return home empty from commuting trips or circle the block after dropping off a passenger, ride-hailing services that may need to reposition vehicles, and cars that need to travel to refuel or recharge. Studies of the use of Uber and Lyft in several cities indicate that ride-hailing vehicles drive empty, without a passenger, 36% to 49% of the time.[33] To be conservative, our analysis assumes a more modest empty driving rate of 25% for private and ride-hailing vehicles.[34] The rate of empty travel will be lower for ride-pooling vehicles.[35]

[30] The most aggressive estimate comes from a 2017 report that projects that 95% of vehicle miles will be driven by self-driving vehicles by 2030. *See* Arbib, J. and Seba, T. (2017). *Rethinking Transportation 2020-2030.* https://static1.squarespace.com/static/585c3439be65942f022bbf9b/t/591a2e4be6f2e1c13df930c5/1494888038959/RethinkX+Report_051517.pdf?pdf=RethinkingTransportation/. *See* also Seba, T. (2014). *Clean Disruption of Energy and Transportation.* https://tonyseba.com/portfolio-item/clean-disruption-of-energy-transportation/. Another study projects that 25-87% of vehicles will be Level 4 Autonomous Vehicles by 2045. *See* Kockelman, K. et al. (2016). *Implications of Connected and Automated Vehicles on the Safety and Operations of Roadway Networks: A Final Report.* University of Texas Center for Transportation Research. https://library.ctr.utexas.edu/ctr-publications/0-6849-1.pdf. A final study projects full penetration in the 2050s or 2060s. *See* Litman, T. (2017). *Autonomous Vehicle Implementation Predictions, Implications for Transportation Planning. Victoria Transport Policy Institute.* https://www.vtpi.org/avip.pdf.

[31] Self-driving vehicles at Level 4 or 5, according to SAE International. See SAE Automation Levels at http://www.sae.org/misc/pdfs/automated_driving.pdf.

[32] A recent behavioral experiment gave 13 subjects access to a chauffeured vehicle to test possible user response to private autonomous vehicles. The study found a 76% increase in vehicle miles, with 22% empty miles and a 94% increase in longer trips of more than 20 miles. While it was a small sample, it corroborates the widely held expectation that vehicle miles are likely to increase. See Walker, J. (2017). The Traffic Jam of Robots: Implications of Autonomous Vehicles for Trip-Making and Society. Presentation for ASILOMAR 16th Biennial Conference on Transportation and Energy. Slide 14.https://its.ucdavis.edu/wp-content/uploads/S3-3-Joan-Walker.pdf.

- ***Latent demand:*** Self-driving cars will enable many who cannot drive, including the young, the elderly, and people with disabilities, to use a car. This will result in an estimated 12% increase in miles driven.[36]

- ***Induced demand:*** The number of miles traveled is projected to increase as consumers are able to use their time in motor vehicles for other tasks, enabling them to travel further and take trips they would otherwise avoid.[37] Our analysis estimates a 24% increase in mileage for private and shared self-driving cars.[38]

- ***Vehicles miles saved through ride pooling:*** Wide adoption of ride-pooling services, like UberPool, Lyft Line, and Waze Carpool may reduce vehicle miles traveled. This analysis estimates that ride pooling saves about 36% of vehicle miles traveled.[39]

Changes to vehicle fleet. The characteristics of the vehicle fleet, including its size, vehicle age, new sales of vehicles, and the price of those vehicles, will affect vehicle sales and excise taxes as well as title and registration fees.

- ***Lower life for ride-sharing fleet:*** For shared vehicles, the size of the car fleet will be smaller, and the average life of cars will be lower. The average life of shared vehicles may drop to an estimated 6.8 years because cars will drive more miles each day, which leads to higher fleet turnover.[40] Our analysis suggests that, if the entire vehicle fleet is made up of ride-pooling vehicles, the fleet size in the Commonwealth may drop by 83%.[41]

The number of miles driven is expected to rise, and it will significantly affect both revenues and economic costs.

[33] Traditional taxis may circulate empty, without a passenger, at even higher rates than these ride hailing companies. In fact, a study found that taxis in Boston are empty approximately 63 to 75% of the time. See Cramer, J. and Krueger, A. (2016). Disruptive Change in the Taxi Business: The Case of Uber. *American Economic Review,* 106(5): 177-182. http://www.nber.org/papers/w22083; Nelson\Nygaard. (2013). *Taxi Consultant Report.* City of Boston. ES-8. http://www.cityofboston.gov/mayor/pdfs/bostaxiconsultant.pdf; Schaller, B. (2017). *Unsustainable? The Growth of App-Based Ride Services and Traffic, Travel and the Future of New York City.* http://www.schallerconsult.com/rideservices/unsustainable.pdf.

[34] This estimate, based on several studies, represents a mid-point between the optimized and observed empty miles for fleets. See Appendix B for more details.

[35] It is important to note that, across the entire vehicle fleet, some empty vehicle miles may serve to reduce overall vehicle miles traveled. For example, if a grocery delivery truck serves many customers in a neighborhood, that vehicle's empty miles could offset the individual trips that each household would make to the grocery store. Our report reflects this by selecting a conservative empty vehicle miles traveled estimate. See International Transport Forum. (2015). *Urban Mobility System Upgrade: How shared self-driving cars could change city traffic.* https://www.itf-oecd.org/sites/default/files/docs/15cpb_self-drivingcars.pdf.

[36] *See* Harper, C., Hendrickson, C., Mangones, S., and Samaras, C. (2016). Estimating Potential Increases in Travel with Autonomous Vehicles For the Non-Driving, Elderly and People With Travel-Restrictive Medical Conditions. *Transportation Research Part C: Emerging Technologies* 72: 1-9. http://www.sciencedirect.com/science/article/pii/S0968090X16301590; Schoettle, B. and Sivak, M. (2015). *Influence of Current Nondrivers on the Amount of Travel and Trip Patterns with Self-Driving Vehicles.* University of Michigan Transportation Research Institute. http://www.umich.edu/~umtriswt/PDF/UMTRI-2015-39.pdf.

[37] *Id.*

[38] This figure represents the mid-point of a number of academic studies. These estimates come from a number of studies including: 20% (Childress, S., Nichols, B., Charlton, B., and Coe, S. (2015). *Using an Activity-Based Model to Explore Possible Impacts of Automated Vehicles. Presentation, Transportation Research Board 94th Annual Meeting.* https://psrc.github.io/attachments/2014/TRB-2015-Automated-Vehicles-Rev2.pdf), 24% (Kim, K., Rousseau, G., Freedman, J. and Nicholson, J. (2015). *The Travel Impacts of Autonomous Vehicles in Metro Atlanta through Activity-Based Modeling.* http://slideplayer.com/slide/5267202/), 26% (Fagnant and Kockelman [2015]), and a range of 18-41% (Zhao and Kockelman [2017]).

[39] Theoretically, ride sharing could save 50%; however, not all rides will have the same starting point and destination and not all rides will have multiple groups of passengers. See Chen, T., Kockelman, K. and Hanna, J. (2016). *Operations of a Shared, Autonomous Electric Vehicle Fleet: Implications of Vehicle & Charging Infrastructure Decisions. Presentation, Transportation Research Board 95th Annual Meeting.* http://www.ce.utexas.edu/prof/kockelman/public_html/TRB16SAEVs100mi.pdf.

[40] We assume that ride-sharing vehicles drive about 70,000 miles per year (3500 hours at 20 miles per hour based on the life of New York City taxis and a number of studies). In contrast, the average privately owned passenger vehicle in Massachusetts lasts more than 18 years and traveled 10,500 miles in 2014. See Schoettle and Sivak (2015), Chen et al. (2016), and Fulton, L., Mason, J. and Meroux, D. (2017). *Three Revolutions in Urban Transportation.* Institute for Transportation & Development Policy and the Institute of Transportation Studies at UC Davis. https://www.itdp.org/3rs-in-urban-transport/; MAPC Vehicle Census.

[41] Chen et al. (2016).

Key Metrics

- ***Reductions in excise tax income:*** The age of cars is important because excise taxes are much higher for new cars in Massachusetts. Excise taxes are assessed based on 90% of the car's list price in the year of manufacture and only 10% of the car's original list price by the fifth and subsequent years.[42] Because the average car lasts 18 years in Massachusetts,[43] most autos are taxed at 10% of the original list price. With shorter lives, shared autonomous vehicles will incur higher taxes, though the population of cars will be smaller if most autonomous vehicles are ride pooling or, to a lesser extent, ride hailing. The net impact will be to lower excise taxes.

- ***Possible increase in private vehicles:*** For private autonomous vehicles, the fleet size may actually increase by as much as 12%, or 554,000 vehicles, because of people who previously could not drive, including the young, the elderly, and disabled people.[44]

- ***Increased vehicle costs:*** Self-driving software and hardware will add to the cost of new vehicles. This analysis assumes that the cost will be 15% higher, which adds to vehicle excise taxes.[45]

Collision costs. Collision costs totaled $5.5 billion per year in 2015, excluding congestion,[46] and are projected to be $3.4 billion in 2050. Experts estimate that more than 90% of crashes result from human error, much of which can be avoided by autonomous vehicle technology.[47] However, it is unlikely that self-driving cars will completely eliminate all crashes. First, increased vehicle miles traveled may moderate collision reductions. Second, the software in self-driving cars may introduce new causes of crashes. In addition, in the early years of self-driving car deployment, interactions between self-driving cars and human-controlled vehicles may actually increase collision levels.[48] For our analysis, we assume that autonomous vehicle technology will lead to a 75% reduction in collisions at full deployment.

Efficiency improvements. Autonomous vehicles will operate more efficiently than human drivers, which will mitigate the increase in miles traveled to some extent. This efficient driving is likely to generate a 15% reduction in per-mile fuel consumption for internal combustion self-driving cars from improved acceleration and braking.[49] The efficiency savings will lower carbon and air pollutants from internal combustion engine vehicles.

[42] MASS. GEN. LAWS c. 60A.

[43] MAPC Vehicle Census (2014).

[44] The size of a private self-driving car fleet will depend on whether self-driving cars return home empty after commutes. About 20% of vehicle miles traveled are used to commute and the average household had 1.69 vehicles. If heavily used to return home, autonomous vehicles could reduce the size of the automobile fleet by the size of the fleet could decline by approximately 25% (assuming that 75% of households with more than one vehicle give up the extra vehicle, and assuming that latent demand leads to addition vehicles. See Schoettle and Siva (2015); Harper et al. (2016).

[45] *See* Lang, N., Ruemann, M., Mei-Pochtler, A., Dauner, T., Komiya, S., Mosquet, X., and Doubara, X. (2015). Self-Driving Vehicles, Robo-Taxis, and the Urban Mobility Revolution. BCG Perspectives. https://www.bcgperspectives.com/content/articles/automotive-public-sector-self-driving-vehicles-robo-taxis-urban-mobility-revolution/; Burns, L., Jordan, W., and Scarborough, B. (2013). *Transforming Personal Mobility.* The Earth Institute, Columbia University. http://sustainablemobility.ei.columbia.edu/files/2012/12/Transforming-Personal-Mobility-Jan-27-20132.pdf; Fulton et al., (2017).

[46] Blincoe et al. (2015), 145, adjusted downward by 12% for congestions impacts, which are estimated separately in our analysis and upward by the Consumer Price Index increase from 2010 to 2015.

[47] KPMG. (2015). *Self-Driving Cars,* the Next Revolution, 7. https://assets.kpmg.com/content/dam/kpmg/pdf/2015/10/self-driving-cars-next-revolution_new.pdf.

[48] *See,* e.g., Sivak, M. and Schoettle, B. (2015). *Road Safety with Self-Driving Vehicles: General Limitations and Road Sharing With Conventional Vehicles.* University of Michigan Transportation Research Institute. https://deepblue.lib.umich.edu/bitstream/handle/2027.42/111735/103187.pdf?sequence=1&isAllowed=y.

[49] This estimate is drawn from several studies. Barcham, R. (2014). *Climate and Energy Impacts of Automated Vehicles.* Prepared for the California Air Resources Board. https://www.arb.ca.gov/research/sustainable/automated_vehicles_climate_july2014_final1.pdf; Lovejoy, K. and Handy, S. (2013). *Impacts of Eco-driving on Passenger Vehicle Use and Greenhouse Gas Emissions.* Prepared for the California Air Resources Board. https://www.arb.ca.gov/cc/sb375/policies/ecodriving/ecodriving_bkgd.pdf; Brown, A., Repac, B., and Gonfer, J. (2013). *Autonomous Vehicles Have a Wide Range of Possible Energy Impacts.* National Renewable Energy Laboratory. https://www.nrel.gov/docs/fy13osti/59210.pdf.

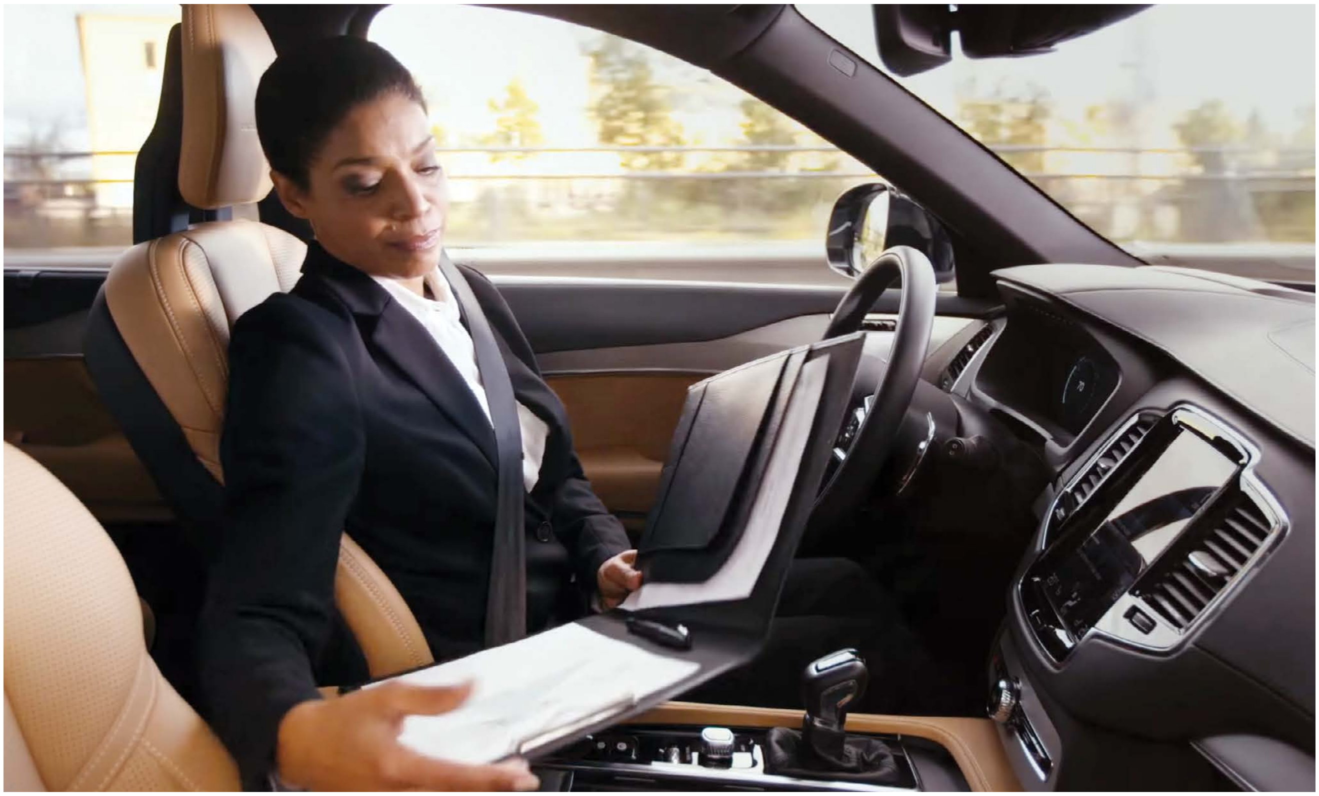


Photo credit: Volvo

Independent impacts of expected increases in fuel efficiency and vehicle safety. Improvements in vehicle fleet fuel efficiency and safety are expected to take place even in the absence of autonomous vehicles. These changes will reduce greenhouse gas emissions by 32%, improve vehicle safety by 30%, and reduce gas tax revenue by 32%.[50] At the same time, there will be modest increases in the number of vehicles and vehicle miles traveled, with miles traveled growing by about 11%. Our model incorporates and controls for these anticipated changes, which are attributable to continuous technological improvement and existing regulations, not specifically to autonomous vehicle deployment.

Existing policy and infrastructure landscape. The modeling assumes existing state laws remain in place, including improving fuel efficiency standards[51] and greenhouse gas reduction goals under the Global Warming Solutions Act.[52] It also assumes that self-driving vehicles will deploy in our existing roadway infrastructure without major redevelopment to create driverless-vehicle-friendly "smart roads" that could, for example, communicate with vehicles. This assumption is consistent with the way autonomous vehicles are currently being developed.

[50] Because safety features in cars are improving, we estimate that if current trends continue, the economic impact of collisions would likely by about 30% lower by 2035 even in the absence of full self-driving features.

[51] *See* 310 MASS. CODE REGS. 60.00 *et seq.*

[52] MASS. GEN. LAWS Ch. 21 §3. The modeling does not include state goals for Zero Emissions Vehicle investment in its baseline as it is not codified in statute, as we instead modeled a range of EV deployment levels. See ZEV Program Implementation Task Force. (2014). *Multi-State ZEV Action Plan.* www.nescaum.org/topics/zero-emission-vehicles/multi-state-zev-action-plan/.

V. Scenarios

Given the uncertainty about how and at what rate self-driving cars will deploy in Massachusetts, this analysis models a range of possible scenarios to estimate their economic and fiscal impacts. The findings, presented in Section II, indicate that the enormous economic benefits from a fleet that is largely ride-pooling and electric will likely far outweigh any costs of the transition to driverless vehicles. Despite this positive net impact, when reviewing these scenarios, it is not advisable to focus on the total benefits or costs, as few people would fully appreciate the safety benefits, for example, if they were constantly stuck in traffic. Instead, the range of deployment scenarios modeled in the report is meant to encourage policymakers to consider carefully how to maximize each specific benefit or mitigate each harm across the scope of impacts, from municipal revenues to air pollution.

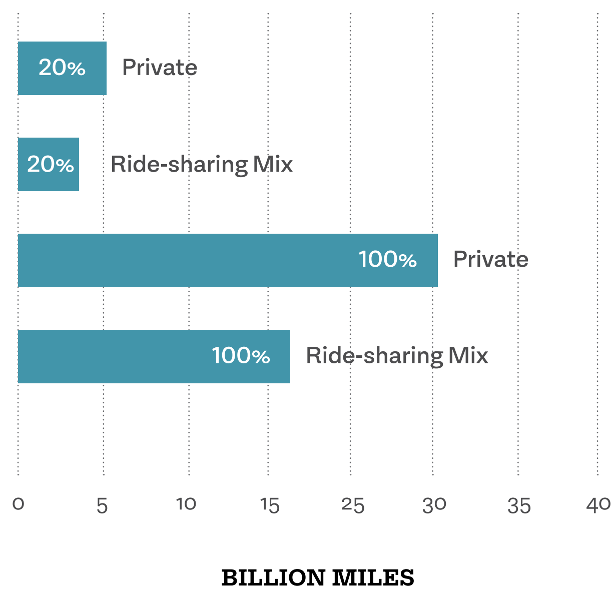
The analysis presents a range of possible scenarios based on the following factors:

The penetration of self-driving vehicles over time. This analysis maps different versions of the relative mix of autonomous vs. conventional vehicles on the road to determine the impact of self-driving cars at varying levels of deployment. For these purposes, we estimate the impacts at 20%, 50%, 80%, and 100% autonomous vehicle deployment. See Appendix A for full results at these levels.

The percentage of self-driving vehicles that are private, ride hailing, and ride pooling. The model analyzes private, ride-hailing, and ride-pooling uses, as well as a ride-sharing mix of 40% ride pooling and 60% ride hailing.

The percentage of electric vehicles. The model estimates the impact of varying proportions of self-driving electric vehicles. Currently, the Commonwealth has a goal of 15% Zero Emissions Vehicles, which includes electric vehicles, by 2030.[53] While Massachusetts is working to incentivize adoption of electric vehicles in the fleet, there is no technological necessity or policy requirement for the autonomous vehicle fleet to be electric. Self-driving vehicles are currently being tested on both petroleum-fueled internal combustion engine and electric platforms, and we cannot assume that a high percentage of the autonomous vehicle fleet will be electric absent continued policy incentives or requirements.

FIGURE 5.
Additional Annual Billion Miles Traveled



[53] *See* Massachusetts Zero Emission Vehicle Commission, https://www.mass.gov/service-details/zero-emission-vehicle-zev-commission.

The following figures present some of the key results of the modeling of a range of scenarios, based on the assumptions contained in the metrics described in Section IV.

Figures 6 through 8 show the economic impacts of a private, ride-sharing electric autonomous vehicle fleet. Figures 9 through 12 show the fiscal impacts of that same set of scenarios. In these figures, 20% autonomous vehicle deployment represents near-term impacts, and 100% autonomous vehicle penetration reflects longer-term impacts.

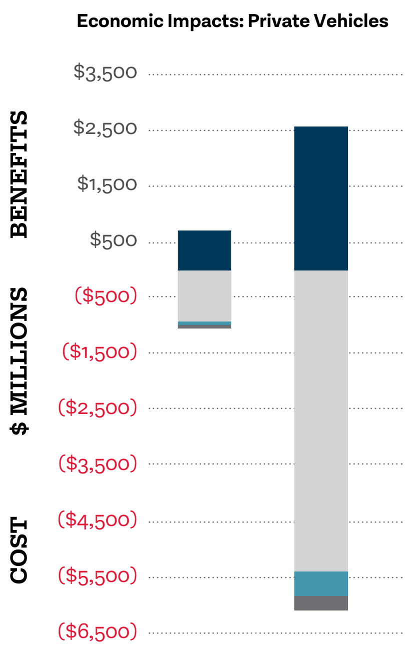
Findings for 50% and 80% penetration are available in Appendix A.

The key outcomes of these results are discussed in the Findings in Section II. It's important to note that we can put smart policies in place to capture the benefits we seek in the transition to driverless vehicles while thinking ahead to mitigate impacts on state and municipal budgets.

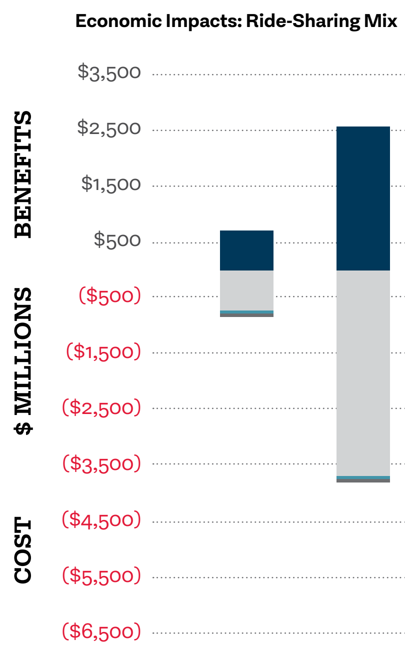
FIGURES 6–8.

Economic Impact of Deployment Scenarios

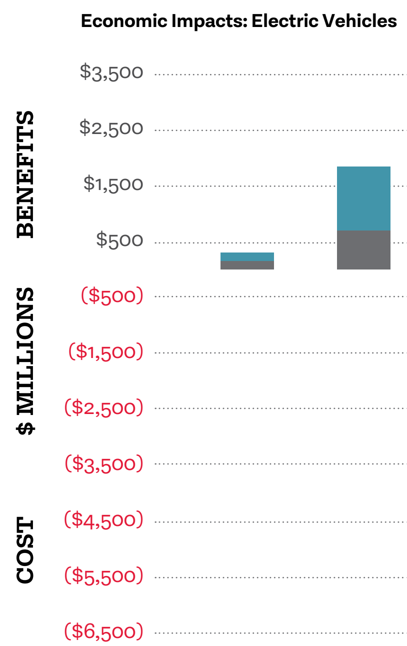
These figures show the marginal economic impact of private, ride-sharing, and electric vehicles at 20% and 100% autonomous vehicle penetration. The ride-sharing mix assumes 40% ride pooling and 60% ride hailing.



	20% Penetration of Private	100% Penetration of Private
Air Pollution	($60)	($300)
Collisions	$618	$2551
GHGs	($51)	($381)
Congestion	($984)	($5382)



	20% Penetration of Ride Sharing	100% Penetration of Ride Sharing
Air Pollution	($35)	($174)
Collisions	$695	$2870
GHGs	($30)	($221)
Congestion	($693)	($3793)



	20% Penetration of Electric	100% Penetration of Electric
GHGs	$140	$1050
Air Pollution	$169	$845

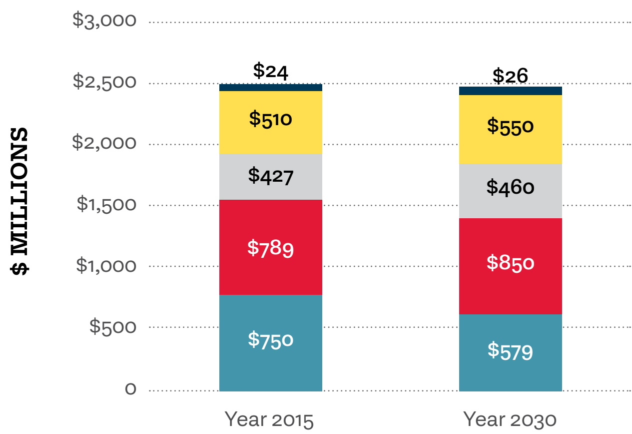
Scenarios

FIGURES 9–12.

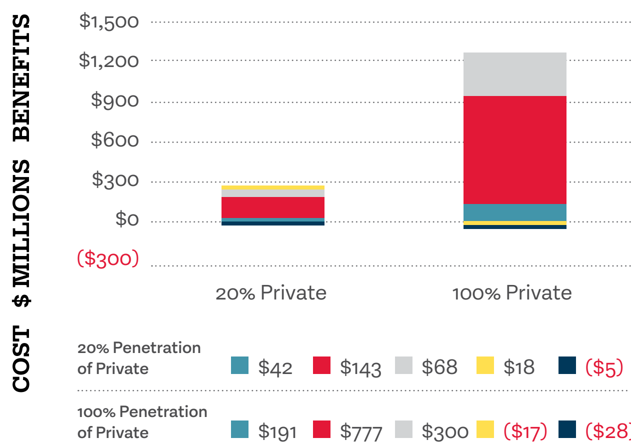
Fiscal Impacts of Deployment Scenarios

These figures show the total fiscal impacts of private, ride-sharing, and electric vehicles at 20% and 100% autonomous vehicle penetration compared with baseline projections for the existing vehicle fleet. The ride-sharing mix assumes 40% ride pooling and 60% ride hailing.

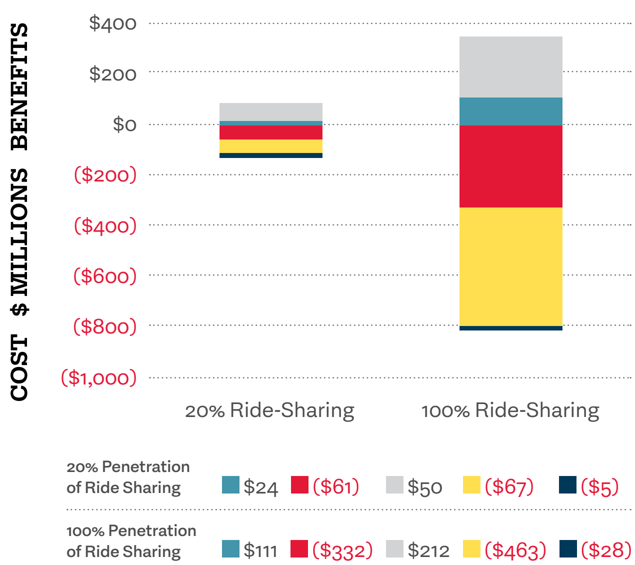
Fiscal Impacts: Baseline, 2015 and 2030



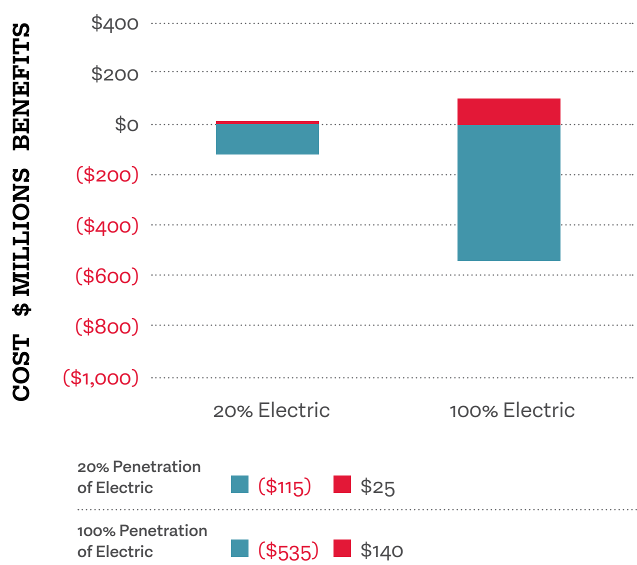
Fiscal Impacts: Private Vehicles



Fiscal Impacts: Ride-Sharing Mix



Fiscal Impacts: Electric Vehicles



Fuel Tax | Sales & Use Tax | Toll Receipts | Motor Vehicle Fees | Moving Violations

VI. Policy Recommendations

Massachusetts has the opportunity to adopt forward-thinking policies to maximize the benefits of the transition to autonomous vehicles, while mitigating some of the drawbacks. With the right policies in place, electric and ride-pooling vehicles can become the norm in the autonomous vehicle fleet. We can avoid tradeoffs between positive economic and negative fiscal impacts with good polices.

It is important to consider the sequencing of this series of policy principles. For example, with more electric vehicles on the roads, we will need to determine how best to supplement gas tax revenues. As parking revenues fall in municipalities, we must address the time lag between that decline and potential new revenue streams from the redevelopment of parking garages. As autonomous vehicles deploy across the state, it will be critical to have a policy framework in place to limit empty vehicle miles and support ride pooling to avoid immediate negative impacts of congestion.

The following principles can help the Commonwealth manage the advent of driverless vehicles in a sensible way.

Zero emissions vehicles. With the rollout of autonomous vehicles and increased miles traveled, the Commonwealth will face increased greenhouse gas emissions, air pollution, and its attendant health impacts. Electric vehicles will mitigate these harms. The Commonwealth has worked to incentivize Zero Emissions Vehicles in law. It should continue these efforts and put additional mechanisms in place to incentivize electric vehicles as the fleet transitions to autonomous vehicles.

Ride pooling. To leverage the potential efficiencies of autonomous vehicles, the Commonwealth must incentivize ride pooling. This type of service, as currently offered by UberPool, Lyft Line, or Waze Carpool, will help temper the increased vehicle miles traveled and associated costs.

Supplementing the gas tax. It will be important for the Commonwealth to supplement lost motor fuel tax revenues, which likely will fall with adoption of electric autonomous vehicles. Instead, policymakers can consider other revenue sources including mileage-based fees. Distance-based user fees, congestion pricing, and access to high-demand curbs for delivery, pick-up, and drop-off are all potential revenue sources. Ideally, these user fees would be applicable to all vehicles, not just self-driving vehicles, and replace the fuel tax.[54]

Limits on zero-occupancy vehicles. The increases in vehicle miles traveled and associated congestion are damaging impacts of autonomous vehicle adoption. The Commonwealth can set limits on the distances that "zombie" vehicles can travel while empty. This will help limit needless circulation of empty vehicles that will clog roadways.

Municipal budget planning. Municipalities may face declines in parking and excise tax revenue over time. Local governments can start planning now to bridge projected shortfalls and deal with economic shifts, such as by reducing minimum parking requirements in zoning codes or increasing the excise tax.

[54] One new transportation fee is already in place. Legislation passed in 2016 provides for a $0.20 per ride fee to be added to each app-based vehicle service—including Uber, Lyft, and others. The fee will be assessed on each ride-sharing credit card transaction. Of this $0.20 fee, $0.10 goes to municipalities, $0.05 goes to the state, and $0.05 goes to taxi operators until 2022, when the taxi provision will be eliminated and a full $0.10 will go to the state. The portion of the fee going to the state will be directed to the Transportation Infrastructure Enhancement Trust Fund. The fee is to be in place from 2018 through 2027. By 2027, it is possible that autonomous vehicles could represent 20% of all trips, but achieving this level of penetration would require that owners of private vehicles choose to scrap their cars. If this fee is extended past 2027, it has the potential to make up some of the revenue loss that could result from the deployment of autonomous vehicles in the early years. The fee could generate $400 million for the state and $400 million for municipalities annually if 50% of rides are provided by ride-sharing autonomous vehicles. If 25% of rides are provided by these services, $200 million could go to the state and $200 million to municipalities annually. See 2016 MASS. ACTS c. 187 § 8-10; see also 220 MASS. CODE REGS. 274.00 (2017). For information about the law's implementation, see the Massachusetts Department of Public Utilities, Transportation Network Division, https://www.mass.gov/orgs/department-of-public-utilities-transportation-network-company-division.

Policy Recommendations

Public transit investments. It is critical for Massachusetts to continue to maintain and improve our public transportation system. A robust transit system will help address many of the potential negative impacts of autonomous vehicles, including increased congestion and air pollution. Autonomous vehicles can be part of or connected with our existing transit system as a "last mile" option rather than a replacement.

Job training. While it is not addressed in our report, the transition to autonomous vehicles will bring with it significant shifts in the employment landscape. The Commonwealth can start planning now to put into place large-scale programs to retrain professional drivers.

With the right policies in place, ride-pooling electric vehicles can become the norm in the autonomous vehicle fleet. We can avoid tradeoffs between positive economic and negative fiscal impacts with good polices.

VII. Conclusion

Massachusetts has an opportunity to put sensible policies in place to maximize the benefits of the transition to autonomous vehicles. While much uncertainty surrounds the deployment of autonomous vehicles, we can be sure that increased vehicle miles will lead to worse congestion and associated economic harms. The Commonwealth can manage congestion and economic costs through an emphasis on electric and ride-pooling vehicles, as well as investments in public transit, and take steps to mitigate impacts on state and local budgets.

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Appendix A: Tables

Economic and Fiscal Impacts of Self-Driving Cars at 100% Penetration

2015 $ Millions

		Base Level 2015	Base Level 2050	Private Vehicles	Ride Sharing**	Electric Vehicles
Massachusetts Miles Traveled (Million Miles)	Vehicle Miles (Million Miles)	50,035	58,992	35,100 Additional Miles	24,800 Additional Miles	*No change from baseline*
Massachusetts Marginal Economic Benefit/(Cost)* 2015 $ Millions	Congestion	NA	NA	$0 to ($5,380)	$0 to ($3,790)	*No change from baseline*
	Greenhouse Gas Emissions	NA	NA	($381)	($221)	$1,050
	Collisions	NA	NA	$2,551	$2,870	*No change from baseline*
	Air Pollution	NA	NA	($300)	($174)	$845
	Total Economic Impacts	**NA**	**NA**	**($3,510)**	**($1,315)**	**$1,895**
Massachusetts Fiscal Benefit/(Cost) 2015 $ Millions	Fuel Tax	$751	$539	$191	$111	($539)
	Sales & Use Tax	$789	$930	$777	($332)	*No change from baseline*
	Toll Receipts	$427	$503	$300	$212	*No change from baseline*
	Motor Vehicle Fees (License, Title, Registration)	$510	$602	($17)	($463)	*No change from baseline*
	Moving Violations	$24	$28	($28)	($28)	*No change from baseline*
	Total State Revenue	**$2,501**	**$2,602**	**$1,223**	**($500)**	**($539)**

* All economic benefits are incremental. Carbon estimates for private and ride-sharing vehicles reflect 15% driving efficiency savings.

** Ride-sharing mix assumes 40% ride pooling and 60% ride hailing.

Economic and Fiscal Impacts of Self-Driving Cars at 80% Penetration

2015 $ Millions

		Base Level 2015	Base Level 2045	Private Vehicles	Ride Sharing**	Electric Vehicles
Massachusetts Miles Traveled (Million Miles)	Vehicle Miles (Million Miles)	50,035	58,041	27,700 Additional Miles	19,500 Additional Miles	*No change from baseline*
Massachusetts Marginal Economic Benefit/(Cost)* 2015 $ Millions	Congestion	NA	NA	($4,236) or less	($2,985) or less	*No change from baseline*
	Greenhouse Gas Emissions	NA	NA	($278)	($161)	$767
	Collisions	NA	NA	$2,155	$2,423	*No change from baseline*
	Air Pollution	NA	NA	($240)	($139)	$676
	Total Economic Impacts	**NA**	**NA**	**($2,599)**	**($862)**	**$1,443**
Massachusetts Fiscal Benefit/(Cost) 2015 $ Millions	Fuel Tax	$751	$539	$152	$89	($428)
	Sales & Use Tax	$789	$915	$611	($260)	*No change from baseline*
	Toll Receipts	$427	$495	$236	$167	*No change from baseline*
	Motor Vehicle Fees (License, Title, Registration)	$510	$593	($14)	($364)	*No change from baseline*
	Moving Violations	$24	$27	($22)	($22)	*No change from baseline*
	Total State Revenue	**$2,501**	**$2,565**	**$963**	**($390)**	**($428)**

* All economic benefits are incremental. Carbon estimates for private and ride-sharing vehicles reflect 15% driving efficiency savings.

** Ride-sharing mix assumes 40% ride pooling and 60% ride hailing.

Appendix A: Tables

Economic and Fiscal Impacts of Self-Driving Cars at 50% Penetration

2015 $ Millions

		Base Level 2015	Base Level 2035	Private Vehicles	Ride Sharing**	Electric Vehicles
Massachusetts Miles Traveled (Million Miles)	Vehicle Miles (Million Miles)	50,035	55,289	16,500 Additional Miles	11,600 Additional Miles	*No change from baseline*
Massachusetts Marginal Economic Benefit/(Cost)* 2015 $ Millions	Congestion	NA	NA	($2,521)	($1,771)	*No change from baseline*
	Greenhouse Gas Emissions	NA	NA	($142)	($82)	$350
	Collisions	NA	NA	$1,477	$1,661	*No change from baseline*
	Air Pollution	NA	NA	($150)	($87)	$422
	Total Economic Impacts	**NA**	**NA**	**($1,377)**	**($286)**	**$772**
Massachusetts Fiscal Benefit/(Cost) 2015 $ Millions	Fuel Tax	$751	$547	$97	$57	($330)
	Sales & Use Tax	$789	$872	$363	**($155)**	*No change from baseline*
	Toll Receipts	$427	$472	$140	$100	*No change from baseline*
	Motor Vehicle Fees (License, Title, Registration)	$510	$564	$47	$171	*No change from baseline*
	Moving Violations	$24	$26	($13)	($13)	*No change from baseline*
	Total State Revenue	**$2,501**	**$2,481**	**$634**	**($182)**	**($330)**

* All economic benefits are incremental. Carbon estimates for private and ride-sharing vehicles reflect 15% driving efficiency savings.

** Ride-sharing mix assumes 40% ride pooling and 60% ride hailing.

Economic and Fiscal Impacts of Self-Driving Cars at 20% Penetration

2015 $ Millions

		Base Level 2015	Base Level 2030	Private Vehicles	Ride Sharing**	Electric Vehicles
Massachusetts Miles Traveled (Million Miles)	Vehicle Miles (Million Miles)	50,035	53,938	6,400 Additional Miles	4,500 Additional Miles	*No change from baseline*
Massachusetts Marginal Economic Benefit/(Cost)* 2015 $ Millions	Congestion	NA	NA	($984)	($693)	*No change from baseline*
	Greenhouse Gas Emissions	NA	NA	($51)	($30)	$140
	Collisions	NA	NA	$618	$695	*No change from baseline*
	Air Pollution	NA	NA	($60)	($35)	$169
	Total Economic Impacts	**NA**	**NA**	**($477)**	**($62)**	**$309**
Massachusetts Fiscal Benefit/ (Cost) 2015 $ Millions	Fuel Tax	$751	$579	$42	$24	($126)
	Sales & Use Tax	$789	$850	$143	($61)	*No change from baseline*
	Toll Receipts	$427	$460	$68	$50	*No change from baseline*
	Motor Vehicle Fees (License, Title, Registration)	$510	$550	$18	($67)	*No change from baseline*
	Moving Violations	$24	$26	($5)	($5)	*No change from baseline*
	Total State Revenue	**$2,501**	**$2,465**	**$265**	**($58)**	**($126)**

* All economic benefits are incremental. Carbon estimates for private and ride-sharing vehicles reflect 15% driving efficiency savings.

** Ride-sharing mix assumes 40% ride pooling and 60% ride hailing.

Appendix A: Tables

Economic and Fiscal Impacts of Increasing Percentage of Ride Sharing

This table shows the impact of increased levels of a ride-sharing mix of 40% ride pooling and 60% ride hailing in an entirely autonomous vehicle fleet with 50% electric vehicles. An increase in the ride-sharing mix leads to decreased vehicle miles and associated congestion, resulting in economic benefit.

Economic and Fiscal Impacts of Ride-Sharing (40% ride pooling and 60% ride hailing) at 100% AV, 50% EV
2015 $ Millions

	Percentage Ride Sharing Incremental Economic Benefits/(Costs)					
	Baseline	**0%**	**20%**	**40%**	**60%**	**80%**
Congestion	NA	($ 5,381)	($ 5,063)	($ 4,746)	($ 4,428)	($ 4,110)
Greenhouse Gas Emissions	NA	$291	$309	$328	$346	$365
Collisions	NA	$2,552	$2,616	$2,679	$2,743	$2,806
Air Pollution	NA	$309	$320	$331	$341	$351
Total Economic	NA	**($ 2,229)**	**($ 1,818)**	**($ 1,409)**	**($ 998)**	**($ 587)**

	2050	**Incremental Revenues/(Lost Revenues)**				
Fuel Tax	$535	($172)	($180)	($188)	($196)	($204)
Sales & Use Tax	$930	$777	$571	$365	$159	($47)
Toll Receipts	4503	$300	$282	$265	$247	$229
MV Fees	$602	($17)	($107)	($196)	($285)	($374)
Moving Violations	$28	($28)	($28)	($28)	($28)	($28)
Total Revenue	**$2,599**	**$859**	**$538**	**$217**	**($103)**	**($424)**

Economic and Fiscal Impacts of Increasing Percentage of Ride Pooling Only

This table shows the impact of increased levels of ride-sharing in an entirely autonomous vehicle fleet with 50% electric vehicles. The scenario assumes the indicated percentage of ride-pooling vehicles, 20% private self-driving vehicles, and ride hailing for the remaining portion of the fleet. As a result of decreased vehicle miles and associated congestion, ride pooling drives major economic benefits.

Economic and Fiscal Impacts of Ride Pooling at 100% AV, 50% EV
2015 $ Millions

	Percentage Ride Pooling Incremental Economic Benefits/(Costs)					
	Baseline	**0%**	**20%**	**40%**	**60%**	**80%**
Congestion	NA	($5,388)	($4,590)	($3,791)	($2,992)	($2,195)
Greenhouse Gas Emissions	NA	$290	$337	$384	$430	$477
Collisions	NA	$2,552	$2,711	$2,870	$3,030	$3,189
Air Pollution	NA	$309	$335	$361	$387	$414
Total Economic	NA	**($2,237)**	**($1,206)**	**($175)**	**$854**	**$1,885**

	2050	**Incremental Revenues/(Lost Revenues)**				
Fuel Tax	$535	($172)	($192)	($212)	($232)	($252)
Sales & Use Tax	$930	$20	($22)	($65)	($106)	($148)
Toll Receipts	$503	$300	$255	$211	$167	$123
MV Fees	$602	($359)	($369)	($377)	($386)	($394)
Moving Violations	$28	($28)	($28)	($28)	($28)	($28)
Total Revenue	**$2,599**	**($240)**	**($355)**	**($470)**	**($586)**	**($701)**

Appendix B: Methodology

A NOTE ON OUR OVERALL APPROACH

To our knowledge, no other studies have been conducted on the effects that self-driving cars may have on state and local finances. Given the diversity of revenue streams that come from transportation, we have had to rely on a mix of studies and, at times, supply our own assumptions. This appendix explains our rationale for selecting different parameters and provides references to relevant research.

For the purposes of conducting economic analysis, we assign dollar values to things that are inherently difficult to quantify, including the impacts of car collisions, air pollution, and greenhouse gas emissions. Translating the harms or benefits into dollar terms allows us to estimate the impacts of certain practices on society. This form of analysis necessarily does not capture the full cost of these harms to an individual who suffers serious injury in a car crash or develops a chronic illness from air pollution, which are immeasurable. Similarly, assigning a dollar amount to the impact of climate change potentially undervalues the scale of impact on future generations. We regret the shorthand of this approach, but we hope that it will help to provide policymakers with a way to begin considering the various choices that lie ahead for transportation policy in the Commonwealth.

Our financial models draw heavily on research into the possible effects of autonomous vehicles. This research takes two forms. First, we use empirical studies on transportation today with plausible analogies to autonomous vehicles. Second, we use simulations that model autonomous vehicles under different scenarios.

Putting these two approaches together, we draw on existing data to inform our modeling. Where possible, we review multiple studies and select estimates that reflect either areas of agreement or mid-point estimations between them.

For example, we assume that the lifespan for a ride-sharing autonomous vehicle will be roughly similar to a current New York City taxicab. New York taxis have an average age of 3.3 years, suggesting a lifespan of 6.6 years. The Institute for Transportation and Development Policy report suggests that shared autonomous vehicles would last 4 to 6 years and would drive five times the mileage of a conventional vehicle. We use a 6.8-year life, traveling about 70,000 miles per year, similar to a New York City cab. Each simulation involves its own particular sets of assumptions.

Photo credit: Tesla Motors/Mashable

BASELINE

We compare our scenarios with a baseline in which vehicle miles traveled and car ownership continue to grow at 0.5% annually. Initial revenue and vehicle assumptions are largely from the year 2015. Some of the data on municipalities (budgets, excise taxes, parking, parking fines) are from 2014 or 2016. They are then increased to reflect vehicle miles traveled and vehicle growth of 0.5% per year.

FINANCIAL ESTIMATES

All financial estimates are in Fiscal Year 2015 U.S. dollars.

TIMELINE FOR AV DEPLOYMENT

There is uncertainty about when autonomous vehicles will be deployed. Based on the literature, we assume that autonomous vehicles will be deployed first in urban areas in the early 2020s, reach 50% market share of the car fleet by 2035, and be 80% of the car fleet by 2045.

PRIVATE AND RIDE-SHARING VEHICLES

A fundamental question is whether autonomous vehicles will be privately owned or operated as ride-sharing fleets. We model fleets that are exclusively private, ride-sharing (both ride hailing and ride pooling), and exclusively electric (private, not ride-sharing). We assume that the most likely outcome will be a mix of these modes. We model two possibilities: (1) a "private" scenario, in which vehicles remain mostly in the hands of private owners, and (2) a "ride-sharing" scenario, in which shared fleets have grown. In the ride-sharing mix scenario, we assume 60% ride hailing and 40% ride pooling unless otherwise noted.

RIDE HAILING VS. RIDE POOLING

Shared fleets of vehicles can serve customers in two fashions as part of the ride-sharing fleet. In ride hailing, vehicles serve riders sequentially, dropping off one passenger before proceeding to the next. This is akin to UberX or Lyft today. In ride pooling, vehicles pick up multiple riders along the way who are traveling in the same direction, similar to UberPool or Lyft Line today.

We make assumptions about the proportion of ride hailing vs. ride pooling. While data about current ride-hailing and ride-sharing services is hard to come by, we glean what data we can. Uber reports that 20% of its trips are made using UberPool, its ride-sharing service. With UberPool, passengers pay less but have a slightly longer trip as the vehicle detours to pick up other passengers. Uber reports that shared rides are 4 to 5 minutes longer on average. It is possible that the proportion of ride sharing will increase in a world with autonomous vehicles. However, removing the driver from the vehicle is expected to significantly reduce the cost of travel, which lessens the difference in price between hailing a personal vehicle vs. a shared vehicle.

We assume that the proportion of ride pooling totals 40% of the ride-sharing fleet, with ride hailing totaling 60%. We do not assume that private vehicles engage in ride sharing.

VEHICLE MILES TRAVELED

Autonomous vehicles can affect vehicle miles traveled in four primary ways: induced demand, latent demand, empty vehicle miles, and ride pooling. Most studies address only one or two of the mechanisms considered here due to constraints in data and simulation techniques. See Grush and Niles (2017) for a discussion of difficulties in autonomous vehicle simulations. We survey a range of studies and chose a mid-point estimate for each mechanism.

The four mechanisms are:

1. Induced demand

Longer trips and additional trips from current drivers will increase vehicle miles traveled. A sample of representative studies finds the effect on vehicle miles traveled (all increases) to be: 20% (Childress et al. [2014]), 24% (Kim et al. [2015]), 26% (Fagnant and Kockelman [2013]), and a range of 18–41% (Zhao and Kockelman [2017]). We estimate induced vehicle miles traveled at 24%.

2. Latent demand and mode shift

Vehicle mile increases due to new users. Sivak and Schoettle (2015) estimate 11% new autonomous vehicle users from the young, elderly, and people with disabilities. Harper et al. (2016) estimate an upper bound of 14% from these groups.

In addition, autonomous vehicles are expected to draw users who previously would have walked, biked, or taken public transportation. There is substantial research on mode shift resulting from lower operating costs for cars, increased roadway capacity, reduced perceived costs of travel, and lower costs of parking, all of which are likely to occur to some degree with autonomous vehicles and thus incentive a shift toward automobiles. See Truong et al. (2017) for a review of the research in these areas.

The impact on mode shift will vary widely in different parts of the state based on the current share of trips for transit, walking, and biking. Statewide, automobiles account for 68.5% of trips, transit makes up 7.6% of trips, and walking and biking comprise 20.1% of trips (MassDOT). Mode shift is not likely to be a dramatic driver of vehicle miles at the state level given the relatively low percentage of current transit trips statewide and the fact that high-capacity rail lines may still retain advantages in time and cost. In some scenarios, autonomous vehicles may improve first-mile/last-mile connections to high capacity transit helping to strengthen ridership on these lines. Infrequent bus service is more likely to lose mode share to autonomous vehicles.

Given the interactions between latent demand and mode shift (since many people without a driver's license currently walk, bike, or take transit), we estimate a single number of 12% growth in new trips resulting from their combined effect.

3. Empty vehicle miles

Both the private and shared modes involve vehicles traveling without occupants. In a private scenario, cars may travel further to find cheap parking or return home to pick up other family members for households that opt to share one vehicle. We assume that empty vehicle miles traveled constitute 25% of total private vehicle miles traveled.

Shared fleets of vehicles travel empty miles for the purposes of repositioning between trips. Chen et al. (2016) find that 7% to 14% of vehicle miles in a shared electric fleet model are empty miles traveled under optimized conditions (including distance traveled for recharging). Recent studies of Uber and Lyft have found that 36% to 49% of their miles are traveled without passengers (Cramer and Krueger (2016), Schaller [2017]). These data come from dense cities and proportion of empty miles traveled may be higher in suburban and rural areas. We estimate empty miles traveled in shared fleet setting at 25% of overall vehicle miles traveled, a mid-point between the optimized and observed empty miles for shared vehicles offered as a ride-pooling or ride-hailing service.

4. Reduced vehicle miles traveled through ride pooling

Average vehicle miles traveled can decrease as people share rides through ride pooling. If two trips are perfectly aligned with the same start and end points, then overall vehicle miles drop by half. Actual vehicle mile reductions depend upon the degree of alignment between the trips. Data on trip alignment is difficult to obtain. Uber reports that UberPool adds 5 minutes on average to a trip and the average trip time is reportedly 10 minutes. We estimate that trip lengths for UberPool users are 25% longer than the average trip due to smaller cost differentials, and so scale our assumed average UberPool trip to 12.5 minutes. From the 5 minutes of extra trip time involved in a shared service, we subtract 1 minute as waiting time for the additional passenger, reflecting Uber's policy of maximum wait time for an UberPool with a passenger, resulting in 4 minutes of non-aligned driving time. This translates into the average trip having 68% of aligned travel and 32% of additional travel. We then find that shared rides result in a 34% drop in vehicle miles traveled for the ride-pooling market. The theoretical maximum for perfectly aligned trips is 50% vehicle mile savings, so average reductions of 34% is a reasonable estimation.

TOTAL EFFECT ON VEHICLE MILES TRAVELED

The total effect of these various factors, including induced demand, latent demand, empty vehicle miles, and ride pooling on vehicle miles traveled will be less than their simple product due to the moderating influence of congestion. Having more cars on the road will lead to more congestion, which will limit how far vehicles can travel. Eventually autonomous vehicles will likely increase capacity as vehicles travel faster, closer together, and in narrower lanes. Assuming congestion limits, we scale back the cumulative effect of these mechanisms by a factor of 30%.

AUTONOMOUS VEHICLES AND CONGESTION

Because self-driving cars are likely to drive more miles, they are likely to initially generate more congestion and delays for drivers. The Addendum to the 1997 Federal Highway Cost Allocation Study Final Report, U.S. Department of Transportation, Federal Highway Administration, May 2000, Table 13 estimates the congestion cost of incremental miles traveled by cars on urban interstates for the year 2000. We adjust this estimate to 2015 dollars and for the median Massachusetts income relative to the national income. This results in a cost of incremental miles traveled of $0.13 per mile. We did not adjust the estimates for the costs on local roads.

We review a number of studies related to congestion impacts. We recognize that the cost of congestion is likely to drop as self-driving cars become pervasive because cars will be able to drive at closer following distances, lanes can be narrower, and autos will be able to more effectively react to changes in traffic conditions.

NUMBER OF VEHICLES AND VEHICLE TURNOVER

Vehicle sales and excise taxes depend upon the total number of vehicles and the rate of turnover. Latent demand may push vehicle ownership up, but households may also be able to manage with fewer cars as autonomous vehicles shuttle between family members. See Schoettle and Sivak (2015a) for a discussion of return-to-home possibilities. For the privately owned model, we assume that the total number of cars remains the same as today, adjusted only for a 9% increase in vehicles to serve the young, old, and disabled. Chen et al. (2016) find that in a shared electric fleet model, each vehicle can replace between 5.5 and 9 privately owned vehicles. We assume that shared vehicles replace 6.8 vehicles, using one of their mid-point estimates.

The average lifespan of vehicles has been increasing and is now 18 years in Massachusetts. We assume that private vehicles will last 12 years because they will drive about 60% more miles than current human-operated vehicles. Vehicles in shared fleets are used at higher rates and wear out faster. New York City taxis last 6.6 years while driving 70,000 miles a year on average (NYC Taxi and Limousine Commission 2014). This is consistent with additional estimates of fleet vehicles lasting 6 to 7 years (Fulton et al. [2017]). We assume that shared autonomous vehicles similarly turn over at 6.8 years on average.

COST OF AUTONOMOUS VEHICLES

Estimates for the additional cost of autonomous vehicle technology range from $2,500 (Burns et al. [2013]) to $6,500 (Lang et al. [2015]) to $10,000 (Fulton et al. [2017]). IHS estimates that the technology will start at $10,000 and drop to between $3,500 and $5,000 per vehicle. We assume that AV technology will cost a premium of 15% (approximately $5,000).

SALES AND USE TAX

The increase in sales and use tax for private autonomous vehicles is driven by four factors. First, we assume that the life of a private car is constant at 196,000 miles, the approximate current life of vehicles in Massachusetts. Second, we assume that there are 9% additional cars from latent demand of young, old, and disabled users. Third, with constant life in miles, vehicles will have shorter lives because they are driving 46% more miles (empty miles and induced demand), which lowers life to 12.5 years from 18.5 years. Fourth, we assume that autonomous vehicles are 15% more expensive. These are all net of the 30% discount in mileage increase. The product of the shorter life, extra cost, and extra cars is 83%, exactly the percentage increase in the sales and use tax.

For shared vehicles, the sales and use tax drops because the mileage life of the car is more than twice the mileage life of a private car (476,000 miles, consistent with taxis in New York). In addition, we assume that electric ride-hailing and ride-pooling cars will have a $10,000 battery replacement, which is a secondary factor.

FUEL EFFICIENCY AND FUEL TYPE

Massachusetts adopted the California Corporate Average Fuel Economy (CAFE) standards for light-duty vehicles starting in model years 2009 to 2011. California standards are now harmonized with federal standards through 2025. The Commonwealth may adopt and implement the California standards going forward as long as they are at least as protective as federal standards. This analysis assumes that Massachusetts will continue to follow the California standards. As a result, all internal combustion engines (ICE), including autonomous vehicles that run on gasoline, will see fuel efficiency increases and a subsequent drop in per-mile gas tax revenue.

For the purposes of estimating gas tax revenue and for estimating the carbon impact and air pollution from petroleum-fueled ICE vehicles, we assume that revenues and economic costs are adjusted from 2015 levels to 2035 (and after) based on the change in fuel efficiency for new on-road light duty vehicles, from approximately 25 MPG to 35.6 MPG. Please note that we use the effective fuel efficiency rate.

Autonomous vehicles may also have independent effects on fuel efficiency. Human beings consume more fuel than necessary through inefficient braking and acceleration. We assume that autonomous vehicles reduce per-mile fuel consumption by 15% (the mid-point of a review of studies presented in Barcham (2014), Brown et al. (2013), and Lovejoy and Handy (2013). Additional energy savings may come from having smaller, lighter vehicles. However, consumer trends in the last decades have been toward larger vehicles, and it is unclear which direction vehicle weight and size will move. Thus, we assume no fuel efficiency due to changes in vehicle weight or design.

PARKING

Parking revenues come from meters, facilities, and parking violations. In our models, we assume that these revenues drop inversely with the proportion of autonomous vehicles in the light-vehicle population.

Over time, in major metropolitan areas including Boston, Cambridge, and Somerville, some parking garages will be redeveloped into much more valuable, multi-floor buildings. For example, some six-story garages in Boston's downtown districts could ultimately be redeveloped into 20- to 40-story office blocks. The tax revenue from these buildings would likely fully offset the loss of parking revenues and parking fines.

We are seeing this happen in Boston through the replacement of parking lots with high-rise office and residential buildings. The replacement of the Government Center Garage with a $1.5 billion pair of office and residential towers is one such example. However, it is likely to take some time for the redevelopment to occur. In a partial survey of garages in Boston, excluding hospital and government garages, we identified a number of garages that if redeveloped could more than fully offset the revenues lost from parking and parking violations through higher valuation and taxes. Gains for redevelopment are likely to lag because of design, permitting, and construction. Thus, municipalities would experience the loss of revenue from parking before they would reap the benefits of any potential development.

MOVING VIOLATIONS

We assume that self-driving cars do not incur moving violations.

SOCIAL COST OF CARBON

In order to estimate the cost of carbon, we use the social cost of carbon from the Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis under Executive Order 12866, table ES1, page 4. We use a 2015 price of $36 and a 2045 price, based on a 3% discount rate of $64.

ESTIMATE OF CARBON IMPACT FROM AUTONOMOUS AND ELECTRIC VEHICLES

For ICE vehicles, we use the following assumptions to estimate the impact of incremental miles described above in the section titled Vehicle Miles Traveled. The incremental mileage estimates includes the following assumptions:

- 18.9 pounds of carbon per gallon of gasoline (EIA)
- Effective fleet mileage for new light duty vehicles 2036 onwards: 36.6 MPG (EIA)
- Social Cost of Carbon: See previous section
- The total cost of carbon per incremental mile traveled by an ICE vehicle is 1.5 cents per mile

For electric vehicles, we estimate the impact of carbon based on the carbon intensity of the electricity used to charge electric vehicles. The key assumptions follow:

- Kilowatt hours per mile: 0.28 Kwh/Mile fuel economy of electric vehicles
- Pounds of CO_2/ Emitting Megawatt Hour in ISO New England: 1,036 (ISO New England 2015 Electric Generators Air Emissions Report)
- Estimate of Non-Emitting Generators (% of Total) in 2030 for ISO New England: 70.3% (ISO New England Planning Advisory Report, page 10, average of Scenario 1 and 3)
- Social Cost of Carbon: See previous section

COLLISIONS

The National Highway Traffic Safety Administration estimates the 2010 economic cost of collisions in Massachusetts to be $5.8 billion. The costs include medical costs, lost productivity, congestion costs, insurance costs, legal costs, and property damage. Adjusting these figures for inflation to the 2015 cost raises the total to $6.3 billion. Of that amount, 12% is attributable to congestion, which we account for separately, lowering the cost to $5.5 billion. Research shows that more than 90% of collisions are attributed to human error. We have not found research that indicates what proportion of those crashes could be avoided by self-driving cars. We also do not have any research that indicates what number of collisions could be caused by self-driving equipment and software. For example, some current self-driving software assumes that any car entering a highway will give way to cars already on a highway. We all know that not all cars merging onto a highway give way to cars already on the highway, thus causing potential collisions. Current software may also make it difficult for cars to make left turns during traffic. For our analysis, we estimate that 75% of collisions could be avoided.

Auto collisions and road fatalities in Massachusetts have been declining approximately 1.4% per year. Many of these benefits come from the incorporation of new safety features in the auto fleet. If this level of decline continues through 2030, then the level of crash reduction economic benefits would drop by about 25% relative to 2010 levels.

STATEWIDE REVENUE SOURCES

Moving violation tickets (state's share)

State motor fuels taxes

Motor vehicle fees, including inspection, registration, license, title

Motor vehicle sales and use tax

Toll receipts

MUNICIPAL REVENUE SOURCES

Case study cities: Boston, Cambridge, Fitchburg, New Bedford, Pittsfield, Plymouth, Sherborn, Somerville, Springfield, and Worcester

Motor vehicle excise tax

Moving violations tickets (local share)

Parking fines

Parking meters

Parking lots and garages

Resident permits

OUR MODEL

To request access to the model, please contact Hoai Tran at httran@clf.org.

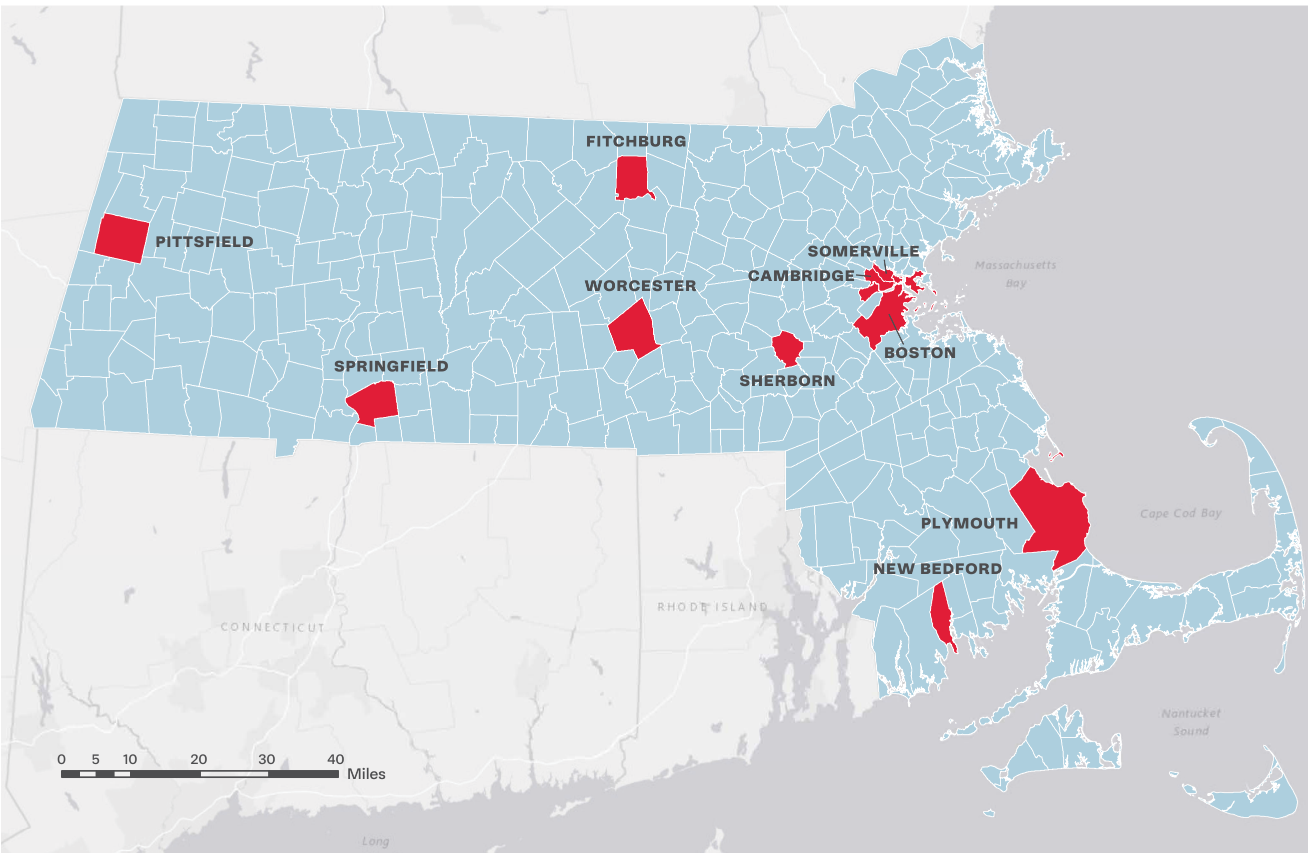
Appendix B: Methodology

MUNICIPALITIES INCLUDED IN OUR ANALYSIS

Autonomous Vehicles Study Area

March 2018, Map produced by CLF. Data layer provided by MassGIS (Bureau of Geographic Information).

Towns/Cities Analyzed: Boston, Cambridge, Fitchburg, New Bedford, Pittsfield, Plymouth, Sherborn, Somerville, Springfield and Worcester.



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