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The $64 Billion Massachusetts Vehicle Economy

Faculty Research Working Paper Series

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Executive Summary

Policymakers and budgetary analysts have long argued that roads are heavily subsidized. The diffusion of spending among federal, state, and local government entities, along with the complexity of indirect costs, make it difficult to understand the fully loaded cost[1] of the vehicle economy. Individual families may track the personal costs of car ownership to their budgets, but they rarely consider the total cost of operating and maintaining the vehicle economy because the vast majority of roads and parking areas are provided free at the point of use. This study is intended to increase transparency regarding road-related spending and to provide a comprehensive estimate of the economic cost of Massachusetts' vehicle economy.

The Massachusetts' vehicle economy is based on nearly 37,000 miles of public roads, adjacent parking areas, and 4.5 million private passenger cars and light trucks. This system provides conduits for exchange and movement for millions of families, businesses, and services in the State.

We conclude that the total *annual* cost of the vehicle economy in Massachusetts is approximately $64.1 billion. Over half this amount, some $35.7 billion, is borne by the public in the form of state budgetary costs, social and economic costs (road injuries and deaths, congestion, and pollution), and the value of land set aside for roads and parking. The remaining $28.4 billion falls on private consumers in the form of financing and operating their vehicles.

Figure 1

Annual cost of the MA vehicle economy

Public costs	$35.7B	55.7%
Consumer costs	$28.4B	44.3%
Grand Total	**$64.1B**	**100.0%**

Several important conclusions follow from our analysis. First, the public costs of the vehicle economy are substantial – amounting to $14,000 per family in Massachusetts, regardless of whether they own a vehicle. Second, this cost is highly subsidized by non-road users – just 1/3 of state budgetary costs (amounting to $5.7 billion) are covered by user fees and gas taxes. Third, the economic impact is regressive: non-car owners typically are lower income and disproportionately from minority communities.

The full cost of the vehicle economy should also throw into perspective the cost of investments in public transportation projects, because the counterfactual of simply relying on roads and vehicles is not free. For example, previous studies have found that that the

[1] We used Litman's definition of cost as "trade-offs that individuals and society must make between uses of resources. This can involve money, time and other resources, or the loss of a potential benefit." While acknowledging the benefits of transportation systems, Litman suggests that studying costs is useful because "most marginal transportation improvements result from reductions in costs, such as travel time and vehicle operating expenses, so measurement of costs is also the basis for determining net benefits" (Litman 1997).

North-South Rail Link would incur a *one-time* cost of $3.8 to $12.3 billion (White et al. 2017; "North South Rail Link Feasibility Reassessment Study" 2019).

This paper is not a cost-benefit analysis, rather it presents a conservative estimate of the costs of the vehicle economy in Massachusetts with assumptions clearly laid out in the body of the paper. The motor-vehicle economy is integral to public safety, business, and recreation in Massachusetts. By providing a better understanding of its full costs we hope to contribute to evidence-based transportation policymaking in the future.

Methodological Approach

This paper develops a conservative estimate of the costs associated with the vehicle economy in Massachusetts using publicly available information, academic research, and financial modeling. The study is neither a cost-benefit analysis of the vehicle economy nor is it intended to be one. We acknowledge that the vehicle economy provides many benefits to society, and another study would be necessary to determine those benefits.

Our methodology defines two distinct types of costs: publicly borne costs and consumer costs. The publicly borne costs calculate trade-offs of resources that everyone incurs regardless of whether one uses a car. Consumer costs are the costs incurred by individuals who own and operate vehicles.

The section on publicly borne costs brings together three types of costs: direct public budgetary costs, indirect social and economic costs, and land use costs. The calculations in each section use publicly available information, primarily published by government entities. We supplemented our financial model of the direct public budgetary costs by interviewing local and state officials. The calculations of the indirect social and economic costs rely significantly on peer-reviewed articles and other reports that study the impacts of factors such as pollution, greenhouse gases, and traffic.

The section on consumer costs sums two categories: the cost of owning and operating a car and the costs of building residential parking areas. In addition to government-published information, the consumer cost section uses documented principles published by the automobile industry.

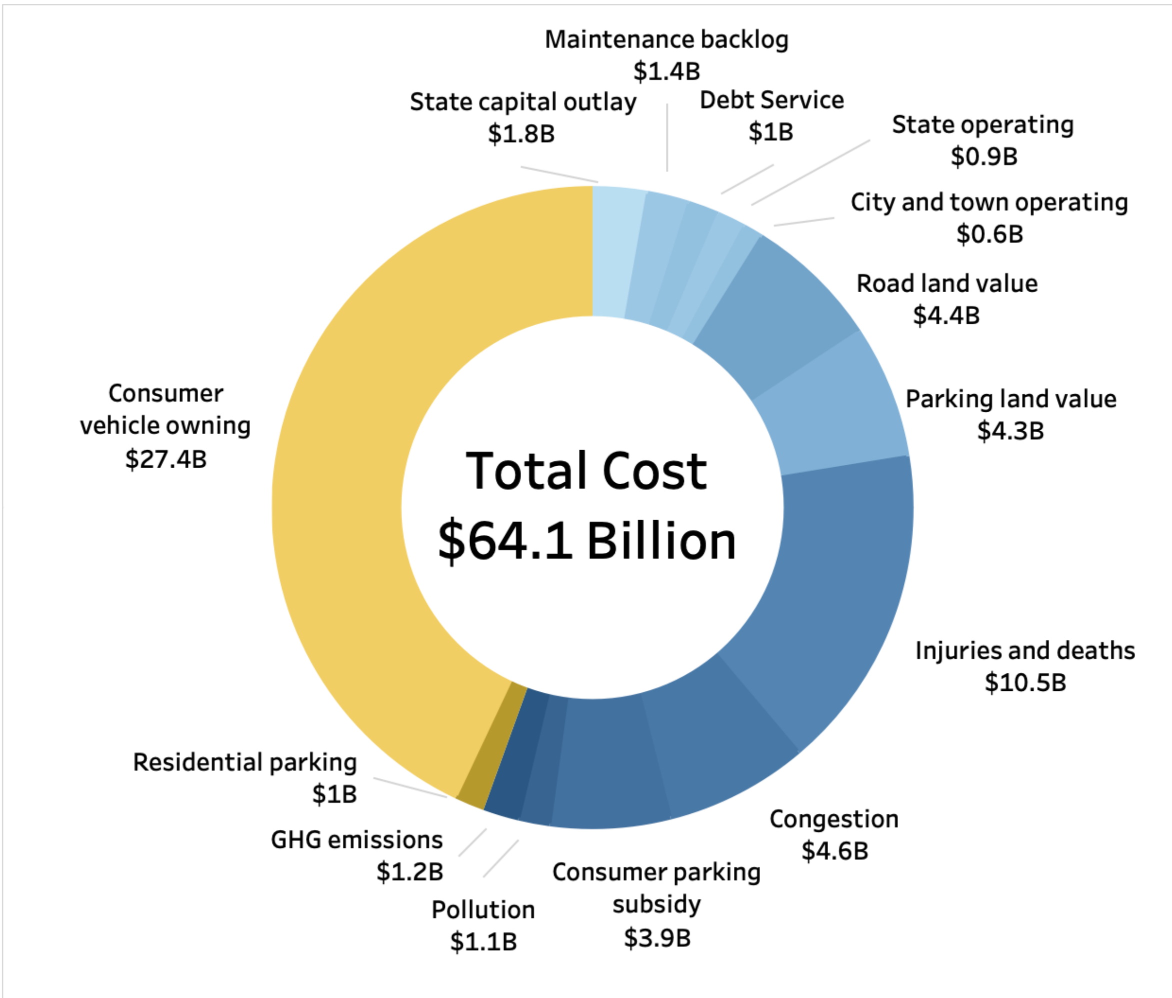
All calculations, assumptions, and sources are detailed in the appendix.

Understanding the Costs

In Massachusetts, nearly 37,000 miles of public roads,[2] adjacent parking areas, and 4.5 million private passenger cars and light trucks underpin the vehicle economy.[3] Based on our analysis, the annual cost of the vehicle economy is approximately $64.1 billion. Of this total, $35.7 billion is public budgetary costs, indirect social and economic costs, and annualized land usage costs. Direct costs to consumers account for the remaining $28.4 billion.

Figure 2

Annual cost of the vehicle economy in Massachusetts



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[2] According to the Federal Highway Administration, 36,723 miles of public roads existed across Massachusetts in 2017 (2018). The state had a total of 77,557 lane miles of roads ("Table HM-60: Functional System Lane-Length - 2017" 2018). Lane miles measure the total length of road by multiplying the centerline mileage by the number of lanes.

[3] This 2018 Registry of Motor Vehicles data obtained and made available by the Boston Globe counts the number of private passenger cars and light trucks in Massachusetts. This figure does not include commercial or public vehicles (Wallack 2018).

Publicly Borne Costs

Publicly borne costs are resources, which include money, time, and land. Massachusetts residents incur these costs regardless of whether they own or operate a vehicle. We categorize this $35.7 billion in annual costs into three categories: public budgetary costs, indirect and direct economic costs, and land value commitments.

Figure 3

Annual public costs of the MA vehicle economy

Direct Budgetary Costs	City and town costs	$0.6B	
	State operating costs	$0.9B	
	State capital outlay	$1.8B	
	State debt service	$1.0B	
	Road maintenance backlog	$1.4B	
	Total	**$5.7B**	**16.0%**
Indirect Social & Economic Costs	Injuries and deaths	$10.5B	
	Congestion	$4.6B	
	Consumer subsidy	$3.9B	
	GHG emissions	$1.2B	
	Pollution	$1.1B	
	Total	**$21.3B**	**59.7%**
Land Value Costs	Roads	$4.4B	
	Parking	$4.3B	
	Total	**$8.7B**	**24.4%**
Grand Total		**$35.7B**	**100.0%**

Direct Public Budgetary Costs[4]

Public budgetary costs are annual government expenditures or deferred expenses that will be reported as expenditures in the future. We calculate that local and state governments in Massachusetts incur $5.7 billion dollars of direct budgetary costs annually related to roads.[5] These expenditures support the maintenance and operation of the road infrastructure.

Public budgetary costs include at least $600 million in local operating expenditures and another $900 million in state operating expenditures. The major categories of government operating expenses determined by our study are snow removal, road maintenance, and vehicle-related emergency activities, including police, fire, and emergency medical technicians. Massachusetts cities and towns fund a variety of additional activities including street sweeping, parking enforcement, crossing guards, and maintenance related to traffic signals and signage. The Massachusetts Department of Transportation also operates the Registry of Motor Vehicles.

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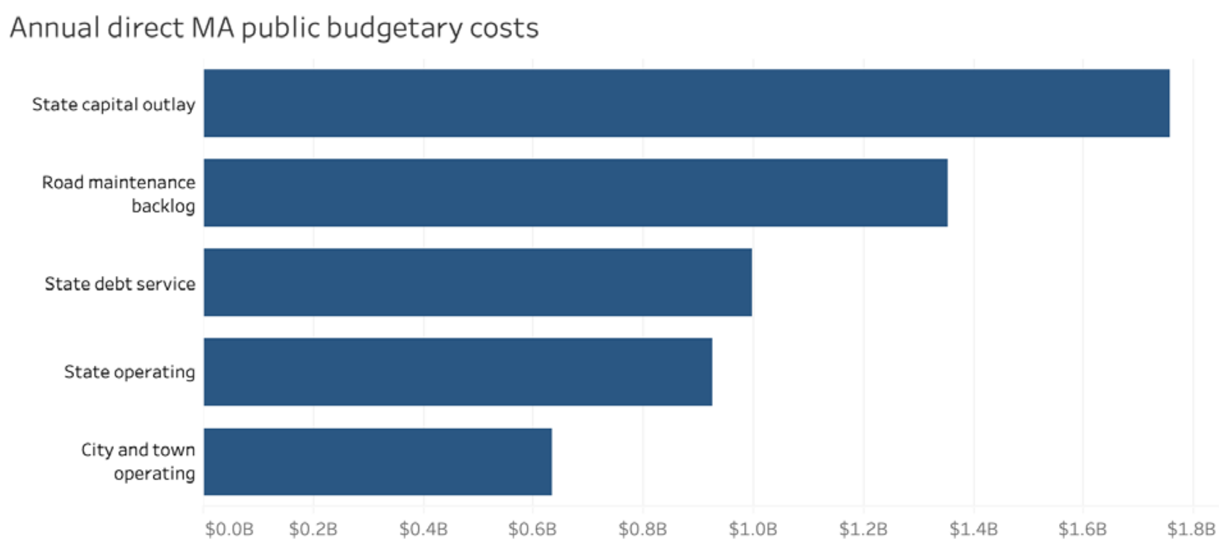
[4] Note that Direct Public Budgetary Costs do not include the costs of purchasing and operating public vehicles such as buses, fire trucks and so forth, since we assume such costs are best ascribed to the services they provide rather than to the road economy itself.

[5] See Appendix for details

The state reports recurring capital expenditures of $1.8 billion for roads and bridges ("Table SF-4: Disbursements for State-Administered Highways - 2017" 2019). In addition, Massachusetts spends $1 billion in debt service related to roads.[6] The majority of the debt service is allocated to the Commonwealth Transportation Fund, which includes financing relayed to the 'Big Dig' and long-term projects such as the Longfellow Bridge (Garrity 2019). We used a lifecycle estimate to determine that $1.4 billion in deferred maintenance is added annually to the state's road maintenance backlog.[7] This amount is the additional annual spending required to maintain Massachusetts' roads in good quality. It does not include tunnels, bridges and related infrastructure.

Figure 4



Indirect Social and Economic Costs

In addition to budgetary costs, the public incurs $21.3 billion in annual indirect social and economic costs. These costs are often not immediately tangible and do not appear on a financial statement. Nonetheless they are real costs that are ultimately borne by society. The largest of these is an estimated $10.5 billion in fatalities and injuries related to vehicle collisions. To calculate this total, we used the Federal Highway Administration's "KABCO"

[6] The $1 billion in debt expenditures sums the debt service from Massachusetts Department of Transportation (MassDOT) and the Commonwealth Transportation Fund (CTF). The MassDOT portion averages six years (FY13-FY18) of road-related debt service from MassDOT "Revenue and Expense Reports." Figures for the CTF average six years (FY13-FY18) of line items in the state budget (Office of the Treasurer and Receiver-General 2019). Senior MassDOT officials reported that between two-thirds (low estimate) and three-quarters (high estimate) of the CTF's debt service is road related (Garrity 2019). We reported the average of the high and low estimates. A more precise estimate would require reviewing the individual bonds in the CTF.

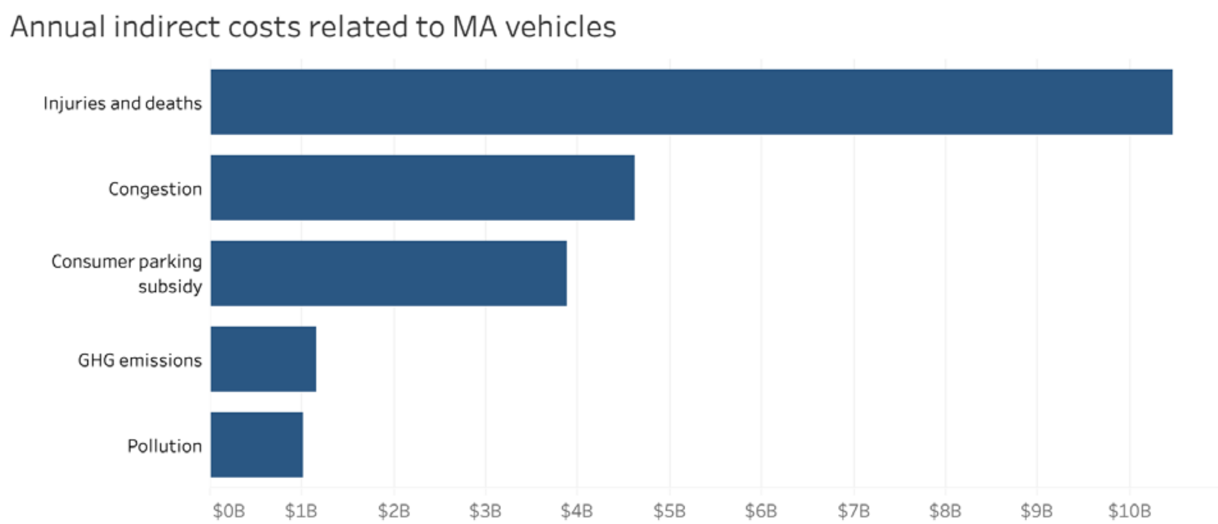
[7] The backlog amount estimates the lifecycle cost to maintain the surface of all Massachusetts roads in "good" condition. The estimate does not include bridges, tunnels, or drainage culverts, which are all integral to the road system. A Better City report used data from MassDOT's Performance and Asset Management Advisory Council to determine the current backlog on state bridges alone is $3.5 billion. We did not include A Better City's estimate that a funding gap of $3.3 billion is projected during the next 10 years (2019-2028) for state-owned bridges and tunnels (Ryan and Carlson 2019).

ratio and the United States Department of Transportation's value of statistical life.[8] The "KABCO" ratio calculates cost from vehicle-related fatalities, incapacitating injuries, non-incapacitating injuries, possible injuries, and no injuries.

Also, in indirect costs, people in the state lose $4.6 billion of lost productivity due to time spent in traffic. The vast majority of congestion costs occur in the Boston-area where drivers individually spend an average of 164 hours in traffic each year (Burfeind 2019). We also calculated the cost to maintain non-residential private parking areas, such as parking lots at retail stores or business offices, because these costs are passed on to consumers in the price of products, services, and rents. We estimate that consumers subsidize $3.9 billion in annual costs related to the construction and maintenance of private non-residential parking lots.

Vehicles in Massachusetts also produced approximately 28.8 million metric tons of carbon dioxide that negatively impact global climate change ("Table MF-21 Highway Statistics 2017 - Policy and Governmental Affairs: Highway Policy Information" 2019; US EPA 2015). We estimate these annual costs to be another $1.2 billion. According to the Federal Highway Administration, vehicles traveled 52.8 billion miles in Massachusetts during 2018 (Office of Highway Policy Information 2018). We estimate that these vehicles produced $1.1 billion in damages from adverse health effects related to pollution. It should be noted that recent research findings are beginning to show a direct impact of pollution on worker productivity, which is not considered in these numbers (Chang et al. 2019).

Figure 5



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[8] This study used KABCO ratios provided in the Federal Highway Administration (Harmon, Bahar, and Gross 2018) and adopted by MassDOT ("2016 Top Crash Locations Report Location" 2018). Officials at MassDOT provided the aggregated 2016 data, which we used in the model (Polin 2019) except when updated information was available (Pollack 2018). The US Department of Transportation's value of statistical life was used (Moran and Monje 2016). According to the Federal Highway Administration's Highway Safety Improvement Program, Massachusetts revised its KABCO to increase the costs of deaths and injuries ("2018 Massachusetts Highway Safety Improvement Program" 2018). Using the revised calculations, the indirect costs for deaths and injuries would be $16.5 billion. In keeping with our conservative total, we did not use the revised calculations.

Land Value Costs
We estimate the public cost of the land committed to the vehicle economy is $8.7 billion. Roads in Massachusetts cover approximately 176 square miles, with parking areas accounting for a further 120 square miles. This area is equivalent to completely paving over the state's nine most populous municipalities—Boston, Worcester, Springfield, Cambridge, Lowell, Brockton, New Bedford and Quincy—and two-thirds of the tenth, Fall River. We estimate the current value of this land is $115 billion. To arrive at an annual value, we assumed the total value was financed by a 20-year, 5 percent interest rate municipal bond and calculated the average annual debt service. According to our calculations, road area accounts for $4.4 billion of the cost, and parking area accounts for $4.3 billion.[9]

Consumer Costs

All drivers are familiar with the personal costs to own a car. We estimate that together vehicle owners in Massachusetts annually incur some $28.4 billion in costs. Although these costs are not borne by the entire public, they are important to this discussion because the vehicle economy requires private owners—many of whom depend on car transportation for their livelihood—to bear annual expenses. Without these costs to consumers, roads would have hardly any cars and not serve one of their primary purposes: allowing individuals to travel.

This total includes $27.4 billion in costs to consumers who own and operate vehicles. Individuals who drive cars or trucks face the annual costs of financing, depreciation, fuel, regular maintenance, and repair. [10] The financial model averages the annual costs to consumers during a 5-year period using publicly reported figures on the 10 most-owned vehicles in Massachusetts.[11] The costs for each car are associated with the base models, which are the versions of the car with the minimum manufacturer specifications. Because the average car in Massachusetts is 10 years old, the costs are distributed across different ages with a mean of 10 years ("State Facts" 2019).

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[9] See Appendix for detailed methodology.
[10] To avoid double counting costs, we excluded state and federal fuel taxes, vehicle sales and excise taxes, registration and inspection fees from the consumer total.
[11] The ten most registered vehicle in Massachusetts are the Toyota Camry, Honda Accord, Toyota Corolla, Honda Civic, Honda CRV, Toyota RAV4, Chevrolet Silverado, Nissan Altima, Toyota Highlander, and Subaru Forester (Wallack 2018). The costs per model are distributed proportionately to rates of RMV registration.

The cost model uses fair market value prices of the 10 most-owned vehicles financed by a 5-year, 3-percent loan with a 20-percent down payment. We assume depreciation occurs at a rate of 20 percent for brand new cars and at 10 percent in all subsequent years. The fuel cost estimate uses the average number of vehicle miles traveled per car, the EPA's fuel efficiency information, and the average price of gas. Average maintenance and repair costs are reported for specific vehicles and their ages. Taxes and fees are excluded from consumer costs to avoid double counting in the public budgetary section.

The additional $1 billion in costs to consumers accounts for building and financing residential driveways and garages. The model uses an estimated cost for asphalt parking areas, which are significantly cheaper than concrete. We assume that 15 percent of residential parking spaces are in garages.

Analysis

Budgetary Costs and Road Quality

In our study of local municipalities, we found cities and towns incur four major road-related costs: snow removal, road maintenance, fire and emergency medical technicians responding to vehicle-related events, and police activities. An array of miscellaneous expenditures including replacing road signage, street sweeping, crossing guards, and other activities made up approximately one-tenth of city and town road-related spending.

Some cities and towns in Massachusetts spend only the state allocation for road maintenance, known as Chapter 90. Others (generally those with higher per capita property values) use local funds to supplement the state transfer by as much as three times (Olbrot 2019). The funding mechanism of raising local dollars to repair roads fosters disparities in the quality of roads among municipalities. To compound this difference, once a road deteriorates beyond a certain point, routine maintenance is no longer cost effective, and major replacement is needed (Birken 2019). Cities and towns able and willing to dedicate funds to repair roads adequately experience lower costs longer term by mitigating costly replacement.

According to the Federal Highway Administration, Massachusetts has the second-highest proportion of roads in poor condition in the country.[12] The cost of poor roads manifests as safety hazards, wear and tear on vehicles, and other inefficiencies. Other studies have found that Massachusetts spends the second most per lane mile on road construction.[13] This is partially due to the state's high population density (Craighead 2018). The Midwest Economic Policy Institute found a strong correlation between population density and road construction costs. The Institute cited higher construction costs in urban areas related to more stringent design standards, complicated intersections, and work zone dynamics. Massachusetts is the third most dense state in the US.

Revenue from Users

Based on user fees reported by the Massachusetts Department of Transportation, the state gas tax and federal gas tax together cover approximately 34 percent of public budgetary costs ("Revenue and Expense Report: Budget Fiscal Year Ended June 30, 2018" 2018). Calculating user fees can be complex and controversial. For example, a portion of the state gas tax funds mass transit activities ("Table SDF: Disposition Of State Highway-User

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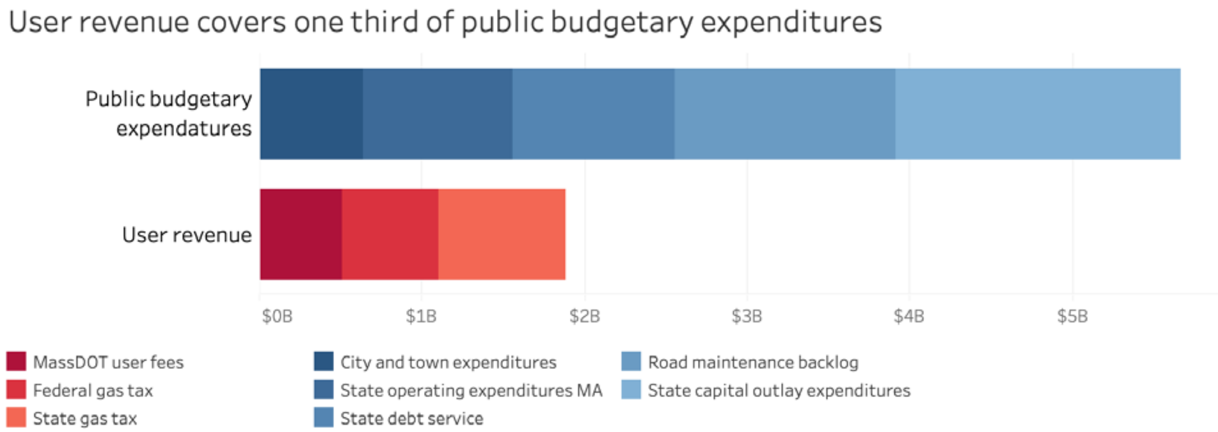
[12] In 2017, 28 percent of Massachusetts roads were rated in poor condition. The national average was 10 percent. Only Rhode Island had a higher proportion of poor roads ("Table HM-64 - Highway Statistics 2017 - Policy" 2017).

[13] Federal Highway Administration data shows that between 2015 and 2017, Massachusetts dispersed more money per state-controlled mile of road than any other state with the exception of New Jersey ("Table HM-10 Highway Statistics 2017 - Policy and Governmental Affairs: Highway Policy Information" 2018). A study by the Midwest Economic Policy Institute confirmed these findings reporting that Massachusetts ranked only behind New Jersey in annual spending on road construction between 1993 and 2015. The state spent an annual average of $145,029 per lane mile of construction during this period. Massachusetts ranked first in per lane mile road-related engineering costs and seventh in per lane mile right-of-way acquisition costs (Craighead 2018).

Revenues - 2016" 2018). Rather than parse out how the tax revenue is spent, we show the entire tax as a road-related user revenue. The result is a massive funding gap between user revenues and public budgetary expenditures, which must be covered from other sources.

Figure 6



Publicly Borne Costs by Household

The $35.7 billion in publicly borne costs are equivalent to an annual cost of nearly $14,000 for each of the 2.6 million households in Massachusetts. Vehicle-owning households spend on average an additional $12,000 annually ($6,000 per vehicle) in direct costs.

Because a significant proportion of the public costs are non-budgetary, families bear these costs in ways other than taxes. People are killed or injured in vehicle accidents, reducing their future social and economic contributions. Individuals require medical treatment after road accidents or to treat conditions (such as asthma) that are related to vehicle pollution. People waiting in traffic lose work productivity and home time. Consumers pay more for goods and services because businesses pass on the cost of maintaining parking lots. Communities sacrifice taxable land, open space, bike paths, and promenades for roads and parking lots. These are some of the indirect costs of the vehicle economy.

It should be noted that while the $14,000 is the average cost per household, the publicly borne costs are not necessarily distributed equally. For example, people who live near busy roads are more likely to be affected by automobile pollution.[14] Drivers in areas with heavy traffic experience higher congestion costs, and individuals living in municipalities with more roads arguably bear more of the land commitment costs.

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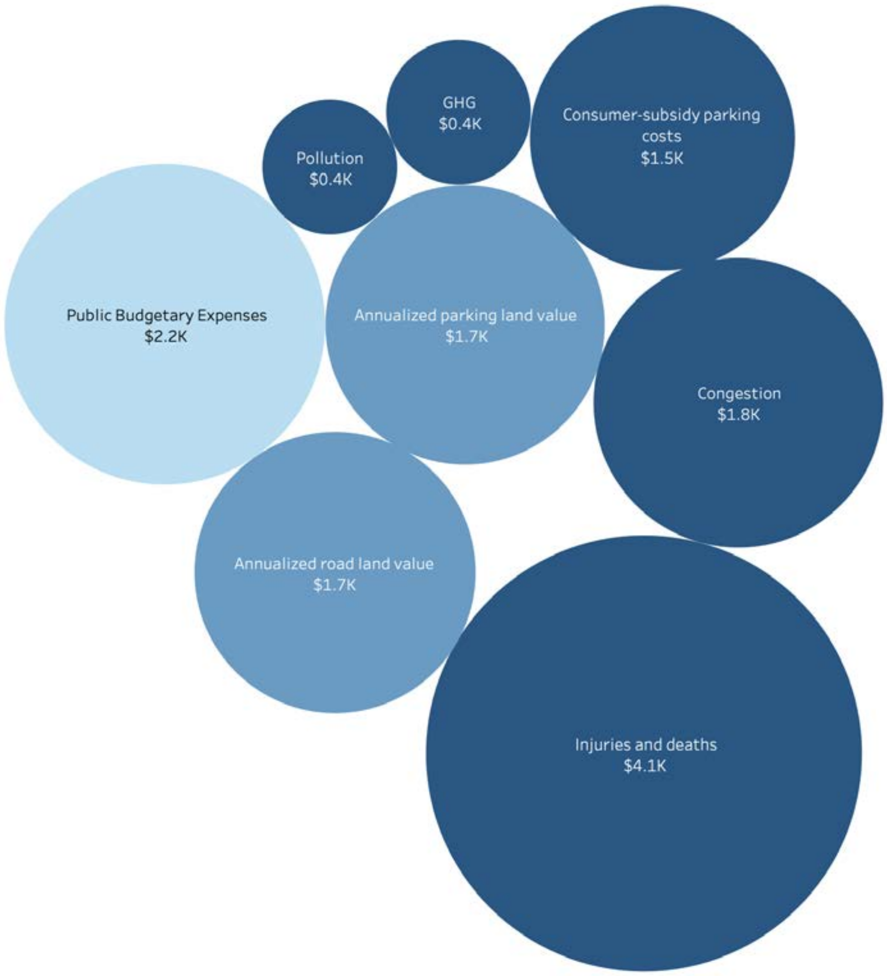
[14] A 2019 Union of Concerned Scientists report found that Asian American, African American, and Latino residents in Massachusetts were disproportionately exposed to air pollution from vehicles relative to the state average ("Inequitable Exposure to Air Pollution from Vehicles in the Northeast and Mid-Atlantic," 2019).

Figure 7

A MA household without a car still bears $14,000 in annual vehicle-related costs



Implications for Income Distribution

Policymakers may consider the large subsidy dedicated to the vehicle economy in several dimensions. The public costs of the vehicle economy do not result in equitable access across different social and economic classes in the state. According to the National Equity Atlas, over 90 percent of White households in Massachusetts have access to a vehicle. This compares to 74.3 percent for Black households and 73.7 percent for Latino households ("Car Access - Massachusetts" 2018).

People living in poverty are less likely to own a car, and thus benefit far less from the vehicle economy (Klein and Smart 2019). Moreover the cost per household of $14,000 is not spread evenly across the State. The indirect costs (pollution, congestion, land value and so forth) are certainly higher for those who live closer to Boston. The concentration of low-income and minority residents in these areas makes the system of subsidies even more regressive. And since the eastern part of the State bears the majority of the indirect costs, this amounts to a subsidy for the driving economy of Western Massachusetts – something that is largely overlooked when debating how the entire state should pay for rail and other transportation services located primarily in the East.

Ridesharing companies including Lyft and Uber benefit from the large public subsidy related to vehicles. The Massachusetts Department of Public Utility reported that rideshare companies provided 81.3 million rides in 2018 (Vaccaro and Hagan 2019). The shareholders of these companies and their customers (who tend to be higher-income consumers) benefit disproportionately from public spending on the vehicle economy. Moreover, studies suggest that rideshare companies reduce the usage of public transportation, which decreases user fees collected on those systems. By contrast, private companies are not permitted to use the public infrastructure of a rail system or an airport without an agreement that ensures safety, efficiency, and cost sharing.

Conclusion

The vehicle economy is expensive, and there is certainly a significant opportunity cost incurred in the public expenditures. Moreover road users do not cover the system's costs. Policy options include raising the state gas tax or introducing congestion pricing in order to make users cover a larger share of public budgetary expenditures. To maintain the cost sharing burden over time, such taxes or charges may be indexed with inflation. Taxes or charges can also be used to change user behavior. For example, congestion pricing can reduce travel to certain areas or at specific times. A true Pigouvian tax would account for the indirect social and economic costs of vehicles and make users pay for the true cost of the vehicle economy.

Policymakers who do not have an appetite for tax increases may nonetheless find this study provides a valuable perspective on the true costs of the vehicle economy. The maintenance and expansion of public transportation projects of all types come with substantial costs for taxpayers. It is important that the cost of such projects should not simply be judged in isolation, but rather should take into consideration the full cost of alternative solutions that rely on the vehicle economy.

Appendix: Methodology and Assumptions

Detailed methodology used for each category of costs is described below.

Publicly Borne Costs

Direct Public Budgetary Costs

Public budgetary costs related to the vehicle economy are calculated by accounting for local and state government expenditures as well as deferred maintenance related to public roads. These annual costs are the amounts that Massachusetts town, city, and state governments spend or will need to spend to operate and maintain the road infrastructure.

<u>Local Public Budgetary Costs</u>

The major road-related costs incurred by local municipalities were determined through research in Lynn, Massachusetts. When possible, we averaged the road-related costs over a five-year period. The costs we found include:

- Snow and ice removal ("Comptroller's Office" 2019).
- Road maintenance expenditures (Hall 2019).
- Fire Department costs, including emergency medical technicians (EMT) services found by multiplying the percentage of vehicle-related calls reported by the Fire Department by Department's expenses (Hamill 2019).
- Police Department costs of issuing traffic-related citations. To determine the total hours police spent issuing traffic-related citations, we multiplied the annual average number of vehicle citations issued reported by the Police Department by 0.25, assuming a citation takes 15 minutes to complete (Hamill 2019). We then multiplied the time spent issuing traffic related citations by the municipal minimum rate for a police detail reported by MassDOT. The minimum rate reported is 50 percent lower than the maximum rate. We did not calculate administrative costs related to citations. Both factors would increase the total cost.
- Crossing guards costs reported by the Mayor's Office (Hamill 2019).
- Repairs to traffic signals costs reported by the Mayor's Offices related to contractors, police details, engineering, and Department of Public Works overtime (Hall 2019; Hamill 2019).
- Street sweeping costs contract costs provided by the Mayor's Office (Hamill 2019).
- Police Department reporting automobile accidents. To determine the total time police spent at automobile accidents, we multiplied the annual average number of accidents by one, assuming each accident takes one hour of police activity. We then multiplied the police time spent at accidents by the municipal minimum rate for a police detail reported by MassDOT. The minimum rate reported is 50 percent lower than the minimum rate. We did not calculate administrative costs related to citations. Both factors would increase the total cost.
- Costs of weather-related events related to roads, such as flooding or downed branches reported by the Mayor's Office (Hamill 2019).
- Costs of replacing signage reported by the Department of Public Works (Hall 2019).

The vehicle-related municipal costs determined in Lynn were used to extrapolate costs to all 351 Massachusetts municipalities. The major costs identified for local municipalities are snow removal, police, fire and EMT, road maintenance, and miscellaneous costs.

Each municipality's annual costs for snow removal was calculated by averaging five years of snow and ice expenditures reported by the Massachusetts Division of Local Services ("Schedule A General Fund" 2019).

The vehicle-related costs for police services were determined using the Massachusetts Division of Local Services, which report each municipality's police department expenditures ("Schedule A General Fund" 2019). Figures from 2018 were used. In the rare case when data was not available for year 2018, data from year 2017 was used. Based on data collected in Lynn, we assumed that the vehicle-related share of each municipality's police expenditures was between 2.5 and 7.5 percent. Daily traffic density was used as a proxy for whether the vehicle-related share of a municipality's Police expenditures was likely to be 2.5 percent, 5.0 percent, or 7.5 percent of its budget. We assumed that municipalities with higher traffic density were likelier to have higher vehicle-related costs for police services because a higher volume of traffic increases the likelihood of police interventions. To determine a municipality's traffic density, the average daily vehicle miles traveled in each municipality, as reported by the Massachusetts Registry of Motor Vehicles in 2014 ("Massachusetts Vehicle Municipal Summary Statistics (Municipal)" n.d.), was divided by the number of center lane miles in that municipality, as reported by the MassDOT for 2016 ("Massachusetts Road Inventory Year End Report" 2017).

Each municipality's budget for fire and EMT services was determined using the Massachusetts Division of Local Services, which reports each municipality's fire department expenditures ("Schedule A General Fund" 2019). Figures from 2018 were used. In the rare case when data was not available for year 2018, data for year 2017 was used. We assumed that the vehicle-related share of each municipality's Fire and EMT budget was between 2.5 and 7.5 percent, based on our findings in Lynn and interviews with several fire departments in the state. Daily traffic density was used as a proxy for whether the vehicle-related share of a municipality's fire and EMT budget was likely to be 2.5 percent, 5.0 percent, or 7.5 percent of its budget. We assumed that municipalities with higher traffic density were likelier to have higher vehicle-related costs for fire and EMT because a higher volume of traffic increases the likelihood of EMT and fire interventions. To find traffic density, the average daily vehicle miles traveled in each municipality, as reported by the Massachusetts Registry of Motor Vehicles in 2014 ("Massachusetts Vehicle Municipal Summary Statistics (Municipal)" n.d.), was divided by the number of centerline miles in that municipality, as reported by the Massachusetts Department of Transportation in the year 2016 ("Massachusetts Road Inventory Year End Report" 2017).

The amount of funding each municipality received for road maintenance from the state via Chapter 90 transfers is publicly reported ("Chapter 90 Apportionment" 2019). Figures from the fiscal year 2019 were used. Chapter 90 is intended to fund local road maintenance. Based on our findings in Lynn and interviews with local officials in other municipalities, we assumed that some towns and cities would not contribute more monies to road maintenance than Chapter 90 funds while others would spend two or three times more than the Chapter 90 allocation. Property value per capita was used as a proxy for whether a municipality was likely spending only their Chapter 90 funds or exceed their allotment by two or three times. Informed by our interviews, we assumed that municipalities with a higher property value per capita were more likely to spend beyond their Chapter 90 allocation. Each municipality's total property value was divided by its population. Property value data was averaged from the years 2015-2019, as reported by the Massachusetts Division of Local Services ("Municipal Databank: Assessed Values by Class" 2019). Population data was from the year 2015, reported as an estimate by the Census Bureau ("City and Town Population Totals: 2010-2018" 2019).

Miscellaneous costs were determined by assuming that roughly 10 percent of a local municipality's vehicle-related costs were incurred from activities in addition to snow removal, police, fire and EMT, and road maintenance. This proportion was determined in Lynn, and these costs include traffic signal repair, street cleaning, crossing guards, and weather-related incidents. To calculate this amount, the estimated costs of snow removal, police, fire and EMT, and road maintenance were summed for each municipality. Assuming this amount was 90 percent of the total vehicle-related costs in each municipality, the sum was multiplied by a coefficient of 1.11 to estimate 100 percent of the total cost.

To account for multiple scenarios of vehicle-related spending proportions across multiple activities, probabilities were assigned to each city being accurately identified as a "floor," "moderate," or "ceiling" municipality in terms of its spending on each activity. For example, a city in the top third of Massachusetts municipalities in terms of property value per capita was assumed to be the "ceiling" in terms of its spending on road maintenance (i.e. the city or town would spend three times their Chapter 90 allocation). To account for uncertainty, a 70 percent probability was assigned that the municipality was correctly identified as a "ceiling" city or town based on its property value per capita, and that they would spend at this level for road maintenance. A 20 percent probability was assigned that the city was a "moderate" spender on road maintenance, and a 10 percent probability that the city was the "floor". The same probabilities were used for police, fire and EMT expenditures based on traffic density. In Excel, 1,000 trial simulations were run, each of which resulted in a different sum of the total vehicle-related spending by all 351 Massachusetts municipalities. The average of all 1,000 of these trials was reported as the estimate of total vehicle-related spending by Massachusetts municipalities.

<u>State Public Budgetary Costs</u>

Publicly available information from the Massachusetts Department of Transportation (MassDOT) legislative reports and the Massachusetts state budget published online provided the key inputs for this section. In addition, we interviewed officials from MassDOT and Department of State Police to clarify assumptions from the publicly available budget documents.

MassDOT operating budget information from legislative reports was collated from fiscal years 2013 to 2018. The financial model includes items from "Operating Expense Detail by Division" for Highways, Planning and Enterprise Services, and Registry of Motor Vehicle divisions. Paygo Maintenance and Snow & Ice are only included as separate line items for fiscal year 2013. In subsequent years, those items are included in other line items of the

MassDOT budget. Based on interviews with MassDOT officials, we estimated that 80 percent of the Planning and Enterprise Services expenses were road-related. Each line item was averaged over the six-year period. The Department of Conservation and Recreation (DCR) budget line item 2810-0100 - State Parks and Recreation is appropriated “For the operation of the division of state parks and recreation; provided, that funds appropriated in this item shall be used: (a) to operate all of the division's parks, parkways, boulevards, roadways, bridges and related appurtenances under the care, custody and control of the division, flood control activities of the division, reservations, campgrounds, beaches and pools; ...provided further, that the crossing guards located at department of conservation and recreation intersections shall continue to perform the duties where state police previously performed such duties; ...provided further, that up to $3,000,000 may be used to support costs of snow and ice removal.” We estimated that 50 percent of funds in line item 2810-0100 is spent on vehicle-related activities; however, we were unable to confirm this estimate with a DCR official. The percentage is easily adjustable in the model, and the overall size of this line item does not significantly change our final estimate. The Department of State Police budget line item 8100-1001 - Administration and Operation of the Department of State Police includes funding for highway patrol (Office of the Treasurer and Receiver-General 2019). Based on interviews with an official from the Executive Office of Public Safety and previous reports by the National Council of State Legislatures, we estimated that 55 percent of this line item is dedicated to highway patrol (Merrick 2019; “State Highway Patrol Funding: Fiscal Year 2015” 2017).

Each state transportation agency reports annual capital outlay disbursements for roads and bridges to the Federal Highway Administration. These figures can be found in Table SF-4 of the Federal Highway Administration Highway Statistics reports. Before fiscal year 2017, MassDOT had not reported capital outlay disbursements to FHWA since 2011. In fiscal year 2017, MassDOT reported capital outlay disbursements of nearly $1.8 billion (“Table SF-4: Disbursements for State-Administered Highways - 2017” 2019). We chose to use that figure since it is the most up-to-date representation.

MassDOT debt service is reported as part of the MassDOT operating budget. We chose to separate it from the operating budget section of this model in order to separately analyze recurring operating expenses and debt service. The Commonwealth Transportation Fund (CTF) includes capital spending for road-related projects, MBTA, and other transportation infrastructure. CTF debt service is itemized either as individual line items in the state budget (0699-0014, 0699-2005) or as a percentage of larger debt service line items (0699-0015, 0699-9100). This model includes all four line items as publicly reported on the Massachusetts state budget website from fiscal year 2013 to 2018 (Office of the Treasurer and Receiver-General 2019). We assume that the percentage of 0699-9100 is congruent with the overall percentage reported in account language for 0699-0015. Based on interviews with senior MassDOT officials, we estimate that between 66-75 percent of the CTF is for road-related projects. A more precise estimate of this proportion would require individual review of bonds in the CTF. We reported the estimated annual CTF debt service by averaging top range (assuming 75 percent of CTF is for road-related projects) and bottom range (assuming 66 percent) of road-related project estimates.

MassDOT user fees were gathered from the "Operating Revenue Detail" of the MassDOT legislative reports from fiscal year 2013 to 2018. Revenue from Commonwealth Fund Transfer and Federal Grants were excluded since revenue is not generated by user fees. The Federal Highway Administration's "Motor Fuel & Highway Trust Fund" 2018 monthly reports were used to determine how many gallons of gas were sold and taxed in Massachusetts ("Monthly Motor Fuel Reports - Policy and Governmental Affairs: Highway Policy Information" 2019). The number of gallons of gas sold was multiplied by the state and federal gas tax to determine the revenue collected ("How Much Tax Do We Pay on a Gallon of Gasoline and on a Gallon of Diesel Fuel? - FAQ" 2019).

Road Maintenance Backlog

The road maintenance backlog was calculated by estimating the annual amount of funding required in an infrastructure lifecycle cost to maintain the roads in a state of good condition and subtracting the actual amount spent. The number of square lane miles in Massachusetts were identified from the Federal Highway Administration data ("Table HM-60: Functional System Lane-Length - 2017" 2018). The cost to perform three levels of road maintenance—preventative, rehabilitation, and reconstruction with their associated lifespan in years, two, 30, and 60 respectively—were determined through interviews with local officials and industry experts (Olbrot 2019; Birken 2019). In other words, at a minimum, governments need to perform preventative maintenance (crack sealing, etc.) every two years, rehabilitation (mill overlay, etc.) every 30 years, and reconstruction (full-depth) every 60 years (Olbrot 2019; Birken 2019). The costs of maintenance types were multiplied by the area covered by roads in Massachusetts, and then divided each by their respective lifetime to calculate at an annual upkeep cost. This figure, which calculates the necessary funds to maintain the roads in good condition, was subtracted by the estimated amount spent on road maintenance by municipalities and the state. The difference is the annual backlog of road maintenance. It does not consider infrastructure beyond the road surface, such as bridges, tunnels, on and off ramps, or drainage culverts. Calculating these deferred maintenance costs would significantly increase the public budgetary cost total. If we underestimated the actual amount spent on road maintenance, the backlog would decrease by the underestimation. Likewise, if we overestimated the amount spent on road maintenance, the backlog would increase accordingly. In these two scenarios, the public budgetary total would remain the same.

Indirect Social and Economic Costs

Social and economic indirect costs related to the vehicle economy are borne by society, but often are neither directly tangible at the time they occur nor appear on a balance sheet. The indirect social and economic costs accounted for in the study are congestion, pollution, emissions, private parking lot construction, injuries and deaths from vehicle-involved collisions.

Vehicle Crashes

The cost of vehicle crashes relied on the value of a statistical life (VSL), which was determined from the U.S. Department of Transportation (Moran and Monje 2016). The number and severity of deaths and injuries due to vehicle crashes was obtained through conversations with the MassDOT (Polin 2019). Updated information was used when available (Pollack 2018). The KABCO ratio system that was developed by Federal Highway

Administration (Harmon, Bahar, and Gross 2018) and adopted by MassDOT ("2016 Top Crash Locations Report Location" 2018) was used to convert injuries into fractions of costs using the VSL baseline. Finally, the number of injuries of each type was multiplied by the cost ratio of VSL for each respective type and summed to reach an annual cost of crashes.

Congestion

The cost of congestion was calculated based on data and a methodology used by INRIX, a mobility analytics company. INRIX compiled the cost of congestion per driver for the greater Boston area, based on time lost in delays and average wages ("INRIX: Congestion Costs Each American 97 Hours, $1,348 A Year" 2019). We extrapolated their analysis to the rest of the state, assuming that drivers outside the Boston area faced 25 percent of the delays that Boston drivers did. The sum of these figures is the annual cost of congestion for the entire state.

Consumer Parking Subsidy

The consumer parking subsidy is a cost of business bundled into the price of rents, products, or services. The consumer parking subsidy was determined by calculating the total amount of parking spaces and multiplying that figure by the cost to finance their construction. The number of registered cars in Massachusetts were determined using data provided by the Registry of Motor Vehicles and made available through the Boston Globe (Wallack 2018). The number of cars was multiplied by 4 to calculate the amount of parking spaces and the area they cover. Four is a reasonable number of parking places to use for this determination (Shoup 2005; Gellerman and Ben-Joseph 2012). Estimates of the parking space to vehicle ratio span from three to eight. We multiplied this total by 99 percent because 1 percent of the parking spaces are maintained through government spending that was already counted in the public budgetary section. This proportion was extrapolated using data gathered in Lynn (Hamill 2019). The proportion of parking garage spaces to parking lot spaces was assumed to be 15 percent to 85 percent. This assumption was based on reporting that in some urban areas one-third of parking spaces are in structures (Cudney 2017). The cost per parking space when constructing a garage and a flat lot were identified (Cudney 2017; "2019 Asphalt Paving Cost | Asphalt Driveway Cost Calculator" 2018). For flat spaces, the estimated price for an asphalt space was used because it can be as much as five time cheaper than a concrete space. We conservatively assumed a parking space life of 60 years based on interviews with transportation infrastructure analytics company and local officials(Olbrot 2019; Birken 2019). The cost per each type of space (garage or lot) was multiplied by the number of each type of space. To arrive at an annual value, we assumed the total value was financed by a 60-year (the life of the space), 3 percent interest rate loan, and calculated the average annual debt service. Three quarters of the parking spaces were assumed to be non-residential, so this proportion was allocated as cost as the consumer parking subsidy. The other one quarter is attributed in the consumer cost section.

Pollution
The cost of pollution relied on Parry and Small's research that established a baseline of $0.019 in pollution damages per mile of vehicle traveled (Parry and Small 2005).[15] The number of vehicle miles traveled (VMT) in Massachusetts was identified from Federal Highway Administration data (Office of Highway Policy Information 2018). The baseline cost was multiplied by the annual VMT in Massachusetts to arrive at a yearly cost of vehicle-related pollution.

Greenhouse Gas Emissions
The cost of greenhouse gas emission relied on the widely-cited cost of carbon, $40 per metric ton (Parry and Small 2009; "Technical Support Document: Social Cost of Carbon for Regulatory Impact Analysis - Under Executive Order 12866" 2010; "The Social Cost of Carbon" 2017).[16] The annual amount of metric tons of carbon dioxide emissions from vehicles in Massachusetts was determined using data from the Federal Highway Administration the Energy Information Administration ("Table MF-21 Highway Statistics 2017 - Policy and Governmental Affairs: Highway Policy Information" 2019; "Greenhouse Gases Equivalencies Calculator - Calculations and References" 2015). The cost of carbon was multiplied by the number of metric tons emitted to determine the cost of greenhouse gas emissions.[17]

Land Value Costs

Land value costs related to the vehicle economy account for the area dedicated to roads and parking. Understanding costs as a tradeoff, large areas of land used for operation of the vehicle economy could be used for other purposes. This cost was determined by annualizing the value of land covered by roads and parking lots.

Parking Land Value
The land value per acre in each Massachusetts county was based on data from the Federal Housing Finance Agency (Larson et al. 2019). The number of cars registered per municipality was identified using Boston Globe data (Wallack 2018). The number of cars was multiplied by the same number of parking space discussed previously (4 spaces per vehicle) to calculate the number of parking spaces per county. We assume that all four parking places are in the county where the car is registered. While this may not be true, commuters often live in areas of less valuable land than where they work (i.e. a suburb compared to Boston proper), so this assumption produces a conservative cost. The area taken up by parking spaces in each county was determined by multiplying the number of parking spaces by the average size of a space, 20 square yards (Holland 2014). We calculated the value of the land taken up by parking spaces by multiplying the county-level parking area by the respective land value in each county. To reach an annual cost, the total value of the land was financed in a 20-year bond at a five percent interest rate. This term and interest rate were assumed after studying general obligation bonds. The average of the debt service during 20-year term was reported as the parking land value.

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[15] The other studies we reviewed report a range of figures; $0.019 per vehicle mile traveled is considered a reasonable minimum for the cost of pollution.
[16] This cost of carbon accounts for impacts on the entire globe.
[17] This cost of carbon accounts for impacts on the entire globe.

Road Land Value

The land value per acre in each Massachusetts county was based on data from the Federal Housing Finance Agency (Holland 2014). The area taken up by roads in each county was based on data from the Massachusetts Department of Transportation ("Massachusetts Road Inventory Year End Report" 2017). The value of the land taken up by roads was determined by multiplying the county-level road area by the respective land value in each county. To reach an annual cost, the total value of the land was financed in a 20-year bond at a five percent interest rate. This term and interest rate were assumed after studying general obligation bonds. The average of the debt service during 20-year term was reported as the parking land value.

Consumer Costs

In addition to the public costs, there are significant costs to individuals who own vehicles. While not borne by the entire public, costs to consumers are important to consider because they are integral to the de facto private-public partnership that is the vehicle economy. The owners of private vehicles derive a variety of benefits that have differing magnitudes from their personal spending. As noted with the total costs, this study is not a cost-benefit analysis and does not intend to consider the benefits of car owning.

Consumer Cost of Owning a Motor Vehicle, MA

The top-ten registered personal passenger cars and light trucks by make and model were determined using data obtained by the Boston Globe from the Massachusetts Registry of Motor Vehicles (Wallack 2018). The 2018 list contained information from 4,571,544 motor vehicles. The cost estimate averages five years of the costs to own a 2019, 2011, and 2004 automobile for each of the top ten registered makes and models in Massachusetts. These years were chosen because Auto Alliance reports the average age of an automobile in Massachusetts is 10 years and the five-year average of these models proportionally allocated (one-third each) is 10.2 years ("State Facts" 2019). A number of industry sources were used to determine the five largest costs of owning a car. To avoid double counting from the publicly borne section, we did not include state or federal fuel taxes, sales and excise taxes, or registration and inspection fees. The following costs were calculated:

- the amount of depreciation for each year, make, and model by reducing the Kelly Blue Book Fair Purchase Price of the base (cheapest) version of each of the top ten-registered make and models in good condition by 20 percent in the first year a new car is bought and at a rate of 10 percent thereafter. This guideline of depreciation for automobiles was provided by CARFAX (Krome 2018).
- the amount of financing for each year, make, and model by allocating a 20 percent down payment of the Kelly Blue Book Fair Purchase Price to the first year, then assuming the remaining amount will be financed by a 5-year-term, 3 percent loan ("New and Used Car Price Values, Expert Car Reviews" 2019).
- the annual amount spent on fuel for each year, make, and model by dividing the average number of vehicle miles traveled per automobile in Massachusetts by the EPA's reported miles per gallon ("FuelEconomy.Gov" 2019). The number of gallons consumed by each year, make, and model was multiplied by the five-year (2013-2018) average price per gallon of all gasoline types in Massachusetts excluding state

and federal taxes ("How Much Tax Do We Pay on a Gallon of Gasoline and on a Gallon of Diesel Fuel? - FAQ" 2019).

- the amount spent on the full-coverage insurance rate for someone with a good-driving record for the year, make, and model in Massachusetts using Edmund's Cost to Own Calculator ("Cost of Car Ownership - 5-Year Cost Calculator" 2019). Data was not available for the 2011 and 2004 years, so we used the closest year as a proxy.
- the amount spent to repair and maintain for the year, make, and model in Massachusetts using Edmund's Cost to Own Calculator ("Cost of Car Ownership - 5-Year Cost Calculator" 2019). Data was not available for the 2011 and 2004 years, so we used figures from a Consumer Reports survey to determine how much people spend repairing and maintaining each make of a 10-year old car ("The Cost of Car Ownership Over Time" 2017).

The five-year cost to own each make and model of the top ten registered vehicles was averaged for the three years 2019, 2011, and 2004. This average cost to own a car was multiplied by the number of personal passenger cars and light trucks to calculate the amount of money spent on private ownership of motor vehicles in Massachusetts.

<u>Consumer Parking Costs</u>
The number of registered cars in Massachusetts was identified using data provided by the Registry of Motor Vehicles and made available through the Boston Globe (Wallack 2018). The number of cars was multiplied by 4 to calculate the amount of parking spaces and the area they cover. Four is a reasonable number of parking places to use for this determination (Shoup 2005; Gellerman and Ben-Joseph 2012). Estimates of the parking space to vehicle ratio span from three to eight. This total was multiplied by 99 percent because we assumed 1 percent of the parking spaces are maintained through government spending that we counted in the public budgetary section. This proportion was extrapolated using data from Lynn (Hamill 2019). The proportion of parking garage spaces to flat parking spaces was assumed to be 15 percent to 85 percent. This percentage is a conservative estimate based on Department of Commerce reporting that indicates since 1971 new homes constructed in the Northeast have been built with garages or carports at a rate of 66 percent (Cudney 2017). The cost per parking space when constructing a garage (Cudney 2017) and a flat lot ("2019 Asphalt Paving Cost | Asphalt Driveway Cost Calculator" 2018) we identified respectively. For flat spaces, the estimated price for an asphalt space, which can be as much as five time cheaper than a concrete space, was used. Parking space life was assumed to be 60 years based on interviews with transportation infrastructure analytics company and local officials (Birken 2019). The cost per each type of space (garage or lot) was multiplied by the number of each type of space. To arrive at an annual value, the total value was financed by a 60-year (the life of the space), 3 percent interest rate loan, and the average annual debt service was reported as the consumer parking cost. We assume one out of every four parking spots is at a vehicle owner's resident, so one quarter of this total cost is allocated to private costs. The other three quarters are considered the consumer parking subsidy.

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