Institutional Obstacles to New Transportation Technology Adoption

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A White Paper from the Pacific Southwest Region University Transportation Center

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16. Abstract

New transportation technologies are changing the ways we travel. This paper examines the institutional obstacles to not only adopting these technologies but deploying them in a way that increases equitable access and reduces greenhouse gas emissions. Meeting environmental and social targets will depend on how governments and private firms shape the implementation of new technologies. This paper reviews research from Political Science, Public Policy, and other relevant fields to show the role institutions play in guiding the implementation of new technologies. The review focuses on four areas of innovation– shared mobility, integrated mobility, road and congestion pricing, and connected and autonomous vehicles – to provide an overview of salient obstacles for new technologies. The paper then analyzes how the institutional landscape contributes to these issues through path dependence and jurisdictional fragmentation and uses insights from the literature to recommend policy actions to bolster cooperation and ease the creation or modification of institutions that will help steer new technologies toward a more equitable transportation system.

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Contents

About the Pacific Southwest Region University Transportation Center

The Pacific Southwest Region University Transportation Center (UTC) is the Region 9 University Transportation Center funded under the US Department of Transportation's University Transportation Centers Program. Established in 2016, the Pacific Southwest Region UTC (PSR) is led by the University of Southern California and includes seven partners: Long Beach State University; University of California, Davis; University of California, Irvine; University of California, Los Angeles; University of Hawaii; Northern Arizona University; Pima Community College.

The Pacific Southwest Region UTC conducts an integrated, multidisciplinary program of research, education and technology transfer aimed at *improving the mobility of people and goods throughout the region.* Our program is organized around four themes: 1) technology to address transportation problems and improve mobility; 2) improving mobility for vulnerable populations; 3) Improving resilience and protecting the environment; and 4) managing mobility in high growth areas.

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Disclosure

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Abstract

New transportation technologies are changing the ways we travel. This paper examines the institutional obstacles to not only adopting these technologies but deploying them in a way that increases equitable access and reduces greenhouse gas emissions. Meeting environmental and social targets will depend on how governments and private firms shape the implementation of new technologies. This paper reviews research from Political Science, Public Policy, and other relevant fields to show the role institutions play in guiding the implementation of new technologies. The review focuses on four areas of innovation– shared mobility, integrated mobility, road and congestion pricing, and connected and autonomous vehicles – to provide an overview of salient obstacles for new technologies. The paper then analyzes how the institutional landscape contributes to these issues through path dependence and jurisdictional fragmentation and uses insights from the literature to recommend policy actions to bolster cooperation and ease the creation or modification of institutions that will help steer new technologies toward a more equitable transportation system.

Institutional Obstacles to New Transportation Technology Adoption

Executive Summary

This paper examines the role of institutions in guiding the implementation of new transportation technologies. Institutions are the set of rules that govern every aspect of transportation, from the design of autonomous vehicles to where shared mobility devices can park. As newer technologies expand and add innovations, institutions should support and guide the implementation of technologies to further safe, equitable and sustainable transportation. Yet, institutions can also significantly hinder the development of new technologies. This paper provides a broad overview of the institutional needs of new technologies, the difficulties in meeting those needs, and recommendations for how to overcome common institutional obstacles.

The first part of the paper examines the institutional needs of four areas of innovation the California Transportation Plan 2050 identified as central to the future of the state's transportation system:

- Shared mobility – the ability to share vehicles across users.
- Integrated payment system – the ability to pay for multiple mobility services with a single method.
- Congestion and road pricing – levying a fee on drivers based on congestion level or distance travelled.
- Connected and Autonomous Vehicles (CAV) – vehicles that are self-driving through either connected or autonomous technology.

Addressing new technologies' institutional needs requires working with existing rules. The next part of the paper focuses on three types of rules where gaps exist between existing rules and the needs of new technologies: standards and regulations, finance and investments, and data governance and identifies developments that are likely to create contradictions.

The two primary sources of obstacles in meeting the needs of new technologies are jurisdictional fragmentation and path dependency. Jurisdictional fragmentation refers to the large number of different organizations, governmental, private sector, and non-governmental, that shape the rules governing the transportation system. Path dependency refers to how the adoption of a particular technology, past and future, fosters supportive infrastructure that can have the effect of "locking in" a technological solution, making it difficult to readjust to meet new demands. The third part of the paper provides a brief overview of the issues and draws from research to highlight how these obstacles may be overcome.

Based on our review, we recommend the following in the final section:

- **Use the California Transportation Plan (CTP) to spur cooperation between technology developers and communicate benefits to the public**. The CTP can work as an important communication tool to identify areas where cooperation between developers will be beneficial and to increase awareness of new technologies, especially in underserved communities.
- **Assess options for strengthening data governance and building local data-management capacity**. Multiple options have emerged for coordinating data management, including creating a new state agency or working with a third-party organization. Research and input from the public and private sectors are needed to establish clear guidelines to help decision makers choose a framework.
- **Invest in developing a versatile mobility wallet that will accommodate new technologies and efficient pricing.** Mobility wallets can be a powerful and inclusive tool to pay for multiple mobility services while integrating discounts and subsidies. The state should support mobility wallet innovations that span the full range of potential uses, including integration with road pricing.
- **Further curb space management reforms and integrate the use of connected infrastructure.** Cities are gaining momentum in reforming curb space usage to meet the varied needs of delivery services, shared mobility, and drivers. Connected infrastructure that can communicate space usage in real time to analysts and users can significantly increase flexibility, streamline revenue generation, and encourage shared mobility.
- **Encourage wider scheduling and fare coordination at the megaregional and state scales.** An increasing number of people commute across regional lines where public transit coordination often deteriorates. The state should expand on the progress regions have made in coordinating services to improve services and contribute to an integrated mobility system.
- **Pilot Transportation Network Company congestion pricing to investigate integration with location-based tolls.** The cities that implemented congestion pricing rely on existing, well-established technologies. California, however, is also considering a broader road pricing program that is best served by location-based tolls. Ride-hailing companies already use the technology that would enable such a toll and a pilot program would provide valuable data on congestion and road pricing, and shared mobility.
- **Develop rules for in-vehicle data collection.** The most reliable means of enforcing road pricing is through a device embedded in vehicles. While people are reluctant to have a device record their locations, the technology exist to ensure no information ever leaves the vehicle except the fee that is due. The state should develop a regulatory framework and gather input from the public and private sector to safeguard privacy.
- **Establish a land use governance initiative to anticipate the introduction of automated vehicles.** A fully automated transportation system is likely decades away. However, the increasing automation of driving, even if gradual, will impact how roads are used much sooner. Cities will benefit from guiding urban development in a way that is compatible with automated vehicles but also privileges shared mobility and active transportation.

Introduction

California is charting a path toward a more sustainable transportation system. Assembly Bill 285, signed into law in October 2019, mandates the California Department of Transportation to detail how the state can meet targets for reducing greenhouse gas emissions to 40% below 1990 levels by 2030. A specific element of this mandate is to include "a forecast of the impacts of advanced and emerging technologies over a 20-year horizon on infrastructure, access, and transportation systems" (Friedman, 2019). Developing such a forecast is challenging because the impact of new technologies is difficult to predict. Not only is technology changing quickly, but the scale at which any technology is adopted and how it is deployed are often unpredictable in early stages.

There are several obstacles to the widespread adoption of new technologies. Technological limitations are often the most obvious. Market forces and the willingness of users to adopt the new technologies can curtail the scale at which new services are used. These factors determine how quickly technologies progress. In addition, how new transportation technologies are adopted, the specific ways in which they are deployed, where, and at what scale, depends on how technology is governed (Docherty et al., 2018). Without strong guidelines, technological innovations are more likely to reproduce inequality in access to transportation, exacerbate environmental harm, and fail to ease commuting (Creutzig, 2021). In short, new transportation technologies need innovative institutions to govern them. This paper synthesizes the literature on institutional obstacles to not only adopting new transportation technologies, but also deploying these technologies in a way that maximizes their benefits.

What are institutions and why do they matter?

Institutions are broadly defined as the 'rules of the game,' a set of constraints that reduce uncertainty by providing structure to human interactions (North, 1990: 1). The first part of this definition highlights the role of institutions in facilitating cooperation and coordination between governments entities and between the public and private sectors by reducing the risk inherent in deploying new technologies. The second part emphasizes institutions' ability to shape behavior by creating rules that dictate what is legal or rewarded. Institutional obstacles, then, are rules that prevent the full deployment of a technology or constrain its development.

There is little doubt that technological innovation will move forward regardless of how institutions shape the transportation sector (Moscholidou and Pangbourne, 2020). The issues in the current transportation system, like congestion, air quality, and uneven access, create plenty of market opportunities for firms to exploit. The goal of this review is to show that institutions can hinder innovation by constraining how, where and when new technologies can operate. We also emphasize in this paper the ability of institutions to support technological development to achieve goals that have become central to the mission of transportation departments at the federal and state level, such as investing in a system that is safe, sustainable, and equitable.

The transportation sector is at what institutional scholars call a 'critical moment.' A clear problem exists in the form of congestion, pollution, and inequitable access, solutions are available, and people are weighing what to do (Buitelaar et al., 2007). Policymakers, community organizations, and technology firms have an opportunity to significantly shape the future of transportation. This paper emphasizes the importance of making institutions a central feature of next steps.

Scope of research

This paper reviews academic and expert research to show how institutions shape new technologies' integration with the current system and how that should guide future efforts to regulate and foster new transportation technologies. The review proceeds in four sections that develop a broad understanding of the wide-ranging role of institutions.

1. What are the institutional needs of the main technological innovations likely to disrupt the transportation sector? This paper focuses on four areas of innovation that the California Transportation Plan 2050 identified as central to the future of the state's transition to a more equitable and sustainable transportation system:
    a. Shared mobility – the ability to share vehicles across users.
    b. Integrated mobility – the ability to pay for multiple mobility services with a single method.
    c. Congestion and road pricing – levying a fee on drivers based on congestion level or distance travelled.
    d. Connected and Autonomous Vehicles (CAV) – vehicles that are self-driving through either connected or autonomous technology.
2. Addressing new technologies' institutional needs requires working with existing rules. This section examines how new technologies fit within the existing structure of transportation governance. The section focuses on standards and regulations, finance and investments, and data governance as priority areas for government interventions.
3. It will take time to modify a system that has developed around the dominance of the personal vehicle. This section provides and overview of two sources of obstacles: jurisdictional fragmentation and technological path dependency. Jurisdictional fragmentation refers to the large number of different organizations, governmental, private sector, and non-governmental, that shape the rules governing the transportation system. Path dependency refers to how the adoption of a particular technology will foster supportive infrastructure that can have the effect of "locking in" a technological solution, making it difficult to readjust should circumstances change.
4. The last section draws from the review to make two sets of recommendations. The first focuses on cross-cutting interventions that would benefit the development of all the technologies highlighted in the paper. The second set of recommendations focuses on recommendations specific to individual technological innovations.

While the review begins with an overview of the four individual areas of innovation, one of the main insights is that coordination between technologies is essential to achieving targets set by the state. Throughout the paper, we emphasize how facilitating coordination across different technologies will increase the benefits to users. This complementarity across different technologies has implications for how technology should be governed and associated public investments.

New Transportation Technologies and institutions

The four areas of innovation – shared mobility, integrated mobility, congestion and road pricing, and autonomous vehicles – while still evolving, all have real world applications and are in use on public roads in at least some cities. Institutional obstacles, therefore, are not so much hindering development as the obstacles shape how the technologies are deployed and who has access to them. Without institutions to guide the expansion of technologies there is a significant risk that new technologies will reproduce many of the issues and inequities found in the existing transportation system (Creutzig, 2021; Davis, 2018; Geels, 2012).

This section provides a brief description of each technology and outlines the institutional areas important to addressing transportation issues such as congestion, pollution, and accessibility. Three themes emerge:

1. Data and communication: Governments have begun to regulate how the personal data created by transportation services can be used. Much less has been done to build the capacity of governments to manage the large volume of data that new technologies will generate and to ensure that different transportation services can communicate with each other when needed.
2. Infrastructure: All four technology categories (shared mobility, integrated mobility, congestion pricing, CAV's) will rely primarily on existing infrastructure. Their development, therefore, relies in large part on traditional investments in public transit, road maintenance, and bike lanes, for example. But new technologies will change how existing infrastructure is used, requiring updates to land use regulation and integration with communication infrastructure.
3. Cooperation: The rapid pace at which the private sector is advancing the technological frontier leaves little time for governments to adapt. The uncertainty that this creates makes cooperation essential. There is a need to establish strong links between industry, government, and communities, but also among different government entities.

Shared Mobility

Shared mobility refers to shared transportation resources (like shared cars) and the technologies that streamline access to these resources for users (e.g., smartphone interfaces). The transportation services that fall under shared mobility include Transportation Network Companies (TNC) or ride-hailing firms (e.g., Lyft and Uber), micromobility (e.g., e-scooters), and car sharing. Each of these services is already well-developed with many programs throughout the country but each continues to innovate and to have the potential to expand considerably in their reach.

Shared mobility is a distinct kind of transportation technology because it relies largely on existing technology and requires little new physical infrastructure. The innovation is in how the services are distributed and accessed. Users use an app on their smartphone to schedule a ride, or rent a car, bike, or scooter. The technology's relatively easy integration with existing transportation systems and regulations means that governments have primarily been enablers of the technology (Dudley et al., 2017). Governments' role is to ensure access does not conflict with other road and sidewalk uses (Smith and Hensher, 2020). The enabling role of institutions has led to a ride hailing, as the most widespread form of shared mobility, doing little to reduce congestion (Henao and Marshall, 2019b; Machado et al., 2018) or increase carpooling (Morris et al., 2019), while creating concerns for safety (Morris et al., 2019), parking usage (Clark and Brown, 2021), and equitable access (Barajas and Brown, 2021).

Other forms of shared mobility are contributing to a more sustainable transportation system. Bike sharing and car sharing decrease the amount users drive overall and reduce the number of cars on the road (Shaheen et al., 2018). Innovations in secure communication that allow individuals to rent their personal car have the potential to greatly increase car sharing and private firms are well positioned to create zero-emission fleets (Martin and Shaheen, 2011). Car sharing, while a substitute for driving a personal car, has been estimated to remove up to 15 cars from roads for every shared car, making it a particularly effective means to decongestion (Millard-Ball and Murray, 2005). For these reasons, shared mobility has been identified as the cornerstone of a more sustainable transportation system. Increasing vehicle sharing could significantly decrease congestion and pollution without any other technological changes (Grindsted et al., 2022; Merlin, 2019).

The main institutional obstacles to the expansion of shared mobility are rules governing land use and data collection. While shared mobility does not require new immediate public investments to develop, the technology's expansion can quickly be limited by existing land use around parking and curb space management. The availability of parking directly affects people's decision to use shared mobility. People use ride-hailing more in areas where parking is expensive and scarce (Henao and Marshall, 2019a). At the same time, one study showed with data from Seattle that increase reliance on ride-hailing leads to induced demand for parking. Parking occupancy is estimated to not decline until shared mobility usage is over twice as high as current levels (Clark and Brown, 2021).

The increasing demands on curb space from shared mobility services, deliveries, and parking is in conflict with most existing rules that offer often-free parking and fixed prices (Dowling, 2018). Cities have begun to experiment with new rules to increase adaptability in how curb spaces are used. Some of these rules, like demand-based parking pricing will have indirect effects on shared mobility by increasing the cost of parking. Other programs that reform the prioritization of curb space toward active shared mobility (e.g., shared bikes) in Washington

D.C. (DDOT, 2021) or entirely upend the hierarchy of curb use in San Francisco will have more direct impact (SFMTA, 2020) by reducing parking at the benefit of shared mobility.[1]

Parking regulation and linking parking usage to real-time communication is especially important for car sharing. Car sharing can rely on two-way trips (returning the car to its original location), one-way trips (driving between two designated locations), or free-floating (parking anywhere within a designated area). For all forms of car sharing, parking availability is crucial for how cars are distributed, reducing uncertainty about availability, and incentivizing use through reduced parking cost (Ferrero et al., 2018). Research on free-floating car sharing is limited due to the small number of existing programs. Simulations show that parking policies like bundling the cost of the car rental with guaranteed parking or increasing the cost of parking for non-shared cars can lead to higher rates of car sharing (Balac et al., 2017; Jian et al., 2020). One study, based on data from a program in Austin, shows that higher cost and scarcity of parking increases the probability that a vehicle will be rented four-fold (Thakuriah et al., 2017).

The wider adoption of shared mobility, especially modes that are not car reliant, depends on broader changes to transportation infrastructure and land use. The lack of infrastructure to increase safety while using e-scooters and shared bikes is an important deterrent for potential users, especially those in marginalized areas with lower quality infrastructure (Pan and Shaheen, 2021). Therefore, while shared mobility requires the least investments for its deployment, it fits within a much broader effort to change transportation infrastructure through road diets (DDOT, 2021), the creation of linked transportation hubs (SCAG, 2022a), the integration of shared mobility in long-range planning (McCoy et al., 2018), and, generally, increasing the safety of roads.

The cities spearheading shifts in land use pair their efforts with an expansion of data collection. Some of these efforts focus on investments in complementary technology that can assist in tracking curb space usage and enforcing rules (NACTO, 2017) or increasing the efficiency and equitability of shared mobility hub siting (DDOT, 2021; Sandoval et al., 2021). An area that is particularly rife for institutional issues is the rectification of existing rules. San Francisco, for example, identified the regulations of TNC at the state level as an impediment on the city's ability to steer the industry toward more equitable goals and highlighting the need for supplementary local rules or reforms at the state level (Matute et al., 2020; SFMTA, 2020). One approach is to make the licensing of TNC and other shared mobility providers conditional on sharing some of their data (McCoy et al., 2018; SFMTA, 2020). Data sharing and governance has also been identified as a crucial factor in addressing issues of accessibility and discrimination that private providers can skirt without oversight (Barajas and Brown, 2021; Creutzig, 2021).

[1] The Santa Monica Zero-Emission Delivery Zone pilot is another example which, while not shared mobility, test how the shift in curb space use can benefit shared mobility indirectly. For more information: https://www.santamonica.gov/zero-emission-delivery-zone accessed August 28, 2022.

Integrated Mobility

Integrated mobility is a set of technologies that enable users to pay for multiple transportation services as a package, or in the same purchase. The earliest example of integrated mobility was farecards that allowed the user to travel on multiple transit systems with the same token. The ability of the farecard to communicate with the transit terminal means the terminal can adjust fares based on the agency, the distance traveling, or time of day, giving the user greater simplicity and transit agencies greater flexibility (Giuliano et al., 2000). An important feature of integrated farecards (and significant drawback if not included) is the ability to automatically apply discounts for riders.

This limitation has led to the development of a next generation of payment technology. Some agencies, like LADOT in Los Angeles, are partnering with other mobility services to develop a mobility wallet that will greatly enhance the ability to provide subsidies and discounts to mobility disadvantaged populations.[2] A mobility wallet takes advantage of the connectivity of smartphones (or alternative device) to allow the users to pay fares for all participating transit agencies and private mobility services without having to worry about different discounts offered. The wallet can also be designed to allow governments to easily credit users' accounts or update their discounts without using banks as intermediaries.

Mobility as a Service (MaaS) expands on the idea of a mobility wallet by integrating, information on schedules and connections, booking, and payment across all modes of transportation within a single platform (Jittrapirom et al., 2017; Sochor et al., 2018). Several MaaS program exist that offer a means to pay for a trip that includes public transit, ride-hailing, and micromobility within a single app. Some programs, like Whim in Helsinki, Finland, have started offering subscriptions that give subscribers unlimited use of all mobility services for a flat monthly fee (Jittrapirom et al., 2017; SCAG, 2022a).

Mobility as a Service builds on shared mobility but is a distinct service with broader needs. Shared mobility is a set of services provided by separate firms. Each service can function on its own and usually is available only where demand is most concentrated (Barajas and Brown, 2021). MaaS, in contrast, relies on a comprehensive coverage of services that, unlike shared mobility services, are dense and well connected (Arias-Molinares and Carlos García-Palomares, 2020; SCAG, 2022a). In addition, while shared mobility is largely the purview of private firms, governments tend to be more involved in MaaS, mobility wallets, and integrated farecards because they rely heavily on the integration with public transit systems.

[2] The Universal Basic Mobility Pilot was launched in April 2022. The program will provide 2,000 residents of South Los Angeles with a smartphone that link to a mobility account that can be used on public transit and private mobility services like Uber. Accessed on August 27, 2022: https://ladot.lacity.org/sites/default/files/press-releases/press-release-ladot-launches-universal-basic-mobility-pilot.pdf

Integrated farecard programs, as a precursor to MaaS, are a rich source of insights on obstacles to the integration of different systems. The California Integrated Travel Project (Cal-ITP) has identified access to reliable transit information, reducing friction in payment methods, and standardizing eligibility for discounts as priority areas (Baud, 2020). In addition, interoperability across networks, fare standardization and data infrastructure are major obstacles that require institutional support (Arias-Molinares and Carlos García-Palomares, 2020). Even if information is available and accurate, coordination between services that run on a fixed schedule, like buses, is essential for people traveling over longer distances (Du et al., 2016).

The integrated nature of Mobility as a Service heightens the need for seamless data sharing and, therefore, concerns about data privacy and security (Belanche-Gracia et al., 2015). Standardizing data formats and regulating access so that transit agencies and private mobility providers can easily share their data are essential to the service functioning (SCAG, 2022a). Many models currently exist for building an integrated data system, including platforms like the General Transit Feed Specification that provides real time transit information. MaaS, however, requires payment and service coordination across the public and private sector, a task that may be better handled by a third-party entity unaffiliated with governments or participating businesses (D'Agostino et al., 2019). The inclusion of discounts and subsidies requires further integration with administrative data, which are subject to strict privacy laws.

Alternatively, some have proposed a framework that enables data to work across systems (Pasquale, 2017). Instead of establishing a common data format and centralizing data, firms provide the language to read their data and allow the framework to generate the information relevant to the end user without having to collect data. This solution, however, requires high level coordination and authority to develop and implement the framework (which is proposed to work across European countries). The use of such a framework effectively solves the fragmentation issue by allowing a single farecard to 'talk' to all fare collectors.

The most significant limitation to MaaS, however, and reason the technology is more developed in Europe, is that MaaS relies on a dense, interconnected transportation system (Falconer et al., 2018). Europe developed a dense network of rail, public transit, and active transportation that is difficult to emulate. However, US regions have the potential to reach a critical mass that would enable a substantial uptake of MaaS. Beyond data interoperability, this requires coordinated investments in infrastructure. In other words, governments are not only enablers of the technology, but also participants in its development (Smith and Hensher, 2020).

Road and Congestion Pricing

The theory of congestion pricing assigns a dollar value to the time spent in traffic and assumes enough people will be willing to pay that amount to reclaim the time drivers would otherwise waste on the road and reduce congestion (Arnott and Small, 1994). In 2018, the overall cost of congestion was estimated at $87 billion (INRIX, Inc, 2019). The idea has since been expanded to consider emissions as another cost that congestion pricing can address. Road pricing, in contrast, is simply the idea that people should pay for the usage of roads.

The difference between road and congestion pricing is the goal. Road pricing is put in place primarily to raise revenue (usually for the purpose of road maintenance). Traditionally, road pricing was implemented with the use of tolls. Congestion pricing, in contrast, aims to improve the flow of traffic (or reduce emissions) by reducing the volume of cars on the road at any given time in a specified area. Cities in California are more focused on congestion pricing while the state has piloted road charges (based on vehicle miles travelled) as a fee that could replace the fuel tax (CalSTA, 2017; Wachs et al., 2018).

Congestion pricing, because it is area based, is easier to implement technically. There are five main tools for implementing congestion pricing (Cottingham et al., 2007; de Palma and Lindsey, 2011; SCAG, 2022b):

- **Cordon pricing**: This pricing program charges road users when they pass through (inbound, outbound, or both) a designated cordon around an area, such as a central business district. Examples include Stockholm and Singapore.
- **Area pricing**: Like cordon pricing, this method charges users that enter or exit an area, but also anyone who drives entirely within the area. The main example is London.
- **Highway pricing**: This pricing program charges road users for using specific lanes on a segment of highway or all lanes on a segment of highway. Highway pricing is commonly used throughout California and the United States.
- **Corridor pricing**: This pricing program charges road users for driving on certain roadways in a specific corridor. Vehicles are charged each time they pass a tolling point and tolling points are designed so the charge is closely related to the total number of miles driven on a priced roadway. This differs from highway pricing in that the tolls are located on local arterials, in addition to highways.
- **Distance-based pricing** : This method charges the user based on the distance traveled by a vehicle. The primary existing use of this method is applied to trucks in Austria, Germany, and Switzerland.

In addition, each of the pricing methods can be refined by varying the fee based on the time of the day and vehicle type (de Palma and Lindsey, 2011).

The technology to implement congestion pricing is well-developed. Since the use of toll booths, several alternatives have become more common.

- **Automatic license plate recognition** uses cameras to read the plate of passing cars and process them automatically to generate either a bill or deduct the fee from an account. The programs in London and Stockholm rely on this technology.

- **Dedicated short range communications** use a transponder equipped inside vehicles to communicate with a receiver on the road and charge the user automatically. Singapore and some highway tolls in the US (like FasTrak in California) rely on this technology.
- **GPS and Cellular technologies** rely on the information collected by a GPS unit installed in the vehicle or a cell phone connected to the vehicle to calculate the fee. This technology has only been applied to trucks in Europe.

As the existing programs in London, Stockholm, and Singapore show, technology is not the main obstacle to successfully implementing congestion pricing. Financial considerations are also in favor of congestion pricing programs. The existing programs all generated substantial revenues within two years of implementation (de Palma and Lindsey, 2011; SCAG, 2022b). The main obstacles are the willingness of drivers to pay fees and, in the case of multi-jurisdictional system, jurisdictions' willingness to participate in the program.

The primary institutional need for congestion pricing is in regulating revenue sharing. Even in cases where congestion pricing covers a single jurisdictions, other jurisdictions and constituents have a stake in the implementation since drivers from outside the congestion area are paying into the system (King et al., 2007). Cities are most likely to advocate for tolling if they stand to gain directly in the form of revenues. From an equity perspective, cities through which freeways pass (or are adjacent to freeways) should be the direct beneficiaries of revenues because they carry a disproportionate share of the pollution externalities (King et al., 2007; SCAG, 2022b).

For systems that rely on location-based technologies, the institutional needs become more complex. In contrast to localized congestion pricing which can rely on non-invasive technologies (license plate recognition or short range communication), road pricing works best when using a device that tracks how many miles a driver travels. Comprehensive coverage is not easy based on fixed infrastructure, making the use of devices installed in the vehicle preferable.

Road user charge programs are limited in scope. The only program that has been institutionalized is in Oregon where about 700 people volunteer to pay a VMT-based fee instead of the state's fuel tax (McMullen et al., 2016). California initiated a pilot project that included 5,000 participants (CalSTA, 2017). The Oregon program, like the California pilot project, allow for manual entry of miles travelled to offer the highest level of privacy. The alternative is to equip cars with GPS enabled devices that count miles travelled.

A statewide, comprehensive program, however, would not be able to function if most users opted for manual entry because each entry requires human verification (de Palma and Lindsey, 2011). Technological innovation in this sector, therefore, focuses on protecting the privacy of drivers (Goodin et al., 2009; Gu et al., 2018). A critical concern is that a device that records miles traveled would have a record of locations, and potentially much more, that would be in the hands of a government agency and any third-party entity involved in the processing of the data (as is the case in Oregon). One solution, which the European Union has legislated, is to mandate "thick clients." Thick clients are devices that process all the required information internally (i.e., onboard the car) and only shares the information pertinent to the fee (total mileage or the fee amount) so that no location data ever leaves the users' cars (de Palma and Lindsey, 2011).

Thick-client onboard units are already in use and provide an appealing solution to road pricing generally. Onboard units give government the most flexibility in enacting congestion or user charges and, from the users' perspective, the units have the potential to address important equity issues by automating discounts. Institutional hurdles include the creation of security standards, privacy regulations regarding the use and access of data, program structure (including the use of revenues), and substantial investments in equipping cars and building the infrastructure to collect information.

The high barriers to implementing on-board recording has led some researchers to look for alternatives. The Virtual Trip Lines (VTL) technology is a form of dedicated short range communication that relies on the communication between a collection point and the vehicle (through smartphones, for example). The technology is similar to that already in use by the California FasTrak program (Bayen et al., 2018). While this solution overcomes many institutional obstacles like privacy by strictly controlling what data is needed, VTL are not as comprehensive as an onboard device because the technology relies on fixed collection points (fixed infrastructure that communicates with the phone), which may not have universal coverage, especially outside freeway networks.

Connected and Autonomous Vehicles (CAV)

Vehicle autonomy operates on a spectrum ranging from minimal assistance to the driver to full automation. The U.S. Department of Transportation (USDOT) adopted the SAE J3016 taxonomy to define the different levels of automation. Levels 0 through 2 assist the driver who must always be supervising the car and able to take control. These features have become standard in many cars. As of 2022, vehicles at level 3 and above existed, but were not allowed on roads outside specific areas and were not for sale to individuals.[3]

Level 3 vehicles offer conditional autonomy, freeing the driver from actively driving under certain conditions, but require a person to take control when the conditions are not met (e.g., off freeways). As of 2022, Vehicles at level 4 have been deployed in some locations (e.g., Waymo One in Phoenix and pilot program in San Francisco). These vehicles operate as taxis without a driver on public roads. While the technology to move from Level 3 vehicles to Level 4 is expected to be well established in the 2020s, the transition to Level 5 and a fully automated system is not expected to happen for decades (optimistic estimates are for the 2040s)

[3] Based on information retrieved on August 25, 2022 on: https://www.nhtsa.gov/technology-innovation/automated-vehicles-safety

(Martínez-Díaz and Soriguera, 2018). Level 5 autonomous vehicles can operate under any conditions, fully replacing cars with a human driver.

Vehicles can reach full autonomy without being connected. The Waymo vehicles, for example, carry all the hardware and software on the vehicles and do not communicate with a centralized system. However, transitioning to fully autonomous system is expected to require the additional deployment of a cooperative infrastructure. That is, vehicles must be able to communicate with each other, with the infrastructure around them, and with users, adding the "connected" aspect to autonomy (Martínez-Díaz and Soriguera, 2018). A connected system removes some of the computing load borne by the car by making information available remotely. The ability of the car to connect to a centralized system that communicates real-time information enhances coordination (e.g., parking use) and makes information about the local context available (e.g., accidents) (Bagloee et al., 2016; Kondor et al., 2020).

The transition to autonomous vehicles will be gradual. Features will be added to commercially available vehicles that will increase the level of assistance the vehicle provides over time. While this gives more time for institutions to adapt, there is also a risk that decisions made in the early days of the technology will significantly constrain future innovations or required changes to the technology (Guerra, 2016). Even among the most proactive cities, there is a lack of discussion of these specific parameters and how to establish an institutional framework to govern them (Grindsted et al., 2022). Institutional discrepancies are already worsened by the devolution of rulemaking at the state level, which creates contradictions between states and with federal rules (Davis, 2018; Fagnant and Kockelman, 2015). The discrepancies between state regulations have allowed Waymo to deploy driverless taxi technology in Arizona first, but the lack of regulation elsewhere may limit how (and if) Waymo will operate as the company scales up operations. Local government variation in what technology is allowed could further exacerbate discrepancies.

The gradual introduction of autonomous technology means that a full range of vehicles, from non-autonomous to fully autonomous, will share the road. In a mixed environment where human-driven and autonomous vehicles share the road, the challenges are compounded and benefits of AV reduced (Cugurullo et al., 2021). Some have proposed to segregate autonomous and non-autonomous vehicles to maximize the benefits of driverless operation (Wang et al., 2021). Research shows that CAV will have fewer benefits and significant costs unless the vehicles are integrated with a shared mobility infrastructure (ITF, 2015; Reardon, 2020). The International Transport Forum, based on simulations, found that the lack of sharing would lead to greater vehicle miles traveled, urban sprawl and decreased mobility for lower-income people. Some large European cities are planning for CAV integration while prioritizing transit and non-motorized mobility to reduce the number of cars (Grindsted et al., 2022). While automated buses have similar limitations to human-driven buses, researchers have focused on automation as a solution to the last mile problem. Flexible shuttles that offer on-demand service can act as an effective feeder into the established transit system but the demands of sharing vehicles on routing penalizes the technology compared to personal car travel (Levin et al., 2019).

The human element compounds these issues. The public is able to make decisions when it comes to safety of the vehicle, which are unlikely to match the programmed procedure vehicles follow in case of emergency (Kalra and Paddock, 2016). These perceptions extend to automated public transit vehicles, which many people would not necessarily see as a preferable alternatives (Kassens-Noor et al., 2020). This poses a technological problem and an ethical one. Should humans have ultimate control even if human oversight introduces greater safety risks? In shaping institutions, government must contend with variation in people's perception and openness to the new technology (Manfreda et al., 2021).

Automated vehicle developers emphasize the safety advantages of removing the human factor in driving. Machines are faster to react and more consistent. This makes AV risk averse. The programming prioritizes safety and testing supports this claim. Waymo on-road testing and simulations shows that nearly all accidents were caused by road violations or errors by humans (Schwall et al., 2020). While this is a great benefit for safety, the programming of the cars may inadvertently reduce people's adoption of the technology if people perceive the cars overly cautious and impeding on their travel. The algorithms, for example, may paralyze the car when faced with unruly pedestrians, a feature that is beneficial to pedestrians and pedestrian-oriented planning, but detrimental to the flow of traffic (Millard-Ball, 2018).

How is new transportation technology governed?

The previous section highlighted some of the obstacles and opportunities associated with the development of shared and integrated mobility, road or congestion pricing, and vehicle automation. The review showed that steering these technologies to contribute to a safer, more equitable and sustainable transportation system will require a wide array of investments and changes in regulations, from changing how land use is governed to fine-tuning algorithm to support a walkable environment. This section provides a broad overview of how transportation technology is governed to highlight some of the main levers available to governments to enact change and their limits.

Standards and regulations

Standards are the set of rules that dictate how the transportation system functions, from the design of vehicles and roads to how roads can be used. While standards and regulations can often be used interchangeably in that a standard can be regulatory (i.e., the standard mandates a specific behavior, like adding seat belts to cars), standards include a wider set of rules, including those set voluntarily by industries and that require no government intervention, like computer programing standards (Schepel, 2005).

Regulations are rules that the government enforces based on the law. In the transportation sector, many of these rules are standards that ensure the safety of cars, and the roads people drive, cycle and walk on. The federal and state governments have focused primarily on the development of regulatory standards for new transportation technologies, especially autonomous vehicles which are breaking with established rules (e.g., not needing a steering wheel). Broader regulations have been slower to develop. Setting rules for the liability of autonomous vehicles, for example, intersects multiple areas of law that are more difficult to reconcile than technical standards.

New transportation technologies raise four main issues for the creation of standards and regulations that support innovation.

First, the hierarchy of government creates many opportunities for contradictions and conflicting rules. The ability of vehicles to cross many jurisdictions, local and state, put much of the regulatory mandate on the federal government to ensure safety standards are consistent and infrastructure operates as expected nationally. State agencies complement federal agencies. States have autonomy in establishing some standards, speed limits for example, but most have converged on a narrow set of standards for the rules that govern driving and infrastructure building.

New technologies, however, have created some wider discrepancies in regulation. The lack of a federal framework for regulating many of the new transportation technologies and their associated innovations (e.g., location data collected by TNC) has left states to create their own set of regulations. California has been comparatively proactive in regulating new technologies and has generally been stricter. This resulted in California companies, like Waymo, to test their technologies in different, more permissive, states.

Local governments are bound by federal and state regulations but have considerable authority over transportation through their zoning and planning powers. The ability to regulate street design and parking requirements, for example, has far reaching consequences for much of the transportation system and the ability of new transportation technologies to function universally. Municipalities have the authority to support car-sharing by providing dedicated parking (e.g., Sacramento, CA) or ban e-scooters by not recognizing their right to operate on streets (e.g., Austin, TX). Transit agencies have narrower regulatory powers but have also become important players in the transportation system as multi-modal mobility has become a priority for state and federal governments.

Second, the transportation sector must contend with industrial interests. This is a longstanding issue. The Federal Motor Vehicle Safety Standards was created in 1966 to dictate a set of standards for vehicles the National Highway Traffic Safety Administration (NHTSA) enforces. The NHTSA is illustrative of the difficulty of institutionalizing standards. The agency was developed based on the principle that automobile safety was a technical issue that could be resolved through a set of rules on how to design and operate cars. While the agency was successful in reducing traffic fatalities (Waller, 2002), the enforcement power of the agency was systematically challenged by automakers who made enforcement political rather than technical

(Harfst and Mashaw, 1990). The shortfalls were emblematic of the difficulties of translating an agency's mandate to actions. Rather than fundamental flaws in the agency's structure, the interference coming from powerful carmaker lobbies, judicial review, and changes in administration all played a role in undermining new rules (Nader, 1991).

The influence of car makers and other actors is a defining feature of the governance structure of the transportation sector. Standards do not flow from the federal level to lower levels and industry. The increasing complexity of vehicles and the entry of new firms with little to no background in the transportation sector has created a field where many rules originate locally and within the private sector, including some standards that are wholly private, enforced without state interventions for the purpose of coordination (e.g., computer programing standards). Other standards are enforced by the state but written by specialized groups, like AES, a global association of engineers that focuses on mobility, which developed many of the standards for automated vehicles (Canis, 2019; Schepel, 2005).

Third, new technologies have considerably increased the pace at which regulations would have to be created to keep up with new developments. The rapid pace of innovation in the private sector, and their ability to deploy rapidly, means that governments rarely have the opportunity to plan how to regulate new technologies and coordinate across levels before a service has become embedded in a city (Marchant et al., 2011). This creates issues as a technology often emerges locally, Uber starting in San Francisco for example, only to be regulated at the state level, preempting the ability of the local government to devise regulations adapted to the context in which the technology operates. Similarly, in the absence of federal directives, the California Department of Motor Vehicles regulated the permitting for autonomous vehicles in California, but the rules conflicted with the federal regulations that were later established.[4]

Fourth, new technologies are no longer sector specific. New technologies rely on a mix of physical infrastructure and digital infrastructure. Micromobility quickly becomes complicated when considering the intersection of mobility rules (where e-scooters can travel), infrastructure (provision of parking), and communication (privacy of locational data). Some cities have been relatively quick to adapt. Los Angeles, for example, implemented a data governance framework that mandates data sharing protocols for all micromobility providers that helps enforcing rules, assist the city in planning where to add infrastructure, and reach a broader population. Other technologies, like autonomous vehicles, are not constrained to a single jurisdiction and require greater coordination that usually impedes rapid Reponses. While the federal government has taken a leading role in establishing standards for security (USDOT, 2021), making sure that the private sector meets safety standards, there is a critical gap where communication networks

[4] The DMV initially required that a person to be behind the wheel at all times in autonomous vehicles, but the federal level issued directives that were more permissive creating confusion for firms operating in California. The regulation was updated in 2018 to align with the federal level and other states competing for investments.

are concerned that transportation agencies alone will not be able to fill because communication is outside their mandate.

Finance and investment

Finance and investment are a secondary issue for new technologies developed primarily in the private sector. Governments, however, are instrumental in the development of other technologies that are inherently tied to public infrastructure (road pricing) or public services (integrated mobility). In all cases, state investments are important because all newer transportation technologies currently in use not only rely on public infrastructure (i.e., the road network), but need specific kinds of investments. Shared mobility will only grow if bike infrastructure improves, and curb space use accommodates shared cars and greater flexibility for ride-hailing. Autonomous vehicle function better on roads with clear signaling (e.g., visible lines on the pavement) and fewer obstacles like potholes.

Infrastructure investments are a driving force of transportation planning. The California Transportation budget allocates close to 80% of its $32 billion fund to agencies whose main task is to maintain and expand infrastructure. This includes road maintenance, rail expansions, and investments in transit such as installing a touchless payment system (2021-2022 California Spending Plan). About 60% of the budget comes from the state's special fund, which relies on fuel taxes and vehicle-related fees. Another 20% of the fund comes from federal sources. This means that infrastructure investments are largely determined by the state agency, Caltrans, with significant influence from the federal level.

Local governments, however, have significant capacity to invest in infrastructure through their access to federal, state, and regional funding. The Los Angeles' Mobility Plan 2035, for example, outlines 15 possible sources of funding above the city level (General Plan, 2016). Many of the funding channels are conditional and restricted to a specific use, but their application can cover a wide range of uses, including infrastructure that promotes walking and biking, programs to reduce greenhouse gas emissions, and initiatives to increase road safety.

In addition to direct funding for transportation, funding for agencies like the Air Resource Board significantly expand the range of transportation programs that receive funding, particularly programs that may be more experimental and at the technological frontier. The expansion of electric vehicle charging infrastructure, for example, has been subsidized by the California Energy Commission through the California Electric Vehicle Infrastructure Project (CALeVIP). Pilot programs, like Mìocar, an electric car-sharing project in the San Joaquin Valley, have received most of their funding to buy cars and install charging infrastructure from the Air Resource Board (Rodier, Harold, and Zhang, 2021).

Innovation extends to financing itself. Newer instruments like leveraged procurement agreements and category managements enable the public sector to consolidate and maximize its buying power when investing in transportation infrastructure (Laurent, 2019; SCAG, 2022a). These products rely on the maximizing purchasing power when buying for related purposes and are available to local jurisdictions (Jared and Margolin, 2022). Here, too, the benefits are greatest when working across technologies to identify complementary investments and in coordinated fashion among government entities.

New investments will accelerate the growth of new technologies, but new technologies also create new issues for transportation finance. Traditionally congestion pricing requires careful financial planning because the tolls reliably generate excess revenue. Even when a cordon is entirely within one jurisdiction, revenues are generated by people coming from outside the borders of that city and no congestion pricing will be supported without revenue distribution. In the case of Stockholm, an arrangement was devised to share the revenues in ways that benefitted jurisdictions outside Stockholm by investing in transit expansion and housing development around new stations. In cities where much of the freeway infrastructure passes through marginalized communities, even if residents are not necessarily paying more, the cities should receive compensation for the disproportionate burden of pollution (King et al., 2007). The loss of parking revenue due to the increase reliance on shared mobility may similarly lead to some jurisdictions opposing the technology's expansion.

The clearest impact of newer technologies on transportation finance is the growing momentum to transition the state to selling only electric cars by 2035. The gas tax that people pay every time they fill their tank is a major source of funding. The combination of increasing fuel efficiency and growing share of electric cars will quickly decrease how much revenue the tax generates. People are not opposed to alternative means of generating revenues to fund transportation infrastructure, but the alternative needs to make clear how it benefits users (Wachs et al., 2018).

Data governance

Data governance is an evolving field for governments. Governance pertains to the rules governing the collection, use, management, and sharing of data (the technical aspects) and how those rules are applied and changed (Choenni et al., 2022). Most activity has focused on the regulation of technical aspects, especially security and privacy for good reasons. Large surveys indicate that the public are generally concerned about security vulnerability in the system (e.g. hacking of autonomous vehicles) and the large amounts of personal data collected and shared (Kyriakidis et al., 2015; Manfreda et al., 2021). However, data governance aims to create a broader framework that includes security and privacy but extends to integrating data across services and ensuring equitable access.

The federal government passed the Internet of Things (IoT) Cybersecurity Improvement Act of 2020, which sets standards for securing networks against cyberattacks. The bill mandates the National Institute of Standards and Technology (NIST) and the Office of Management and Budget (OMB). The NIST must develop standards for IoT devices, and the OMB is charged with reviewing agency standards to ensure compliance. While the bill only applies to devices owned by or connected to federal agencies, regulations would cover much of the transportation sector that is often linked to federal agencies.

The State of California anticipated the federal regulation and passed SB-327 in 2020. The bill requires manufacturers of connected devices to take reasonable steps to secure the data collected. The bill also includes text on the data collection and the deemed responsibilities in safeguarding such data. In The United States, California is at the forefront of data governance. It is the only state also to have passed data privacy laws (SB-1121 and the California Privacy Rights Act). Importantly, these laws preempt and supersede any local laws, ensuring a state-wide standard.

In addition to privacy laws, some agencies like the California Public Utilities Commission (CPUC) have taken a leading role in regulating mobility technologies and data (Dudley et al., 2017; Matute et al., 2020). One of the goals is to establish clear standards for data formats so that private mobility firms can be held accountable more easily and their service integrated with the broader transportation system. These initiatives provide a starting point but tend to create gaps with local governments and agencies. For example, standardizing data formats may put increased burden on smaller agencies that lack the capacity to meet these standards or deter startups that operate in a different state with different standards.

Security and privacy focus on the data management of one firm. Much less has been done to facilitate the integration of data across multiple mobility services, which would increase both the volume and complexity of data. It is unclear to which extent existing data governance frameworks are adapted to the demands of massive data flows and coordination with local jurisdictions (Stickel and Vandervalk, 2014). Research based on a focus group of state DOT officials, federal agencies, and experts identified changing the organizational structure of governance and the lack of executive support as primary obstacles to coordination which intersects with the technical upgrading (of both technology and staffing) of state and local agencies that will be needed to operate in a new data rich environment (Hall, 2017; see also Creutzig, 2021; Harrison et al., 2016).

Another sector that does not fit within a security-focused framework is the regulation of algorithms. The algorithms that private firms develop to automate management of rides, placement of shared bikes, and pricing are sets of rules that constrain what the users (both service providers and consumers) can see and do. These algorithms have gone largely ungoverned and risk reproducing the biases embedded in existing institutions and practices (Löfgren and Webster, 2020). Algorithms are proprietary technologies beyond the reach of many regulations, but must conform to enforced rules (e.g., non-discrimination) giving institutions a prominent role in shaping how algorithms are developed.

Institutional change in the transportation sector

The greatest benefits from new transportation technologies will come from them working together. Programs like the Universal Basic Mobility project in Los Angeles and Cal ITP are investing in linking technologies to serve those that have historically been marginalized. The ability of technologies to work together depends in large part on government entities, the private sector, and communities to coordinate their priorities. This section focuses on two obstacles to coordination and highlights how governments have overcome them:

- Jurisdictional fragmentation multiplies the number of actors that have a stake in how technologies are deployed and have the authority to hinder developments that run against their interests. Governance structure, who is at the decision-making table, is often difficult to change. Yet, shifting power structures and building trust through communication can facilitate coordination work within existing structure.
- Path dependency refers to how the structure of the transportation system, the interplay of infrastructure and government entities that regulate the system, favors policies that reinforce the status quo. Climate change is providing the kind of large-scale shock that can lead to rapid shifts in policy and reforms.

Jurisdictional fragmentation

The impact of jurisdictional fragmentation on the deployment of new transportation technologies has not yet been properly studied (Pangbourne, 2021). Many of the documents guiding the regulatory plans for new mobility technology are developed by cities rather than regions (Moscholidou and Pangbourne, 2020). This is evident in initiatives like the reform of curb space use in San Francisco. Changing the rules within San Francisco may incentivize car sharing but miss the opportunity to link with cities with which San Francisco share large commuter flows, like Oakland. Integrated fare cards are an example of successful but incomplete coordination. Clipper includes all transit agencies in the Bay Area and TAP includes all transit agencies in Los Angeles County. However, coordination has been more difficult in connecting to regional neighbors like the Central Valley in Northern California and Orange and San Bernardino Counties in Southern California (SCAG, 2022a).

Fragmentation itself is not an automatic impediment to regional coordination, but overcoming some of the issues it gives rise to requires sustained cooperation and institution building (Bartolini, 2015; Callahan, 2007). Solutions tend to focus on two types of institutional changes. The first is the creation of intra-municipal governance structures like Metropolitan Planning Organization and Councils of Governments. The second is to rely on the state’s ability to supersede municipal rules.

In the American context, both strategies have met with great resistance. Despite the status of municipalities as creatures of the state, entities that are wholly dependent on the state for their political legitimacy, there is substantial evidence to show that local governments possess great autonomy in crucial areas such as land use planning (Berman, 2019). The ability of local governments to control land use, an institutional framework that encourages the proliferation of local governments rather than consolidation, and the structure of revenue generation distribution have all contributed to an environment where local governments are in competition with each other and suspicious of regional and state governance (Freemark et al., 2020; Ulfarsson and Carruthers, 2006).

While land use planning is under the purview of local governments, transport planning is likely to lie within the control of regional governments, causing a disconnect between local land use planning and transportation. At the same time, existing laws about how local governments exercise power over land use and taxes enables resource hoarding. Local governments rely on locally generated property and sales taxes to fund many crucial services. This leads to great variance and inequality between localities, as well as difficulty in generating cross-municipal coordination. In other non-U.S. regions with similar jurisdictional fragmentation, like London and Paris, many services are funded or provided directly by the national or metropolitan governments, making the municipality where an individual lives less relevant to the quality of services they enjoy. When funding is redistributed or shared at a greater regional level, research shows that the motivation and ability to engage in hoarding of services and resources is lessened, and greater coordination across municipal boundaries can be achieved.

The autonomy of local governments has made regional governance challenging. Portland, Oregon established a more representative and powerful structure with elected representatives to bolster the legitimacy of their regional governance institutions. The federal government can also bolster MPO ability to overcome fragmentation by instituting clear mandates the MPO have authority to pursue (Lefèvre, 1998). However, regional mandates tend to be narrow and the autonomy of local governments creates conflicts that regional institutions cannot easily resolve (Freemark et al., 2020).

The variation in governance structure and informal ability of governments to act together leaves much variation in the success of regional organizations with some overcoming important barriers while others do little to mitigate the effects of fragmentation (Weinreich et al., 2018). California stands out thanks to a state-level institutional framework that channels funds through counties and, therefore, mitigates the ability of municipal governments to opt-out of public transit services (Weinreich and Skuzinski, 2021). However, the structure simply shifts the fragmentation to the county level, which in regions like Southern California creates limitations.

The formal structure of transportation funding and requirements for coordination that exist at the state level in California does not eliminate regional variation. The transportation networks in the Bay Area and Los Angeles regions are better coordinated than many places in the United States, but the Bay Area is better integrated across counties than Los Angeles (Weinreich and Skuzinski, 2021). Informal institutions and exogenous factors play a larger role in explaining this variation. The geographic fragmentation the bay creates in the Bay Area has fostered greater intra-county cooperation to knit the region together through the construction of bridges, operation of tolls, and a regional transit network. Geography alone, however, is not the explanation. The networks of actors in the public and private sectors that enabled the planning of a regional infrastructure are the ones that execute a vision that can overcome geography (Rode and da Cruz, 2018; Storper et al., 2015).

The networks that underlie regional governance can also work to undermine local authority by relying on the state government. Here, too, formal institutions are not enough to explain variation in outcomes. While the state's authority supersedes local authority, the state does not use that authority systematically. The California legislative activity in housing policy shows both the increasing willingness of the state to intervene in local land use regulation, but also the reluctance of many legislators to pre-empt local authority. Each measure is the culmination of intense organization by developers, community organizations, and other private actors.

The relationship between industry, local government, and the state is important for new transportation technologies. When ride hailing companies first emerged, they were both very local (San Francisco) and functioning in a regulatory void. When the firms lost the argument for their ability to work without new regulations, TNC moved to establish the regulatory authority directly at the state level rather than with the San Francisco administration (Flores and Rayle, 2017). In doing so, TNC bypassed the fragmentation problem entirely, but also the opportunity for cities to have a say in how ride hailing services would function within their boundaries, or how such services should integrate with public transit agencies (Davis, 2018).

Just as the variation in coordinating actions among jurisdictions has no simple explanation, successes tend to emerge from a complex interplay of factors. A case study of TRANSCOM, an organization dedicated to improving coordination among mostly transportation agencies in the highly fragmented New York Metropolitan Area achieved notable success in developing the institutional infrastructure to facilitate collaboration. The success of TRANSCOM is attributed to having a well- and narrowly-defined purpose, demonstrating organizational legitimacy by providing tangible benefits to members, respecting members' autonomy, sustaining strong relationships and seeking out leaders to advocate on behalf of the organization (Plotch and Nelles, 2017). The results echo a case study of the Bay Area and Los Angeles that attributes the better coordination in the Bay Area to a well-developed network of government and industry leader who share a clear vision for the region (Storper et al., 2015).

While sustaining cooperation relies on some intangible factors, like maintaining good relationships with stakeholders, concrete actions can support these relationships and network development. There have been notable successes, for example, in implementing ambitious programs that impacted multiple jurisdictions without impinging on their autonomy and aligning their interests. The implementation of congestion pricing in Stockholm was the result of sustained effort from the Stockholm city government and national government to build consensus (Olsson and Davis, 2017). The city cleared hurdles through a broad framing effort. In defining the issue along several lines – funding for housing and transportation infrastructure, traffic control, and environmental protection – the city found enough support among the affected jurisdictions to win a popular referendum. How an issue is framed is consequential. The expansion of the bus network in London accelerated thanks to local conflicts over congestion which pushed politicians to shift how they framed addressing congestion from highway expansions to focusing on public transit (Ray, 2021).

Building support for regional- and state-scale transportation innovation should begin with communication to develop a shared vision (Karlsson et al., 2020). Information is important for generating and changing institutions (Briggs et al., 2015; Koski and Workman, 2018; Shepsle, 2001). Information and communication technologies generate vast amount of information that can be instrumental in understanding how institutions should change to meet targets (Koski and Workman, 2018), creating compelling communication to relevant actors (Reardon, 2020), and support transparency and trust. Institutions are uniquely placed to effectively gather and process information because of their regulatory powers.

Path dependency

Path dependency arises when a technology or behavior becomes deeply entrenched and resistant to change. Path dependency is important for innovations in the transportation sector because of the high degree of uncertainty that exist about the technologies and the dominance of the current system centered on the personal car. Path dependency, therefore, applies to the technical aspect of new technologies and public policy.

Early studies of technological path dependency explained why, despite knowledge of superior designs, some technologies persisted. The classic example is the QWERTY layout of the keyboard, which has persisted despite the existence of multiple superior layouts, advances in the technology, and the relatively low cost of change (Torfing, 2009). The QWERTY layout persisted because of the interaction between the technology and the user, who became accustomed to that configuration of keys. As the number of people using keyboards grew, the social and economic cost of changing the layout became prohibitive so that the default layout never changed.

The example of the keyboard illustrates a situation where designers knew which layout was more efficient. The same is not true with new transportation technologies. Shared mobility, a more mature technology, is still undergoing active development and is subject to change rapidly in ways that governments (and competitors) cannot anticipate. This creates a situation where governments can choose to regulate what already exist or wait for the next iteration which may be closer to a stable version of the technology. In the case of TNC, there was no choice. Ride-hailing companies deployed their technology and forced the hand of government to come up with rules to regulate firms and their operations. Automated vehicles are closer to a choice. Governments can mandate that the vehicles stay in controlled testing environment until the vehicles meet certain criteria, leaving regulators more time to create new rules.

The uncertainty surrounding new technologies has two implications. First, the choice of regulation is consequential. Setting a set of rules for how autonomous vehicles behave is likely to be persistent and difficult to change once the rules are implemented. Second, the choice is not just technical and but also political.

Path dependency applied to political system and public policy puts greater emphasis on the role of organizations and the people running them (Curtis and Low, 2016). The transportation infrastructure that supports the use of cars certainly reinforces path dependency but is not enough to explain the persistence of single-occupancy vehicles. Most people in wealthy countries live in cities that encourage car reliance and have grown at increasingly lower density (Briggs et al., 2015). Yet, there is a significant variation in how cities plan and prioritize alternatives to driving and invest in public transit (Curtis and Low, 2016). The way people understand their role within an organization is important for understanding the variation in creating alternatives to driving. Institutional culture lastingly shapes what people see as desirable and acceptable so that even when a city pursues reforms the status quo tends to persist (Davis, 2018; Marchant et al., 2011; Reardon, 2020). The changes to safety standards for cars happened over many years and more slowly than the available technology would suggest because of the structure and culture of the NHTSA made working with car manufacturers difficult (Nader, 1991).

The lack of institutional innovation to match technological innovation is the result institutional inertia. Institutional inertia has been studied at length. The layering of institutions, the creation of new institutions without removing or accounting for the mandate of existing ones, leads to increasing contradictions and conflicts that are difficult to overcome (Orren and Skowronek, 2004). In addition, the incentives of politicians to prioritize stability are strong. In short, politicians would rather work and campaign within a system they know (even if the system is not working for their policy goals) than try to change the system and incur the risk of making things worse (Shepsle, 2001).

The political science literature focuses on understanding institutional change; the field, therefore, provides little guidance on how to guide or accelerate change. One insight from this literature is that rapid institutional changes tend to happen because of a system-wide shock. Traditionally, these might be wars or uprisings. Climate change is an apt analog that is more relevant to the transportation sector, as one of the leading (the leading sector in California) contributors to greenhouse gas emissions. While climate change is not as immediate as an uprising, the mounting evidence and cost of natural disasters has changed the political calculus in California, as evidenced by the adoption of the Advanced Clean Car II regulation in August 2022.

The increasing environmental pressure is a powerful driver for change because climate change directly affects culture, what people see as acceptable. Of the many arguments the Swedish government offered, framing congestion pricing in terms of environmental impact reduction was what convinced citizens of its value (Olsson and Davis, 2017). The shift in people's priorities can lead to increasing demand for multi-modal transportation options, more compact and connected urban environments, opening the field to more aggressive policy interventions (Geels, 2012).

Informal institutions guide expectations about mobility and powerfully influences preferences away from autonomous vehicles for example (Kyriakidis et al., 2015). Consumers' preferential choices are actively shaped by their surroundings and vice versa (Ruxandra & Shahrazad, 2021). If governments can assure commuters that the new transportation technology will adequately improve the system and financial revenue (e.g., future taxes and road charges) can be generated to aid the cost barriers to the changing technology landscape, people will be more willing to adopt new technologies (Briggs et al., 2015).

In addition to providing up-to-date and accessible information about new programs, governments should consider the demands put on users. If a new technology is conflicting with established norms, providing alternatives in anticipation of the disruption can ease the transition. In both Stockholm and London, congestion pricing was tied to investments in public transit to assure people would have a reliable and affordable way of traveling downtown without driving (Kottenhoff and Brundell Freij, 2009). A more difficult version of this issue affects electric vehicle adoption (Anjos et al., 2020). There is considerable risk in large scale investment in charging stations if the market expansion does not follow. This is a specific manifestation of path dependence that involves shifting to an entirely new system. In most cases, however, the transition can be eased with the provision of alternative and the gradual phasing out of the older technology.

Policies for more equitable and sustainable transportation

This paper provided an overview of four areas of innovation in the transportation sector – shared mobility, integrated mobility, congestion and road pricing, and Connected and Automated Vehicles – to highlight areas where existing rules governing transportation hinder the expansion of new technologies toward a more equitable and environmentally beneficial system. The review identified three areas where rules were important barriers: data and communication, infrastructure, and cooperation. While each technology has specific set of issues, those themes established clear commonalty and laid the groundwork for a more integrated treatment of new technologies.

This section outlines two sets of recommendations. The first set focuses on cross-cutting programs. These are initiatives that would benefit the innovation landscape generally and the four areas of innovation the paper focused on. The recommendations emphasize the importance of pushing technologies to work with each other. If firms continue to develop technologies with no regard for how the technologies interact with the rest of the transportation system, the burden will fall on the state to reconcile differences. The development in silos will also lead to significant opportunity costs if, for example, a mobility wallet is not able to integrate with a road pricing device or if data format discrepancies prevent the coordination of curb space planning across neighboring jurisdictions.

California agencies also have a role to play in informing (and gathering input from) the public. Transportation innovations have so far been targeted in terms of users. No technology has had a universal reach the way that autonomous vehicles (if only by their presence) or road pricing will have. Research shows that providing information and selling programs early increases the chances of successes by giving government agencies a chance to revise the proposal to better reflect people's priorities.

The second set of recommendations is more targeted to the specific needs of individual technologies. In addition to echoing the themes for cross-cutting recommendations, the emphasis here is on building on the momentum of cities and regions to invest in shared mobility and public transit. Communication is, again, essential. People need to know about existing programs to understand how an expansion will benefit them. Publicizing demonstrations and transparently showing how a technology will work can ease the wider adoption later.

Cross-cutting recommendations

Use the next California Transportation Plan to focus on how technologies can work better together for communities

The California Transportation Plan 2050 emphasizes the contribution of new technologies to achieving the state's climate and equity goals. However, the plan discusses the contribution of each technology separately. The review shows that the technologies covered in this paper, the same that the CTP highlighted, can benefit substantially from cross-investments. The link between shared mobility and Mobility as a Service is, perhaps the most obvious and best developed (Pan and Shaheen, 2021; SCAG, 2022a). Other technologies can build on each other's innovations. Curb space management and road pricing, for example, may benefit from similar vehicle to infrastructure communication technology. Road and congestion pricing would benefit from integration with a mobility wallet. Shared CAV would benefit from building on the platforms already established for shared mobility.

Complementary technologies can be beneficial, but they need to be developed within a robust framework. The CTP is a long-range document that sets goals for the sector. Additional research should evaluate where technological overlap and potential complementarities exist, but also how they contribute to greater accessibility for lower income people and help the state reach sustainability goals.

1. Create a community-oriented education and communication initiative to inform people on the state's initiatives and existing programs
2. Invite industry representatives to provide input on how they see their technology integrate with others
3. Map technologies' institutional requirements and identify areas where areas of need intersect and where technologies need focused support.

Assess options for strengthening data governance and building state capacity for data management

Data governance and management is an area of high uncertainty that requires further research in the shorter term. Among the options to consider are the creation of an organization dedicated to data governance and management. This would create an entity with high data management capability that complements the work of other state agencies and assist local governments in developing their capacity. Transportation Operations Coordinating Committee (TRANSCOM) that spans agencies across the New York metropolitan area, is a possible model for such an agency. While TRANSCOM centralizes data management operations to coordinate responses to traffic disruptions (e.g., incidents and construction), the organization has no centralized authority. Policies about how to best achieve the organization's functions are decided based on consensus among members.

The first area of research is to determine the governance structure that is best adapted to California. A regional-scale organization that works as a data clearinghouse for each of the main urban regions in the state and can easily coordinate on state issues, may better balance local needs than a new centralized state agency focused on data management and coordination. In the contemporary context, membership structure is an important question. Depending on the level at which the organization operates, state agencies may be the primary stakeholders or transit agencies. The inclusion of shared mobility operators in some capacity is also important.

The second area of research is to evaluate the data management system itself. Cities have an interest in having authority over mobility in their jurisdiction. One of the main mechanisms is to grant cities access to some of the data from private sector mobility services. Los Angeles has an agreement with shared mobility providers that details which data are shared with the city. San Francisco has argued for a similar arrangement with TNC. In these cases, the city established an application programming interface (API) that allows the city analysts to access the service's data under certain conditions. The technology has much wider applications (D'Agostino et al., 2019). For example, cars equipped with a device to records locations can share data on road and parking usage among other things. A strict protocol needs to be in place to determine who can access the information, how much of it, and under what conditions. Given the number of potential applications, research is needed on what the state of the technology is and what the pros and cons are to help agencies make decision about creating standards.

1. Assess the trade-offs associated with using a third-party clearinghouse, interoperability framework, or centralized government authority
2. Convene a forum with mobility providers, public and private, to establish common ground for sharing data and gather input on the system that best aligns with industry interests.
3. Coordinate with federal government to determine at what level data and communication standards should be established.

Invest in the development of a versatile mobility wallet that will accommodate new technologies

The distinct advantage of mobility wallets over other forms of payment (e.g., using a touchless bank card to pay for transit) is the ability to bundle travel services and automate the application of discounts. Mobility wallets do not have to be integrated with Mobility as a Service (which adds the ability to plan and book journeys across multiple modes of transportation). The wallet can integrate sets of rules that automatically apply discounts if, for example, a traveler makes a transfer that qualifies, and incentivizes choices by discounting choosing bike share or public transit over driving (through TNC or car share). The ability to automate discounts, provide subsidies (as with the Universal Basic Mobility pilot program in Los Angeles), and reach marginalized population (e.g., unbanked people) makes mobility wallet a powerful tool for achieving transportation equity goals (Baud, 2020).

Some existing programs, notably Clipper in the Bay Area and TAP in Los Angeles County, offer payment options that integrate many features of a mobility wallet. The development of a versatile mobility wallet would build on these existing programs and expand their reach and streamline access. For example, linking the wallet to administrative data can automate the qualification for discounts or subsidies and remove undue burden on users. The function of the wallet can also be expanded by anticipating the use of other technologies like road pricing or curb space management digital infrastructure. Should road pricing integrate on-vehicle data recording, for example, the infrastructure for a mobility wallet could provide a private and secured mean of paying fees. The Virtual Trip Lines technology, which is a faster means of deploying road use pricing, would benefit greatly from the integration of a mobility wallet.

The mobility wallet is the kind of technological innovation that would benefit from a strong institutional framework, as discussed above, to guide its development. Several steps can be taken to pave the way for an effective and secure technology.

1. Assess the regulatory and technological obstacles to linking administrative data with a payment system.
2. Assess the best means of reaching unbanked populations who may also lack smartphones.
3. Explore the possibility for integrating mobility wallet technology with infrastructure to vehicle communication.

Targeted recommendations

Build on current efforts to reform curb space management to integrate the use of connected infrastructure and CAV

Several cities are implementing new rules for curb space management. These programs are shifting how curb space is regulated (to accommodate the increasing demands beyond parking), but, because the reforms are city-wide, they are not experimenting with new approaches to management. The expansion of Waymo and free floating car sharing services is adding a dimension to curb space management that has been underexplored. Real-time management through infrastructure to user or vehicle communication could support the expansion of car sharing and automated vehicles.

Car sharing is the more developed sector that illustrates the potential of this innovation and already uses technology that lends itself to a pilot. Existing providers like GIG car share rely on agreements with the city to reserve parking spaces where the users can leave a car for free. This works when the fleet of vehicles is small (the largest program in Sacramento has 300 vehicles available) but could quickly hit limitations as the program expands. A pilot to empirically evaluate the ability of parking pricing to shift demand from personal cars to shared car could inform new rules for curb space management.

Such a pilot would require a short term investment in connected parking meters. The parking meters could send and receive information to a centralized system and adjust pricing automatically based on a set of rules. Free floating car sharing relies on a home zone, an area where cars can be dropped off freely. Connected meters within a home zone could take into account the number of shared cars in use to prioritize parking availability for the users by increasing the price of parking for non-shared cars or reserving spaces, the location of which would be communicated to the users through the car-sharing app.

Encourage scheduling predictability and standardization in fares over broader regions

The Los Angeles and Bay Area regions generate among the highest numbers of commutes over 50 miles (Salviati and Warnock, 2021). Many of these commuters have poor transit options and what transit is available often imposes high time and financial costs. Transit has made great strides in providing users with real-time information about transit schedules and some programs, like Clipper in the Bay Area, have coordinated their schedules and fare structure to make transfers easier and automatically apply discounts within their service areas. However, in regions like Los Angeles and the Bay Area where many people travel across counties and use multiple agencies (and modes), this kind of coordination needs to be expanded, eventually to be statewide (Baud, 2020; SCAG, 2022b).

Coordination can be improved through data collection and sharing, and governance. The ability of transit agencies to collect data on ridership has increased with the expansion of farecards. These data could be used to identify priority cross-agency connections and facilitate coordination. The Clipper BayPass Program aims to advance these goals with a targeted pilot that will use data from users who have access to transit for free to evaluate the fare structure of the system and areas for future investments.[5] State agencies can convene forums with MPO and agencies to expand efforts like the Clipper BayPass to include longer commutes and connections to shared mobility resources.

Pilot Transportation Network Company congestion pricing

The enforcement of congestion and road pricing would be easiest through a cell phone network or GPS-enabled device integrated with vehicles. Many technical and institutional hurdles are in the way of implementing this technology, but TNC build the capacity into their system. Each ride as a set start and end point, and the time of the ride is known. There is already a platform for transparent communication between the service and the customer. While TNC already implement a form of congestion pricing based on peak demand times, this pilot would add a fee based on location. Each single-rider trip that ends within a designated areas would be automatically charged a fee.

Research based on simulations finds that such a fee outperforms applying congestion pricing with a cordon that charges all TNC vehicles with no or one rider and a policy that prevents cruising with the designated area (Zhang and Nie, 2022). While the goal is to mitigate the contribution of TNC to congestion, such a pilot would have the benefit of generating data on using smartphones to implement congestion pricing and people's behavior in response to the fee, both of which would be valuable input for designing a broader congestion pricing scheme.

Develop rules for in-vehicle data collection

Research finds that in-vehicle data collection (i.e., location tracking) is the most effective way of enforcing a road pricing program, but also the most contentious. While most people willingly (or unwittingly) allow private companies to track their movements, they are wearier of sharing that information with the government for the purpose of levying a tax (and potentially more). A solution is to ensure people retain complete control of the data they generate when they drive. Data on driving could be collected either through location-enabled smartphones or through a device embedded in vehicles and used to calculate a standard fee to be collected so that no locational data or any derivative ever leaves the car (and could be wiped out regularly).

This technology has several features that deserve further study:

1. Enforcement: while the owner of the car retains control of the data, they also must not be to turn off collection.
2. Collecting information: one of the impetuses for road pricing is the increasing number of electric cars that do not need gas stations. Can the government require drivers to regularly share the fees that correspond to their usage and how?
3. Comprehensiveness: Will all cars be required to be equipped with a device?

[5] The Clipper Baypass is based on the recommendation of a report on fare integration (MTC, 2021) and includes students and residents of affordable housing projects. https://mtc.ca.gov/operations/traveler-services/clipper accessed August 28, 2022

4. Linking to other information: One of the benefits of in-vehicle data collection is that the device can be adaptive and build on other technologies. Fee collection could be linked to a mobility wallet that applies discounts for low-income drivers, for example.

Existing pilot programs in Oregon and California showed that the technology exist and that all these issues can be overcome when participation is voluntary. The next step is to create an institutional framework that protect individual liberty and communicates the benefits of the technology clearly to the public. Therefore, developing alternative scenarios for replacing the fuel tax as gas-powered vehicles are phased out could be a powerful tool for narratively engaging the public in the future of the state's transportation system.

Establish a land use governance initiative to anticipate automated vehicles

The success of Waymo in Phoenix suggests that automated vehicles could become a regular occurrence on roads in the next few years. Much effort has focused on permitting automated vehicles and establishing standards to ensure the safety of users and other people using roads. Many institutional aspects of automated vehicles have yet to be ironed out, like liability and specific rules the conditions under which automated vehicles are allowed to drive.

One area that has been largely overlooked is land use (Rode and da Cruz, 2018). There are many initiatives in California to reform land use around Transport Oriented Development, affordable housing, and curb space. While it is difficult to legislate for a technology that is only at the pilot stage, there are many existing changes in the transportation sector that can help in developing a governance framework.

Shared mobility and its connection to transit, like shared automated vehicle, rely largely on compact urban development (González-González et al., 2019; SCAG, 2022a). Automated vehicles work best in predictable environments easily legible by machines (e.g., clear road markings and demarcations with bike lanes), which aligns with land use planning that prioritizes active transportation and safer streets. In other words, many existing initiatives align with the needs for automated vehicles.

There is widespread skepticism that automated vehicles are a solution or preferable to driving traditionally (Manfreda et al., 2021). As the most disruptive of the technologies bound to enter the transportation system, governments should invest in involving local authorities, citizens, and private firms in how automation could shape our cities. This is an area that is contentious in California and elsewhere, but that is building momentum internationally (e.g. C40 Mayors' Agenda for a Green and Just Recovery, 2020; Rode and Heeckt, 2019). Leveraging pilot programs can help build momentum (Olsson and Davis, 2017). Programs like the Zero-Emission Delivery Zone in Santa Monica, the Waymo pilot in San Francisco, and Miò car share in the Central Valley, can show the benefits of change. Community outreach is becoming standard in transportation programs but are usually tied to a single project. Cities, in coordination with state agencies, should be proactive in involving residents in developing a vision for how cities will change through educational programs, events, and demonstrations.

Conclusion

Institutions are integral to the success of new transportation technologies because they shape the policies and regulations that will guide how new mobility options serve people. The optimism new technology firms project as to their ability to solve persistent transportation issues cannot be expected to materialize without an integrated institutional framework to set concrete goals for equitable and sustainable transportation. The process of changing existing institutions and creating room for new institutions, however, is difficult in the best of circumstances.

This paper outlined some of the factors that are important to consider in planning for institutional development. The evidence reviewed emphasized the stability of institutions and the link between institutions and the dominant form of transportation (tied to the built environment) that conspire against bold reforms. It is also increasingly clear that slow incremental change is not a viable option for addressing climate change (Hickman and Banister, 2014). The bolder and more immediate interventions, such as congestion pricing and shared mobility, require buy in from the public and private sectors and citizens.

California is uniquely placed to take a leading role in harnessing new transportation technologies for a more equitable and sustainable transportation system. The state institutional framework includes mechanisms for direct democracy and supports collaborative metropolitan governance. The state legislature is broadly supportive of an integrated governance structure for transportation and land use, and, importantly, many of the innovators in the transportation sector are located in the state.

The recommendations reflect the momentum of California. The suggested interventions build on existing initiatives and aim to advance innovations that will support institutional change. At the same time, uncertainty is a defining feature of new technologies. The risks of pursuing regulations that will foreclose future opportunities are significant and further research and input from not only experts, but also the public is critical in moving forward.

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Appendix

Conceptual background

This appendix provides additional information on concepts that appear in the paper. The theoretical background helps to understand the complex interactions that shape the transportation sector and why predicting the effects of policy is difficult.

The implementation of new technologies is the outcome of a complex set of interactions between state actors, businesses, communities, and individuals. While institutions are the rules shaping these interactions, they leave much room for interpretation and deviation, which has given rise to the term governance.

Governance is defined in contrast to government and formal institutions. Formal institutions are the set of rules that can be predictably enforced by an authority, usually the government. As such, formal institutions are the domain of government and government is defined by institutions. Institutions set clear boundaries that separate and govern organizations and the limits of their authority. They define how and what government can do. For a long time, policy making was considered to stem exclusively from government (Stoker, 1998). While the constellation of institutions was always complex, there was a clear direction in decision making from the top down.

Most institutional scholars draw a clear distinction between institutions and organizations. Institutions refer specifically to rules. While organizations may represent those rules as enforcers (e.g., court of justice) and be responsible for crafting new rules, they are separate entities. The conceptual separation of organizations and institutions is useful for policy analysis because the policy orientation of an organization may change without institutions changing (Shepsle, 2001).

The 21st century marked a shift in how scholars conceptualized policy and decision making. Globalization, government austerity, the growth of ever larger corporations, and new communication technologies were rapidly destabilizing the top-down hierarchy of policy making. Governance quickly became a catch-all term to discuss and eventually analyze policy outcomes. In the policy context, governance usually refers to a set of interorganizational networks that autonomously organize to achieve specific goals (Rhodes, 1996). The emphasis on networks of diverse actors outside the states shifted the balance of power away from the government in favor of private, especially business, actors (Jordan et al., 2005). However, newer conceptualizations have reached a more balanced definition that integrates institutions, government, and governance (Treib et al., 2007).

The conceptual integration introduces informal institutions as a critical element. Informal institutions are not codified and have no clear enforcement mechanism beyond societal expectations. Informal institutions are crucial because they guide how actors understand their role within the more formal structure. For example, it helps explain the friction that tends to accompany formal restructuring of agencies or businesses as actors' understanding of their role has been shaped under the previous set of rules and developed informal norms to navigate relationships within the organization (Rhodes, 2012). As such, informal institutions are critical in understanding how coordination, change, or implementation are achieved or why they fail to materialize.

Institutional structure is complex, and it often seems like the institutions matter less than who controls them and shapes decisions and enforcement. However, there are two reasons why institutional analysis is critical. First, institutions remain the main conduit through which decisions are made. Even if there is variation in implementation, the existence of an institution responsible for developing and enforcing a set of rules guides implementation (Pierre, 2005). Second, evidence shows that the structure of the institutions is consequential for how they function (Carrigan and Coglianese, 2011). In other words, institutional design and how it changes is effective in countering things like regulatory capture whereby an industry dominates the mandate of a regulatory agency. Similarly, institutional design can support or hinder coordination (Ray, 2021).

Yet, policies are not only about addressing problems, but they are also the product of the time and context in which they are crafted. They tend to focus on what is considered the appropriate response to the problem and not necessarily the most effective solution (Pierson, 2000). Policies, in other words, are the product of politics (Davis et al., 1993) and make politics (Pierson, 1993). For that reason, institutional analysis of change focus on the interactions that lead to decisions rather than the decisions themselves (González and Healey, 2005).

In explaining the link between policy and institutions, 1) policies are rules and therefore institutions, 2) policies change the political calculus and therefore can change how people either operate within the constraints of existing institutions by changing the allocation of resources or modifying the costs and benefits associate with alternative strategies or can change institutions directly (Pierson, 1993). An important and highly relevant consideration for policy making toward new technologies is that policies can significantly influence people's perceptions, a crucial aspect of the adoption of new technologies that deviate from the status quo. Have to be careful about what windfalls policies create and how it may shift the incentives of relevant actors. This may generate opposition (Hacker and Pierson, 2019).