DRIVING A SHARED, ELECTRIC, AUTONOMOUS MOBILITY FUTURE

What China, India, and the United States Can Learn From Each Other

BY GARRETT FITZGERALD AND RICHARD LI

"China and India have two of the fastest developing economies in the world and aspire to become global leaders in vehicle manufacturing and intelligent mobility technologies. Understanding how these countries are playing roles in shaping the global mobility future is the first step to ensuring a clean, efficient, and low-cost mobility future."

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ABOUT ROCKY MOUNTAIN INSTITUTE
Rocky Mountain Institute (RMI)—an independent nonprofit founded in 1982—transforms global energy use to create a clean, prosperous, and secure low-carbon future. It engages businesses, communities, institutions, and entrepreneurs to accelerate the adoption of market-based solutions that cost-effectively shift from fossil fuels to efficiency and renewables. RMI has offices in Basalt and Boulder, Colorado; New York City; the San Francisco Bay Area; Washington, D.C.; and Beijing.

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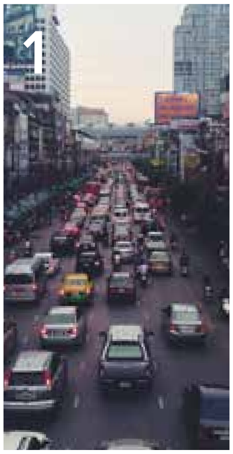


EXECUTIVE SUMMARY

EXECUTIVE SUMMARY

The global mobility ecosystem has been under a continual state of evolution for the past century, transitioning from a reliance on animal- and human-powered vehicles to gas-powered vehicles, and now moving toward shared and electric vehicles. While the rate of this transition and the key drivers behind it vary in different regions of the world, there are important observable trends that are common globally, some of which benefit society and others which have negative consequences. Identifying these trends and learning how they apply differently in different regions enables us to proactively shape the new mobility paradigm in a way that works for rather than against people and the climate.

Personal vehicle ownership continues to grow globally, improving personal mobility but also contributing to congestion and pollution, particularly in dense urban areas. At the same time, there has been an uptake in the use of mobility services such as Ola, Lyft, Uber, and Didi as well as new micro mobility such as e-scooters, bikeshares, and other light vehicles. As the rate of urbanization continues to increase, the demand for urban mobility also rises—putting greater stress on already overburdened systems potentially leading to more traffic, worsened air quality, more space taken for streets and parking, and less convenient travel.

Vehicle electrification addresses pollution issues (noise, particulate matter, and carbon dioxide) and can enable a more flexible electric grid that integrates renewables, but electrifying vehicles creates a need for new charging infrastructure and does not help lessen congestion on its own. Autonomous vehicle technology has the long-term potential to truly disrupt the current mobility paradigm—but the result of that disruption may not benefit society equally and in fact could result in less equitable access, more congestion, and more pollution. Ensuring that rides in autonomous vehicles are both electrified and pooled can mitigate these congestion and pollution issues and provide reliable, low-cost mobility for a rapidly urbanizing society.

China and India have two of the fastest developing economies in the world and aspire to become global leaders in vehicle manufacturing and intelligent mobility technologies. Understanding how these countries are playing roles in shaping our global mobility future is the first step to ensuring we get the best mobility future possible.

In this report we evaluate how mobility ecosystems are evolving in three fast changing markets: China, India, and the United States. Specifically, we evaluate the role of policy, economics, infrastructure, and behavioral norms in shaping the mobility transformations in these three countries. The result of this multi-region and multivariate evaluation provides insights into how society can be proactive at shaping the future of mobility.

The Three Markets

China has seen great success in kick-starting its transition to an electrified transportation future and is slowly phasing out subsidies as EV growth becomes more organic and market driven. China is now focusing on autonomous vehicles (AVs), with a supportive national-level policy and clear framework for road testing. China's head start on electric vehicles, its supportive AV policy, and its willingness to utilize congestion-reducing taxes and regulations puts it on a good path toward a future of shared, electric, connected, and eventually autonomous mobility.

The United States has made some progress with electric vehicles due to state-level efforts and a moderate federal rebate program, but the lack of a robust approach leveraging both push and pull policies has caused the US EV market to fall behind China's. However, the United States is leading the pack in the development of autonomous vehicle technology—even though public perception of the technology has been tepid. Unfortunately, there has been minimal demonstrated success in increasing the pooling and sharing aspect of the new mobility paradigm. In fact, in some denser cities ridehailing has lowered transit ridership and increased congestion, while in other cities with more urban sprawl personal car ownership continues to be the default mode of transportation. The United States can take a lesson from China and India and apply national and local policies to increase the level of sharing and pooling, in addition to electrification across the mobility service ecosystem.

While India has the lowest rate of car ownership of these three countries today, that statistic is changing rapidly as a result of urbanization and economic growth. However, the Government of India has wisely taken a tip from China's success on comprehensive policy and has implemented a national EV policy, FAME II. The rates of ridesharing and pooling are already higher in India but it has taken an approach that for the near term will leave out autonomous technology from its mobility future. Although autonomous technology appears to be a key milestone for mobility service really taking hold in the United States and China it appears to be less of a necessity in India, owing to the lower cost of labor relative to the capital and operational costs of vehicles and infrastructure.

Since each of these countries is at a different stage of development in these emerging technologies, they have the opportunity to share learnings and adapt each other's frameworks to accelerate the global mobility transition, as summarized in Exhibit ES2.

Recommendations and Takeaways

Electric vehicles

- Falling battery costs will bring EVs to price parity with combustion vehicles in the next 5–10 years across all three countries. While prices will naturally fall as scale and learning continues, supportive policies are needed to accelerate this transition and help overcome behavioral norms that bias toward gas vehicles and the advantages of already-built fueling infrastructure.

- A set of coordinated but distinct policies targeting both automakers and consumers with a healthy balance of rewards and punishments has proven to be most effective in China. However, each country has different capacities and appetites for top-down mandates versus subsidies and incentive packages.

- Adopting a uniform, national EV-sales mandate to send a clear message to automakers to scale up production—as has been done in China—can be effective across all countries.

- Focusing finite EV subsidies on high-utilization vehicles —as has been done in India—allows for the greatest leverage of public funds to increase electric vehicle miles while creating broad public exposure to EVs.

- A coordinated and collaborative approach to charging infrastructure investment and buildout that engages public and private sectors across both the transportation and electricity sectors is required for quick and efficient deployment of infrastructure at the level required to support rapid EV adoption.

Shared mobility

- Encouraging pooling and electrification of ridehailing through tiered taxes and incentives can minimize the impact on congestion and air quality and can help overcome the strong behavioral preferences for single occupancy rides.

- Ridehailing services will thrive in dense, urban environments where they are competitive with the price and convenience of personal vehicles and can be integrated with public transit (buses, rail, and subways) and nonmotorized transit modes.

- China and India have the potential to leapfrog the American paradigm of car ownership, due to their rapid urbanization and less entrenched car culture.

- Ridehailing services have the potential to both reduce congestion (through pooling) and integrate with public transit systems to increase ridership and enable better transit services. Well-designed policies should encourage ridehailing companies to develop products that meet these goals, instead of emulating the single-occupancy private vehicles that they sought to replace.

- Shared mobility must be well integrated with existing public transit infrastructure and should be part of future transit planning processes. Increased use of public private partnerships should be encouraged to ensure an efficient use of public resources and private investment.

Autonomous vehicles

- Establishing uniform, national guidelines around AV testing to provide a clear pathway to production by AV companies will create greater confidence in the market and improve public perception.

- Encouraging electrification and pooling for AVs through tiered taxes, to avert congestion and air quality issues, will help to avoid potential negative side effects of low-cost AV mobility services.

- Creating liability standards and vehicle monitoring protocols can help avoid fatal accidents and instill public confidence.

- China's funding and research into AV technology will likely accelerate the pace of AV development globally.

If adopted in isolation, each of these technologies can potentially create new problems and unnecessary additional external cost to consumers in the form of congestion, pollution, and added cost. Various policies have been implemented to minimize these issues and encourage synergistic benefits, however current policy is proving insufficient. Ensuring that rides in autonomous vehicles are both electrified and pooled can mitigate these congestion and pollution issues and provide reliable, low-cost mobility for a rapidly urbanizing society. A summary of policies and industry developments that encourage the codevelopment of EVs, AVs, and mobility as a service (MaaS) is shown in Exhibit ES1.

Technology integration and co-development

- There is huge interest in AV development, due to cost savings in transporting goods and people. However, if AVs are not electric, they will worsen pollution; if they are not shared or regulated, they will worsen congestion.
- Shared mobility companies are also battling to enter new markets globally. But if they are not electric, they will worsen pollution; if they are not shared, they will worsen congestion.
- Electric vehicles are quickly gaining market share in the United States and China with India in a position to follow fast, especially for two- and three-wheelers. Without adequate and collaborative planning among utilities, regulators, policymakers, and the private sector there is potential for inefficient or insufficient investment in charging infrastructure. If done in isolation of the needs of the electricity system, mass adoption of EVs could result in significant added costs that could easily be avoided with intelligent and forward-looking planning processes.

EXHIBIT ES1

Policies and Industry Developments that Encourage the Co-Development of EVs, AVs, and MaaS

	Synergies			SEAMS Support
	EV + AV	**AV + MaaS**	**EV + MaaS**	
United States	In San Francisco, the proposed AV tax is lower for electric vehicles. Currently, 67% of testing miles are electric (Waymo, GM).	In Michigan and San Francisco, proposed AV taxes are lower for shared rides.	California has implemented ridehailing emissions standards.	Medium EV Mixed AV Mixed MaaS Minimal Pooling
China	AVs are likely to be electric due to a maturing EV market and registration restrictions.	NA	High EV penetration in existing ridehailing fleets due to registration restrictions.	High EV High AV Medium MaaS Minimal Pooling
India	NA (AV testing not allowed on public streets)	NA (AV testing not allowed on public streets.)	EV subsidies are limited to 4-wheelers used for commercial purposes.	High EV AV Testing Prohibited High MaaS No Pooling

EXHIBIT ES2

What Countries Can Learn From and Share With Each Other to Accelerate Adoption

Shared Learnings Between Countries			
	EV	**AV**	**MaaS**
United States & China	China's national New Energy Vehicle mandate was modeled after California ZEV. The United States can adopt a more comprehensive policy framework from China with clear benchmarks for bringing EVs to market.	China's AV companies are opening US offices to attract talent while US companies are testing vehicles on Chinese roads to accelerate their technology development.	US ridehailing companies can borrow from China an integrated ride booking system that incorporates public transit and bikeshare as part of a multimodal journey.
China & India	India took a tip from from China's national level EV policy approach. China can adapt India's prioritization of support for commercial EVs and include a component of ridepooling to encourage higher load factors.	India can look to China for guidance on implementing AVs if and when India revises laws that prohibit AV testing. Public perception of AVs in China and India is more supportive than in the United States.	China and India have many rapidly urbanizing, dense cities that are well suited for mobility services integrated with public transit. A robust policy framework can shift the course of development toward pooled rides and away from personal vehicles.
United States & India	The United States can borrow from India's policy framework and target high mileage commercial vehicles for electrification first resulting in both favorable economics for the operator and more vehicle miles electrified.	India can take a tip from the US experience of implementing AVs if and when India revises laws that prohibit AV testing.	India can borrow from the US emerging tiered tax structures on MaaS providers to create market incentives that favor higher load factors.

1 THE RISE OF PERSONAL VEHICLES

Image: pxhere.com

THE RISE OF PERSONAL VEHICLES

With the rapid development and globalization of China's and India's economies, consumers in these countries are following in the footsteps of the United States and demanding personal vehicles to improve their mobility and convenience.

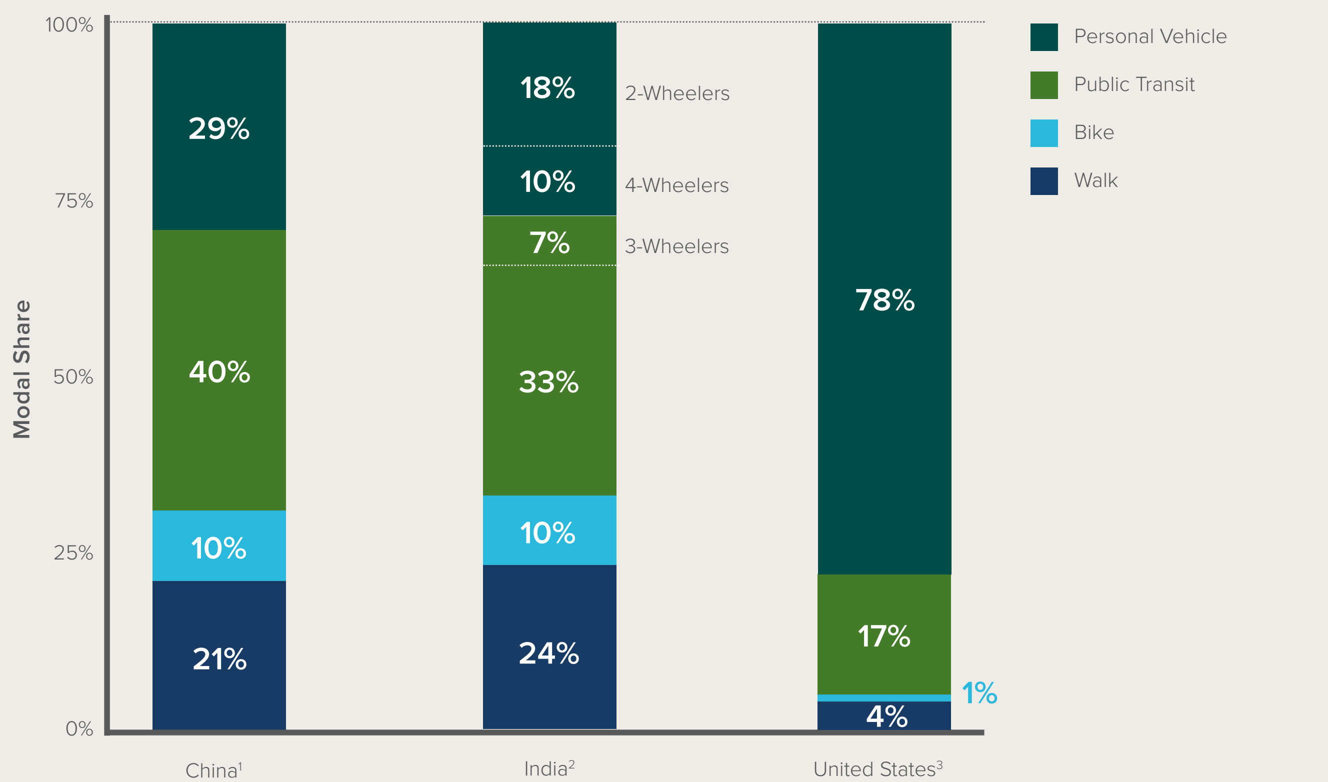
Access to reliable transportation has significant impacts on **employment** opportunities, healthcare outcomes, and social mobility. However, personal vehicles are not the optimal solution in these rapidly urbanizing countries, which are facing mounting issues with congestion, air quality, and affordability. In this report we explore how personal **mobility** is evolving in India, China, and the United States, and the underlying drivers of change that have informed the direction and pace of mobility transformation globally.

TRANSPORTATION MODES OF CHOICE

Personal vehicles dominate transportation in US cities, while public transit and non-motorized transit have a larger modal share in Chinese and Indian cities. Nonetheless, personal vehicle ownership is rising rapidly in China and India, and could approach US levels within a few decades. In the chart below we present the modal split by vehicle type in each country. While 3-wheelers are technically not a public transit mode we include them in a public transit category in India due to the nature of how they are used in the mobility ecosystem.

EXHIBIT 1:

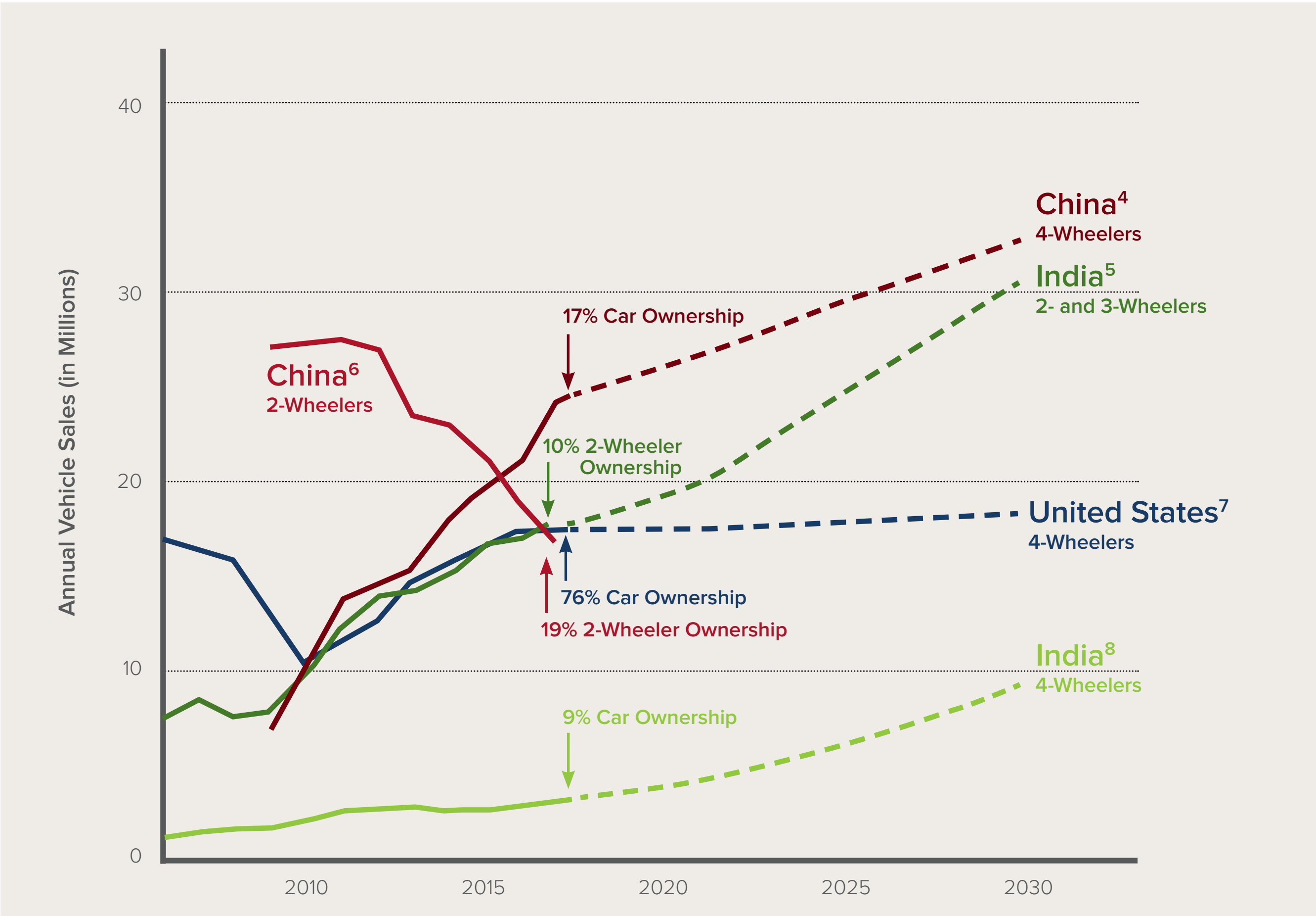
Transportation Methods Used in Large Cities in the Three Countries



Note: Sums may not total 100 due to rounding.

EXHIBIT 2

Annual Vehicle Sales in the Three Countries



United States

Transportation in the United States has been dominated by personal vehicles—cars in particular—for over a century. Once-ubiquitous streetcars were abandoned in the mid-20th century with the rise of automobile, oil, and tire manufacturers. The Eisenhower-era federal interstate highway system, established in 1956, cemented the role of private automobiles for long distance travel. Today, the majority of American cities and towns are designed around the use of cars. With few competing transportation options, the personal car has emerged as the standard for mobility in the United States.

Car sales in the United States have consistently exceeded 10 million vehicles per year since 1960. However, sales have flattened recently, due to the recession and weaker overall demand. This shift has been attributed to a variety of factors, including increased congestion, the cost of cars, a reversal of urban sprawl, and a cultural shift from asset ownership to technology-driven services and sharing, especially among the younger generation in dense urban areas.

China

Once known as the bicycle kingdom, China has largely followed in the footsteps of the United States—increasing reliance on private vehicles. In Beijing, bicycle rides once accounted for **58%** of commutes in 1986, but have now plummeted to less than **10%**. With the rapidly growing economy and influx of wealth, car ownership has become associated with freedom and social status, and represents an aspiration for many Chinese citizens.

China's passenger car sales have increased rapidly over the past decade, surpassing the United States in 2010 to become the largest global auto market. While two-wheelers remain common in rural areas of China, sales have fallen significantly due to strict restrictions on registration and road usage in an attempt to curb mounting congestion and pollution in large cities. Nevertheless, car ownership per capita in China (17%) is still only a fraction of that in the United States (76%). This leaves plenty of room for growth, fueled by the rising middle class. However, if car ownership rates in China even remotely approach US levels, there would be profound implications for China's mounting congestion and air quality issues.

India

India has also seen growth in vehicle sales driven by rapid urbanization and economic growth. India's roads are shared by a diverse set of motorized vehicles, including scooters and motorcycles (two-wheelers), auto-rickshaws (three-wheelers), and passenger vehicles (four-wheelers). Two-wheelers are expected to continue their growth, driven by their affordability and maneuverability through congested roads.

The four-wheeler market is dominated by small vehicles (below $10,000), but even these have historically fallen outside of the price range of most Indian drivers. However, this gap is shrinking with improved job opportunities and disposable income.

WHY PERSONAL VEHICLES ARE NOT A SCALABLE SOLUTION

The current mobility paradigm—characterized by privately owned, single-occupancy vehicles—is expensive, polluting, unsafe, and inefficient, but alluringly convenient.

Expensive

In the United States, the average cost of owning and operating a vehicle is over **$8,400/year**, including depreciation, maintenance and repair, fuel, and insurance. This makes transportation the second-largest expenditure for American households (after housing), and presents a disproportionate burden on low-income households. Without strong alternatives for transportation in most metropolitan areas, low-income Americans are forced to either bear the cost of car ownership or suffer a significant loss in mobility. This mobility gap is even more prominent in China and India because of even greater income inequality and significantly lower average incomes than that in the United States.[i] Since access to reliable transportation has significant impacts on **employment** opportunities, healthcare outcomes, and social **mobility**, improving access to transportation can have cascading benefits for the most vulnerable members of society. But since these three countries are so large, the sheer number of middle- and upper-class buyers is still huge—and cars are in their sights.

Polluting

Transportation emissions (especially from diesels and older cars) are a major contributor to air pollution, which has become a leading public health concern in large cities around the world. Air pollution is strongly linked to cardiovascular **disease**, and accounted for more than 1.2 million premature deaths in China in 2013. In the 20 largest cities in both India and China, particulate levels routinely fall into the unhealthy

[i] **Average income** is $8,690/year in China, $1,800/year in India, and $58,270/year in the United States. While car ownership costs will also be lower in China and India, we assume that these costs do not scale linearly with income levels.

category, as shown in Exhibit 3. To fully address this issue, a new mobility system will need to eliminate emissions both at the tailpipe and at the source of energy generation while also reducing the recirculation of dust caused by heavy congestion and road use.

Unsafe

Human-operated vehicles are also prone to causing traffic accidents, which claim over 502,000 lives each year in the three countries **combined**. The majority of fatal traffic accidents in all three countries can be attributed to speeding, intoxication, and disregard of priority rules, all of which could potentially be avoided through autonomous driving technology.

Inefficient

Traffic congestion has worsened significantly in metropolitan areas in all three countries, as road infrastructure has not been able to accommodate the pace of private vehicle growth. The annual cost of congestion in **India's** four largest cities is estimated to be $22 billion, which does not account for the social costs of traffic-induced **stress** and road rage. A new mobility system should be able to address these inefficiencies without resorting to the buildout of more road infrastructure, which does not solve problems for long if at all. More lanes have been shown to result in more vehicle miles traveled (VMT) with no observable reduction in congestion.

Convenient

Currently, the most compelling advantage of personal vehicles over other modes of transit is the convenience factor. The flexibility to travel at any time of day to nearly any location, in a reliable and comfortable vessel, is the hallmark of a private vehicle. Empirical evidence and observation suggest that these non-economic factors can have an even stronger influence on transit mode decisions than economic factors. Thus, any new mobility services aiming to fill the role of private vehicles must be able to **exceed** this standard of convenience or provide alternative benefits, in addition to addressing issues of affordability, pollution, safety, and efficiency.

THE FUTURE OF PERSONAL VEHICLES

While the United States is at or nearing peak car ownership, China and India are rapidly moving in the opposite direction. These developing countries have the opportunity to leapfrog the American paradigm of personal vehicle ownership and avoid many of its associated issues. However, this leapfrog opportunity will not be realized on its own and will require both policy and cultural change to facilitate the level of system transformation needed. At this critical juncture in their transportation futures, China and India have the potential to divert the worsening patterns of congestion and pollution, capture billions of dollars in economic and social benefits, and set a new precedent for urban mobility in emerging markets worldwide by continuing to implement strategic policies and smart investment in system infrastructure.

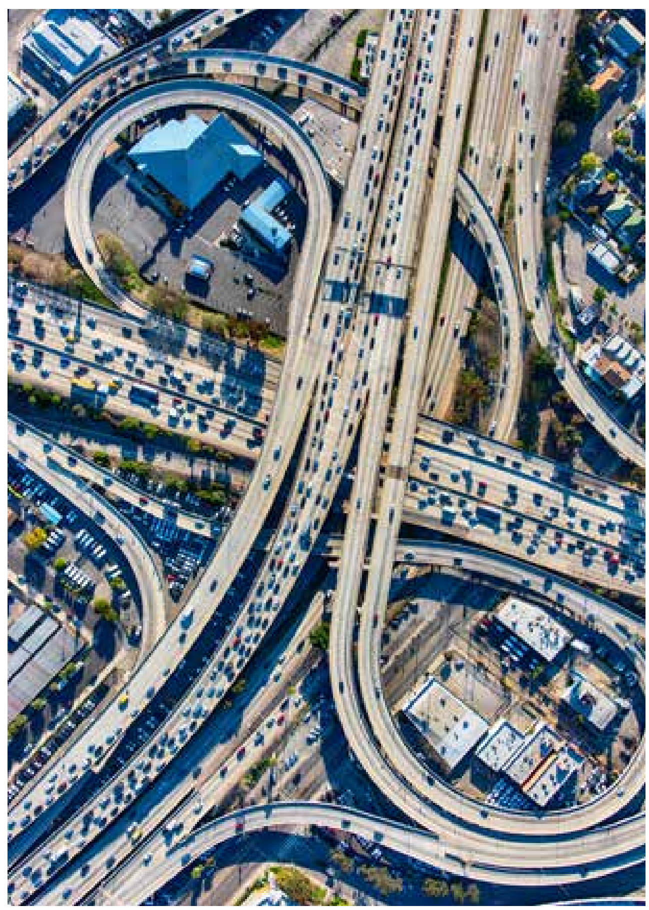
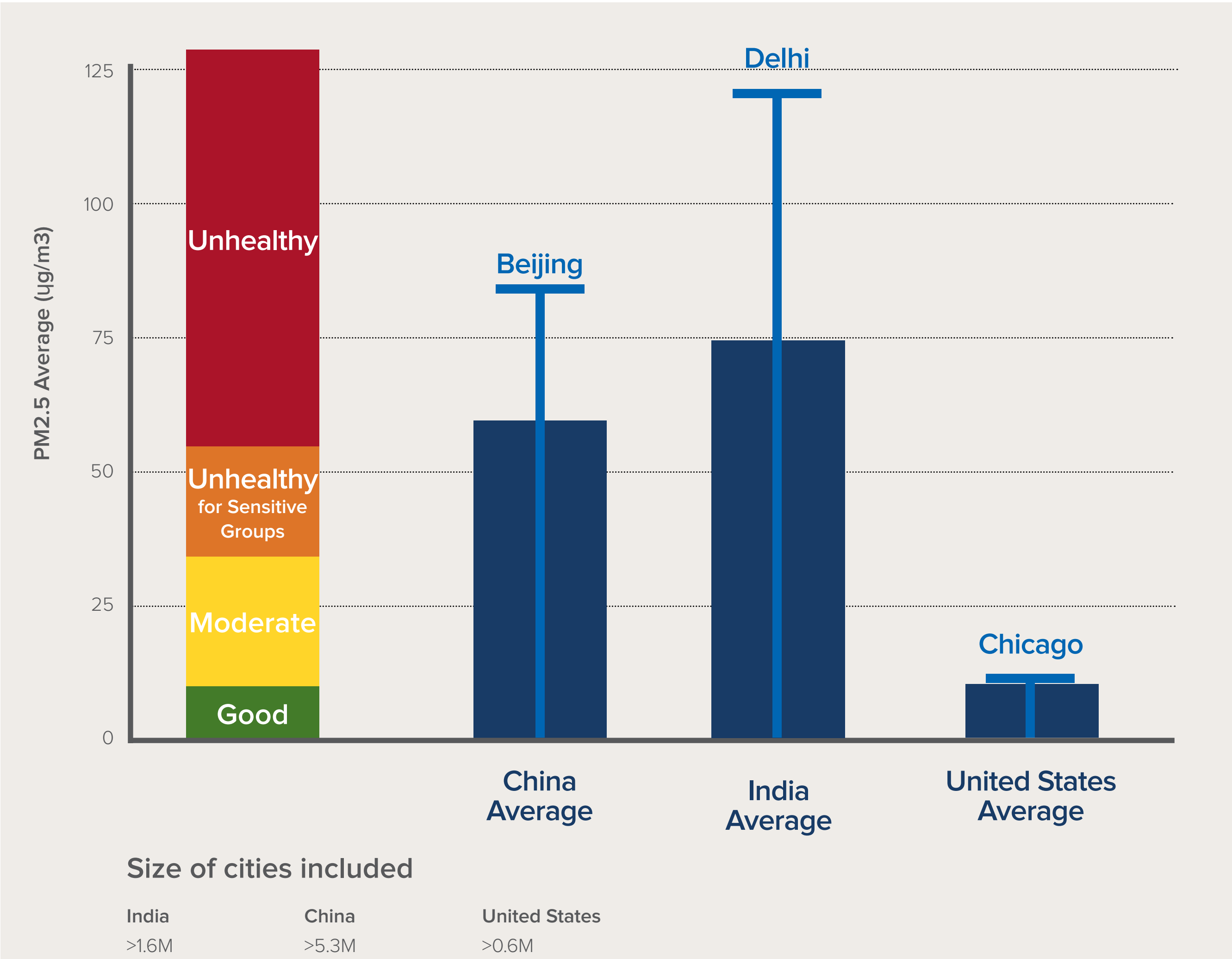


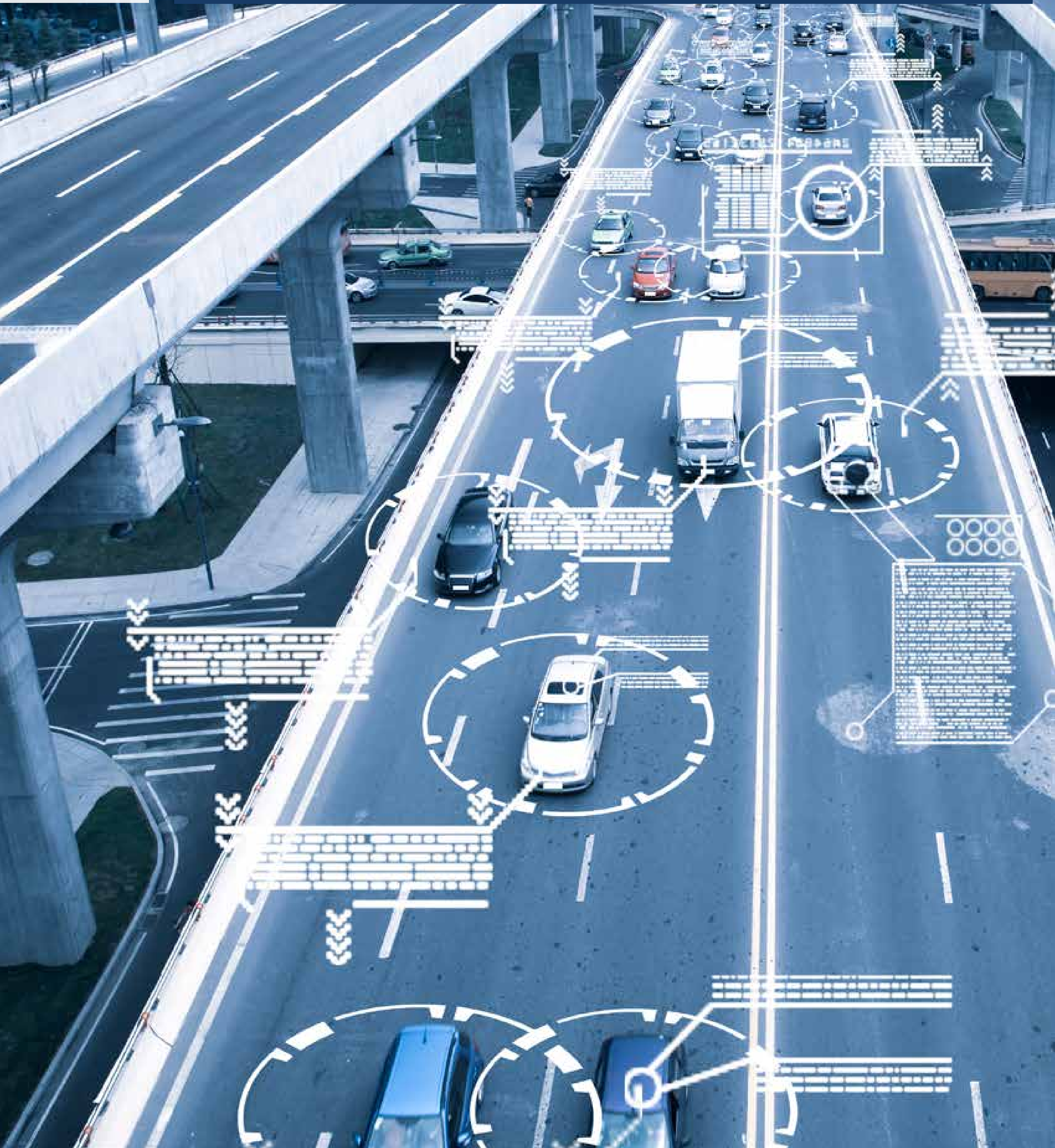
EXHIBIT 3

Air Pollution in 20 Largest Cities of Each Country[9, ii]



[ii] Beijing, Delhi, and Chicago have the worst air pollution (PM2.5) among the 20 largest cities in their respective countries.

02 THE POTENTIAL OF SHARED, ELECTRIC, AUTONOMOUS MOBILITY SERVICES (SEAMS)



THE POTENTIAL OF SHARED, ELECTRIC, AUTONOMOUS MOBILITY SERVICES (SEAMS)

Shared, electric, and autonomous mobility services (SEAMS) are emerging as the most viable solution to address the transportation needs of individuals in cities around the world. When properly deployed, SEAMS have the potential to reduce congestion and traffic accidents and provide mobility at a lower cost per mile than operating a personal vehicle, without sacrificing comfort and convenience. Though no system of this sort is possible yet, significant analysis makes it clear how well—and if done badly how poorly—this could work.

WHAT ARE SEAMS?

Sharing models

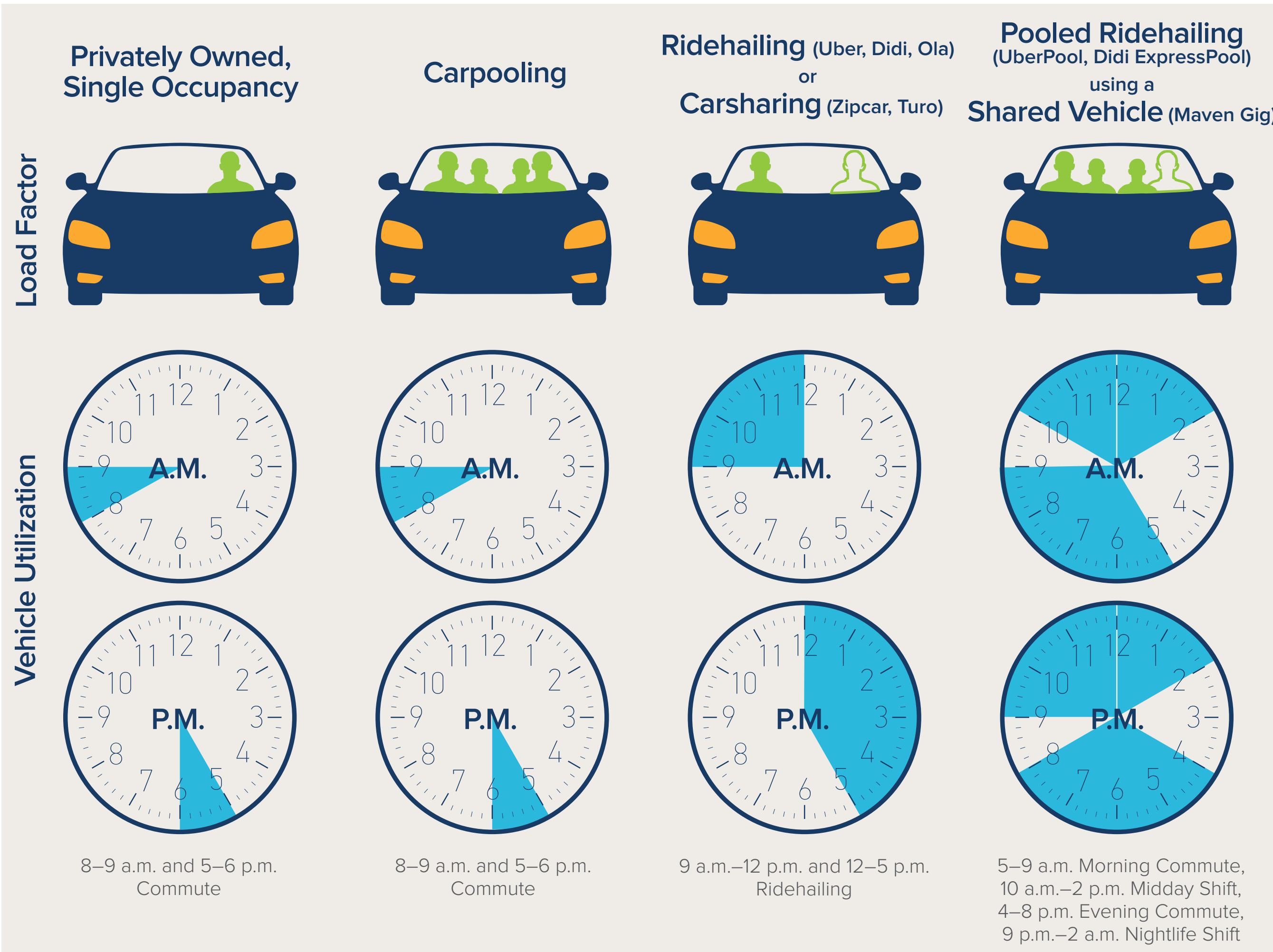
The goal of shared mobility is to reduce the number of vehicles required to satisfy the mobility needs for a population. This can be achieved by either increasing the *load factor* (i.e., pooling several passengers into one vehicle), increasing *utilization* (i.e., operating the vehicle more frequently throughout the day), or both. This is illustrated in Exhibit 4. For example, in the United States, the typical privately owned vehicle is used to transport a single passenger to and from work. This represents a load factor of one, and a utilization of approximately 2 hours out of the 24-hour day (8%). If the owner of the vehicle decides to start a carpool, he or she can increase the load factor, but the vehicle would still remain underutilized for most of the day.

Alternatively, ridehailing drivers could transport several different people to their respective destinations over the course of an 8-hour workday, raising vehicle utilization to 33%. This would obviate the need for all of those individual passengers to operate their own vehicles, freeing up parking and reducing congestion associated with searching for parking. Carsharing services (both fleet-based and peer-to-peer) achieve the same effect of increasing utilization by allowing a single vehicle to be used by several individuals throughout the day.

In addition to increased utilization, ridehailing vehicles can also improve their load factor by pooling passengers. The most optimal sharing solution combines the pooled ridehailing and carsharing models, such that the vehicle can be operated up to 24 hours a day (based on demand) by different ridehailing drivers. When optimally implemented, ridehailing using a shared asset achieves significantly higher efficiency. The advantage of the ridehailing plus carsharing model is its operational flexibility, as vehicles can be rerouted real-time to accommodate shifts in passenger demand, as opposed to a fixed transit route.

EXHIBIT 4

Shared Mobility Load Factor and Vehicle Utilization



Electric vehicles

An electric vehicle (EV) is an umbrella term used to describe any vehicle using an electric motor for propulsion. EVs can include trucks, buses, cars, motorcycles, bikes, and even planes, and can be fully battery electric (BEV), plug-in hybrids (PHEV), hybrids (HEV), or fuel cell-powered (FCEV). In this report we focus on only full battery electric vehicles as they are seeing the most rapid growth and investment globally.

Autonomous driving technology

Autonomous vehicles (AVs) are vehicles of any kind with the capability to drive themselves using a suite of hardware and software without the active physical control or monitoring of a human operator. To qualify as a fully autonomous vehicle, the vehicle must be able to navigate to a predetermined location over roads that have not been specifically adapted for AV use and without any human intervention.

Mobility services

Mobility services, often referred to as mobility as a service (MaaS), describe a wide range of mobility solutions that are consumed as a service as opposed to personally owned modes of transportation such as a personal car or two-wheeler. Typically, MaaS combines various modes of transportation, both public and private, where users can create, manage, and pay for the journey through a single interface, often a smartphone application. The key definition of MaaS is a service that meets the mobility needs of the user and is independent of the vehicle or mode used to meet that mobility need.

ADVANTAGES OF SEAMS

There are many reasons why SEAMS are a viable alternative to car ownership. SEAMS are:

- Affordable: Autonomous driving technology has the potential to reduce the cost of shared mobility services below that of personal vehicles by significantly lowering the cost of operating the mobility service. **Electrification of AVs** can further reduce operations costs associated with fuel and maintenance.

- Clean: Electric vehicles produce zero tailpipe emissions, which improves local air quality. And when fueled with renewable sources EVs do not contribute to greenhouse gas emissions. As the energy system continues to decarbonize, the entire energy supply chain will be emissions-free and carbon neutral, resulting in zero-emissions vehicles at both the tailpipe and the generation site.

- Safe: AV technology is expected to be much safer than human drivers, particularly once the majority of vehicles on the road are automated. AVs can help eliminate occurrences of drunk and distracted driving and human error, providing a safer environment not only for drivers but for all road users and pedestrians.

- Efficient: Increased utilization of vehicles from ridepooling and carsharing will reduce the number of vehicles on the road, reducing congestion. AVs can also platoon and use road space more efficiently, reducing congestion and infrastructure costs.

- Convenient: If implemented well, SEAMS can be as convenient, reliable, on-demand, and as comfortable as personal vehicles while eliminating the chore of fueling, cleaning, maintaining, and storing a vehicle. These benefits are especially pronounced in dense urban environments, where mobility services are far more readily available than parking spaces.

IMPLEMENTING SEAMS

The most efficient implementation of SEAMS does not displace public transit, walking, or biking, but provides an alternative to personal car ownership by strategic integration with these other modes.

Mass transit is the most efficient form of transportation in high-density areas along high-volume corridors. However, US metropolitan areas are generally sprawling and difficult to serve by transit lines, compared to cities in India and China. In the United States, there are only two major cities with densities above 15,000 people per square mile (New York City and San Francisco), whereas India has 14.

Building public transit infrastructure also requires political will. While US transit agencies continually struggle to secure funding due to tepid public support from those who vote and pay the most taxes, China's centralized model allows the government to invest billions in subway infrastructure.

Thus, SEAMS are best suited to replace personal vehicles in areas that are not sufficiently dense for public transit. Mass transit should continue to serve passengers along high-traffic corridors and in city centers, from which SEAMS can be integrated as a first/last-mile solution. By no means should SEAMS displace public transit, which has a significant role in nearly every major city. There is not enough space in the streets for every urban dweller to own a vehicle. For personal vehicles to work, people simply have to be closer together (or, in an economist's view, pay an awful lot for the privilege of the space they use). China, India, and the United States are all moving toward a SEAMS future. However, the key drivers for these technologies vary among the three countries as a result of their unique financial markets, government structures, and cultural attitudes.

In the following sections, we provide a deep dive into the three technologies—electric vehicles, autonomous technology, and shared mobility services. For each technology, we compare the adoption across the three countries and identify the key driving forces behind them. We highlight the successes and setbacks of each country's efforts. At the end of each section we provide a set of key takeaways that can support and accelerate the adoption of SEAMS across all three countries.

03 ELECTRIC VEHICLES (EVS)

ELECTRIC VEHICLES (EVS)

EV ADOPTION

The global electric vehicle (EV) market is still nascent, accounting for less than 2.2% of vehicle sales, but is expected to grow as EVs reach price parity over the next decade. Policies can accelerate this transition by targeting both automakers and consumers.

United States

In the United States, patchwork state policies have sent mixed signals to auto manufacturers, delaying the development of more sophisticated and lower-cost new products (a four- to five-year cycle) and the eventual scale-up of EV manufacturing. Since EVs cost, in the near-term, significantly more than their gasoline counterparts, early adoption of EVs has been limited to the wealthy and the truly committed.

China

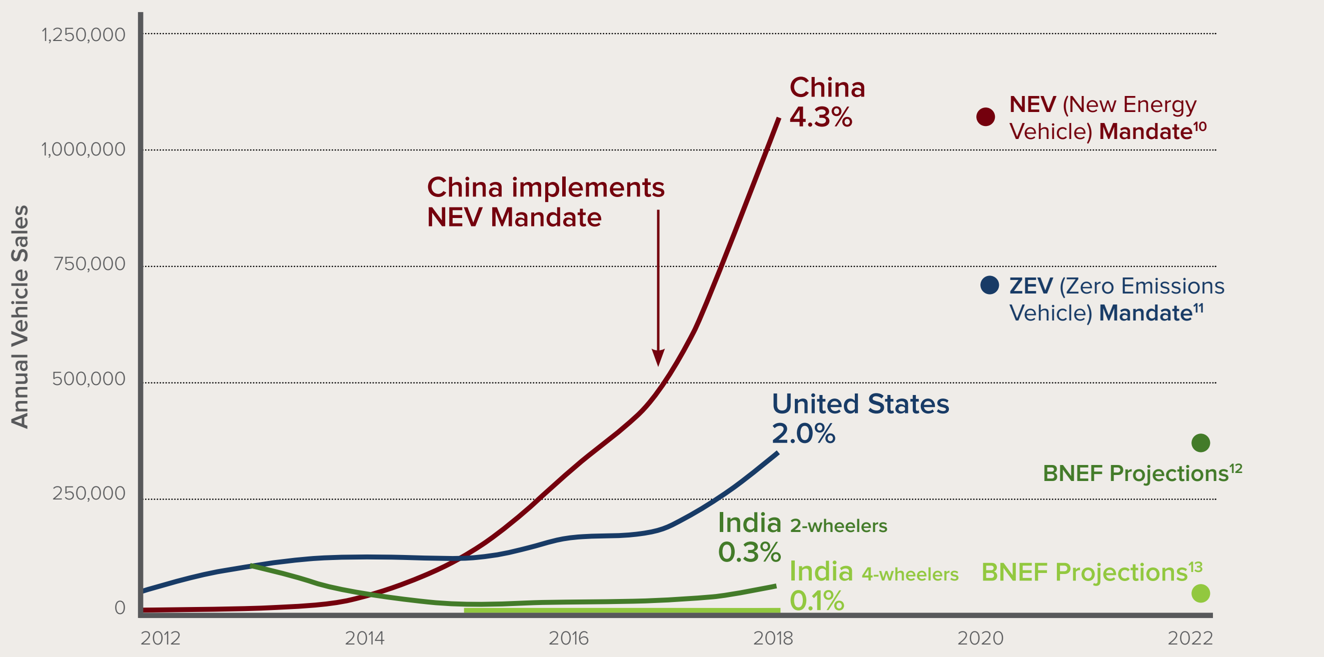
As a result of its aggressive sales mandates and generous subsidies, China reached a record 7% EV sales in Q4 2018 and has already met its 2020 EV sales targets two years ahead of schedule.

India

EV Sales in India tripled in 2018, but India's EV growth has been limited thus far. In February 2019, India announced plans to significantly expand its subsidies for EVs and charging infrastructure and has committed to ambitious electrification goals at the state and central government levels. The government is targeting high-utilization commercial vehicles, which will encourage the electrification of two-wheelers, three-wheelers, and shared mobility vehicles.

EXHIBIT 5

Annual EV Sales in the Three Countries



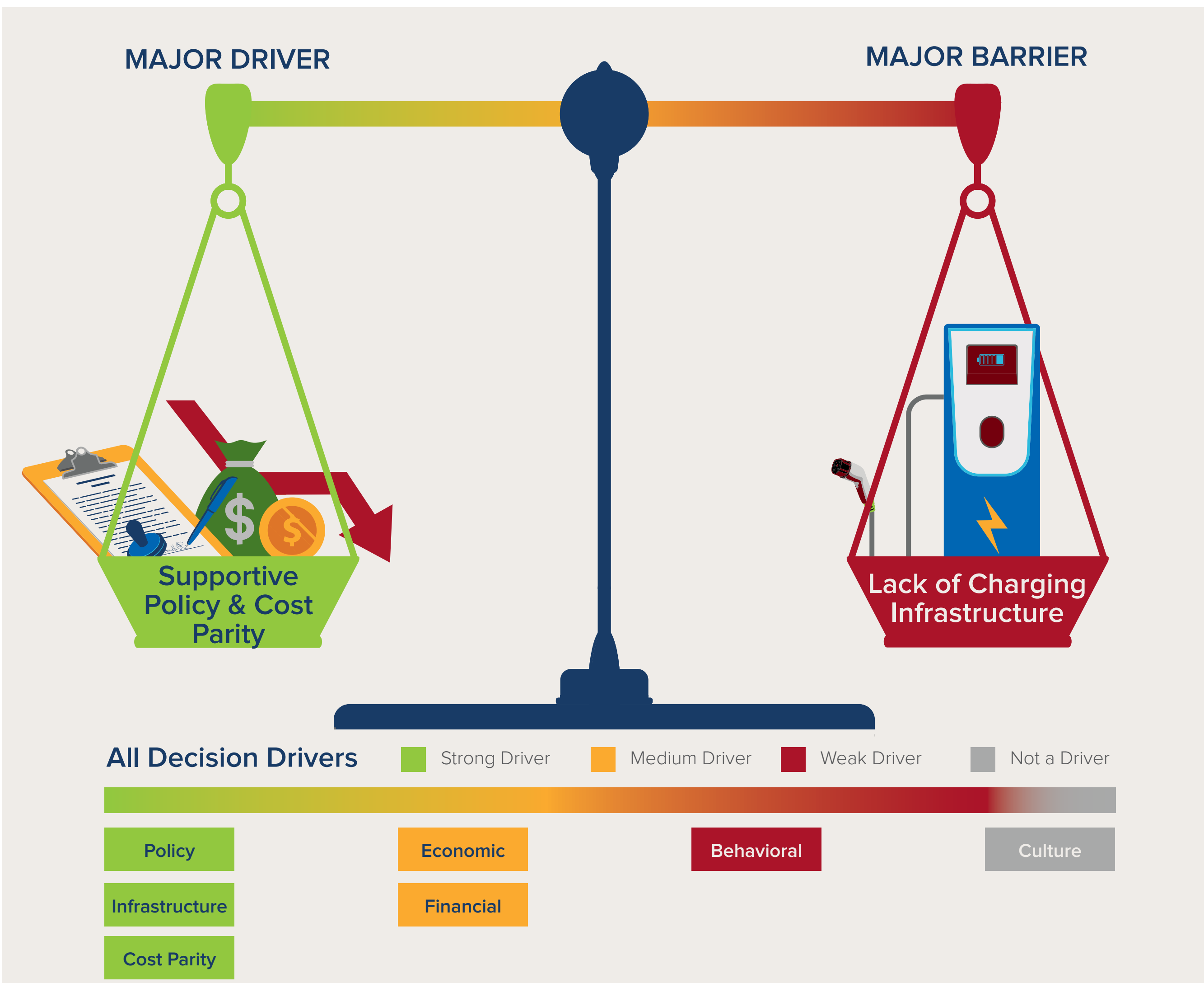
NEV and ZEV provide EV sales targets for automakers. BNEF provides projections for EV sales in India based on the Faster Adoption and Manufacture of Electric Vehicles (FAME) II scheme

KEY DRIVERS

EVs have benefited from significant government intervention in the form of supportive policy, fiscal incentives, and infrastructure investment, which has accelerated the timeline of price parity with incumbent vehicle technology. However, RMI's research into **behavioral economics** shows that commuting decisions are more nuanced than a simple price comparison and involve a complex set of emotions and biases. Although price parity with gas vehicles is one key milestone for EV adoption to take off, there are other important aspects to consider, including but not limited to: An extensive and robust charging network, supportive policy, adequate vehicle model options, new financing options, and cultural biases. In the following section we evaluate the role of five key drivers in the evolution of the electric vehicle markets over the past decade in China, India, and the United States.

EXHIBIT 6

Key Drivers and Barriers for EV Adoption



EV Policy

Overview: Types of Policy

EV policies include supply-side and demand-side strategies, providing both push and pull forces to drive EV adoption. Supply-side regulations encourage auto manufacturers to increase model availability and meet efficiency standards. Demand-side incentives aim to reduce the upfront price of EVs and drive consumer decisions. A successful set of policies should leverage both push and pull strategies to drive EV adoption. Exhibit 7 provides an overview of these different types of policies, which we dive deeper into below.

Pushing the Automakers

EV sales mandates

EV sales mandates require automakers to sell a certain proportion of zero-emissions passenger vehicles as part of their total fleet. Eligible vehicles, including battery-electric, fuel cell, and plug-in hybrid vehicles, are each assigned a certain number of credits. Manufacturers that do not meet their targets have to buy credits from other manufacturers or pay penalties. This supply-side strategy leverages market forces to motivate automakers to accelerate their timelines for entry into the EV market or pay others to do so.

California was the first US state to introduce a zero-emissions vehicle (ZEV) mandate in 2013, which has been voluntarily adopted by 10 other states. In total, these 11 states comprise 31% of the US population. As a result, auto manufacturers are compelled to meet EV sales targets in these ZEV states, while also responding to growing consumer demand for SUVs nationwide. This has created a split market, where automakers are pushed to offer different models in different states, effectively diluting their investments in a wider range of models than would likely occur with a nationwide mandated ZEV program. This market segmentation has prompted Ford to **announce** that it would phase out all of its passenger cars except for two models in order to focus on trucks and EVs.

China adapted California's ZEV to establish its own new energy vehicle (NEV) mandate in 2017, the first of its kind to be implemented at a national level. The main difference in the NEV mandate is that the vehicle credit calculation is more flexible, taking into account the vehicle's weight and energy consumption. This is shown below in Exhibit 8. Unlike the ZEV, this does not penalize manufacturers for selling larger EVs. As a result, the NEV mandate can better accommodate shifts in consumer preference in China, which is similarly trending toward SUVs.

India has not yet implemented a national EV sales mandate. However, seven Indian states have announced state level EV policies that include fiscal and non-fiscal incentives that encourage local EV manufacturing and sales. A national-level mandate in India could help drive EV production from the supply side, to complement the subsidies that India is providing on the consumer side.

EXHIBIT 7

Categories of Supportive EV Policies

	Push forces	Pull forces
Supply side (Automakers)	Sales mandates Fuel efficiency standards	Incentives for local automakers
Demand side (Consumers)	Internal combustion engine registration restrictions	Subsidies/tax credits Priority road/parking access

EXHIBIT 8

EV Sales Mandates

	California's Zero Emission Vehicle (ZEV) mandate	China's New Energy Vehicle (NEV) mandate	India
Implementation level	Adopted by 11 states of which California was by far the largest	Enforced nationally	None currently
Vehicle credit formula	Vehicles are assigned credits based on their zero-emissions range. Credits per vehicle can range from 0.4 to 4.	Vehicles are assigned credits based on several factors, including range, energy consumption, and curb weight. Credits per vehicle can range from 1 to 6.	
Targets	By 2020, 9.5% credits or ~4.1% sales By 2025, 22% credits or ~8.0% sales	By 2020, 10% credits or ~4.0% sales	

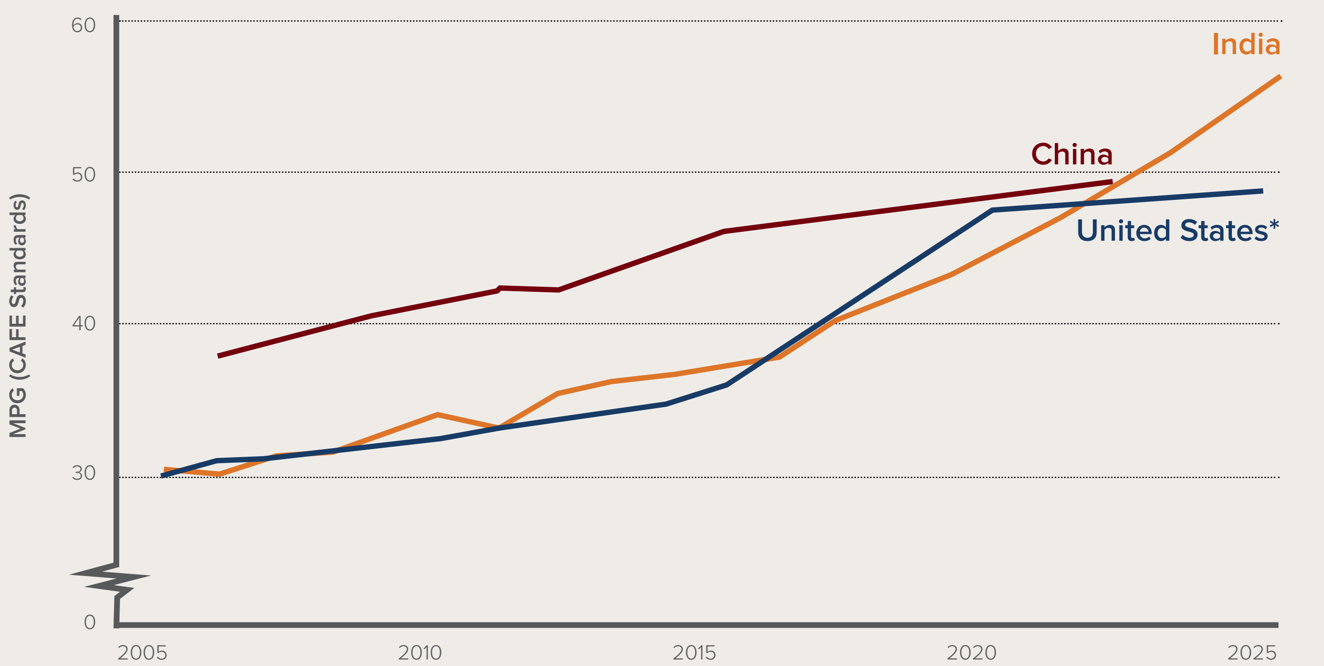
Fuel efficiency standards

Historically, fuel efficiency standards have been considered one of the most successful policies for mitigating emissions in the transportation sector. These standards require car manufacturers to maintain a minimum average fuel efficiency over their vehicle fleets, which increases model availability for consumers. Certain countries have set standards for greenhouse-gas emissions instead of fuel economy as a means to more directly and clearly address their climate goals.

In the United States, the current administration is planning to effectively **freeze** fuel efficiency requirements at 2021 levels through 2026. In response, 14 states have elected to adopt their own, stricter requirements. This may create another split market for US automakers, who will now have to comply with different regulatory environments by state.

EXHIBIT 9

Fuel Efficiency Standards in the Three Countries[14]



*In the United States, the current administration is planning to freeze fuel efficiency requirements at 2021 levels through 2026.

China and the United States appear to be tracking closely in fuel economy improvements, and all three countries have set comparable fuel efficiency targets for the early 2020s.[iii] Comparatively, India's vehicles are significantly more fuel efficient due to their smaller size, less powerful engines, and high diesel penetration. This has led some to believe that India should enact **stricter** regulations that require a proportional improvement in fuel economy. In its current state, India's current fleet characteristics show the best potential for developing right-sized, purpose-built vehicles for shared mobility use.

[iii] All three countries have set targets of 48 mpg by 2020–2022 (by CAFE standards), which corresponds to approximately 35 mpg in real on-road conditions.

Pushing the Consumers

Registration restrictions

Some cities restrict the number of vehicles that can be registered per year to curb congestion and improve air quality. Most tier 1 cities in China have done this through auction or lottery systems. In auction systems, the cost of registration can amount to the cost of the vehicle itself. In lottery systems, the wait time to draw a registration can be two to eight years. These restrictions are often lifted for EVs, providing a strong incentive to purchase an EV even if it requires a small premium.

This type of sweeping restriction is unlikely to gain public support in the United States. Nonetheless, it has been a very effective mechanism for reducing congestion and indirectly promoting EV adoption in China.

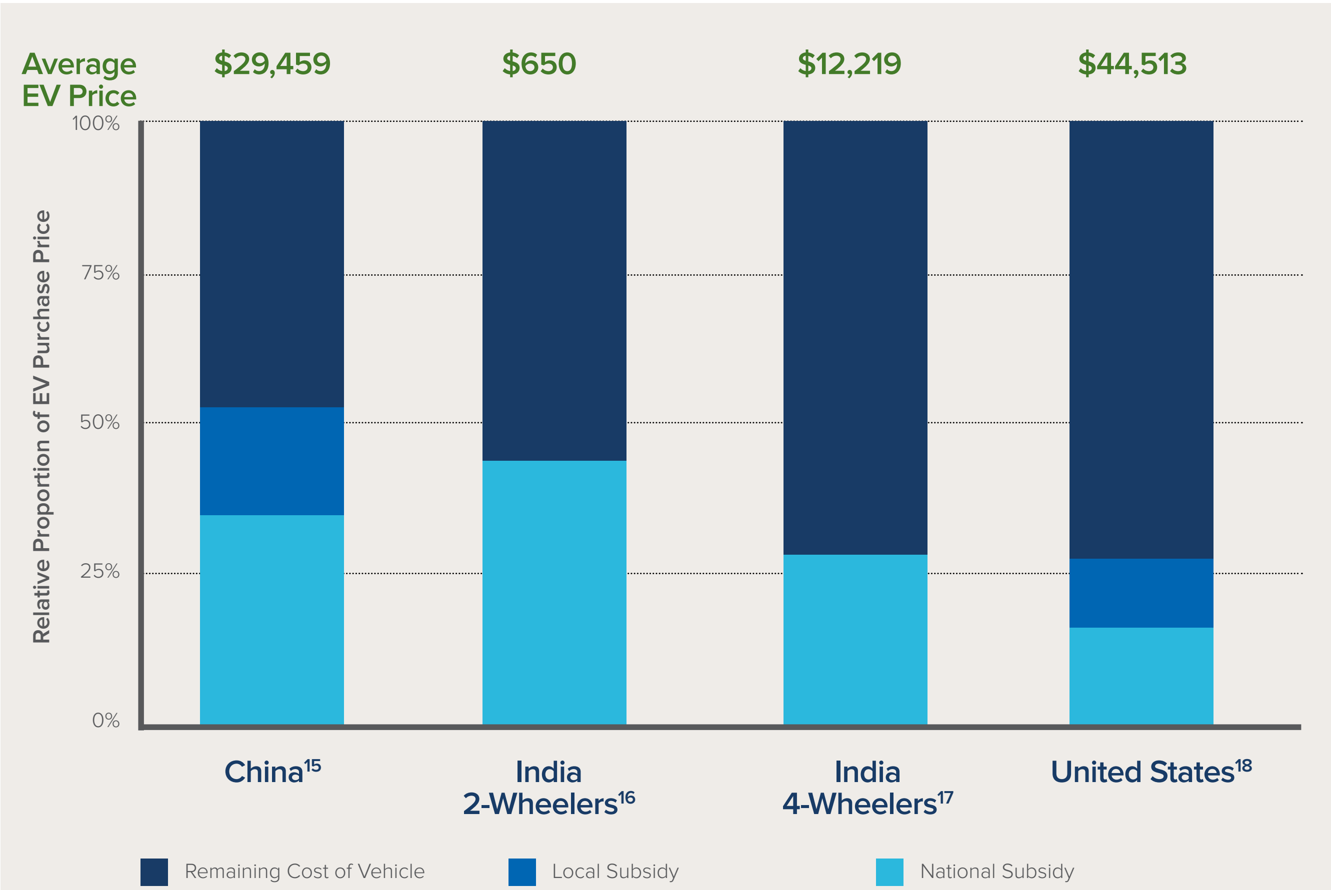
Pulling the Consumers

EV purchase incentives

Financial incentives for electric vehicles are provided by national and local governments to offset the relatively high purchase price of EVs. Exhibit 10 shows the relative fraction of the average electric vehicle purchase price that is covered by national and local subsidies. Due to the high variation in local subsidies across states and regions, with many having no local subsidy, the light blue bar represents the highest local subsidy in each country.

EXHIBIT 10

EV Purchase Subsidies in the Three Countries[iv]



China has historically provided the most generous subsidies, which has spurred mass production of **lower-range**, more affordable EVs. As a result, the total subsidy can cover more than **half** the cost of an EV. This has proven so successful in driving sales that China has **reduced subsidies** by half starting in 2019, and plans to phase them out entirely by 2020. Nonetheless, EV sales are expected to remain high due to internal combustion engine (ICE) registration restrictions, EV sales quotas, and organic demand growth. This is an example of a successful subsidy phasing out after achieving its purpose of catalyzing a nascent market. The subsidies have since been updated with more stringent requirements that encourage automakers to produce longer-range EVs to compete in the global market.

The United States also provides moderate financial incentives for EV purchases, but they represent a smaller proportion of the total vehicle cost, due to higher EV prices. In 2018, the mass production of Tesla's Model 3 brought down the average EV price by $15,000, but that price point of about $45,000 is still $15,000 higher than the average EV price in

[IV] Average EV prices were calculated by taking a weighted average of the MSRPs of the five top-selling EV models in each country.

China. Further, whereas China's subsidies are applied as rebates at the point of purchase, the United States offers a tax credit, the full value of which can only be claimed if the purchaser's annual **income** exceeds $65,000/year. This further restricts EV adoption to wealthier segments of society.

Under its recently amended FAME II scheme, India plans to subsidize 1 million two-wheelers, 500,000 three-wheelers, and 55,000 four-wheelers. Four-wheelers will only be subsidized for commercial and shared mobility use, not for private ownership. This prioritizes vehicle segments that are both high polluting and high utilization. This targeted approach is very well-designed from an economic and environmental standpoint. Auto-rickshaws and ridehailing vehicles have the highest utilization, so electrifying them would eliminate the most tailpipe emissions per vehicle. This also avoids the pitfall of subsidizing high-end vehicles for those who can already afford them without the subsidy. Several state governments in India announced and implemented various demand-side fiscal and non-fiscal incentives, including direct subsidies for vehicles and infrastructure, waived road and excise tax, waived registration fees, favorable electricity tariff structures, and favorable lending rates.

The United States could benefit from refining its EV subsidy to 1) prioritize high-utilization vehicles to maximize vehicle miles electrified, and 2) implement a phase-out strategy with clear benchmarks for bringing EVs to market.

Economics of EVs

Price parity

Currently, EVs cost between 25% and 50% more than comparable ICE vehicles, presenting a significant barrier for consumers. We anticipate that mass adoption will require EVs to reach and likely go beyond price parity with ICE vehicles. In the United States, this is expected to occur between 2024 and 2027, depending on the vehicle type. Falling battery prices are the main driver for

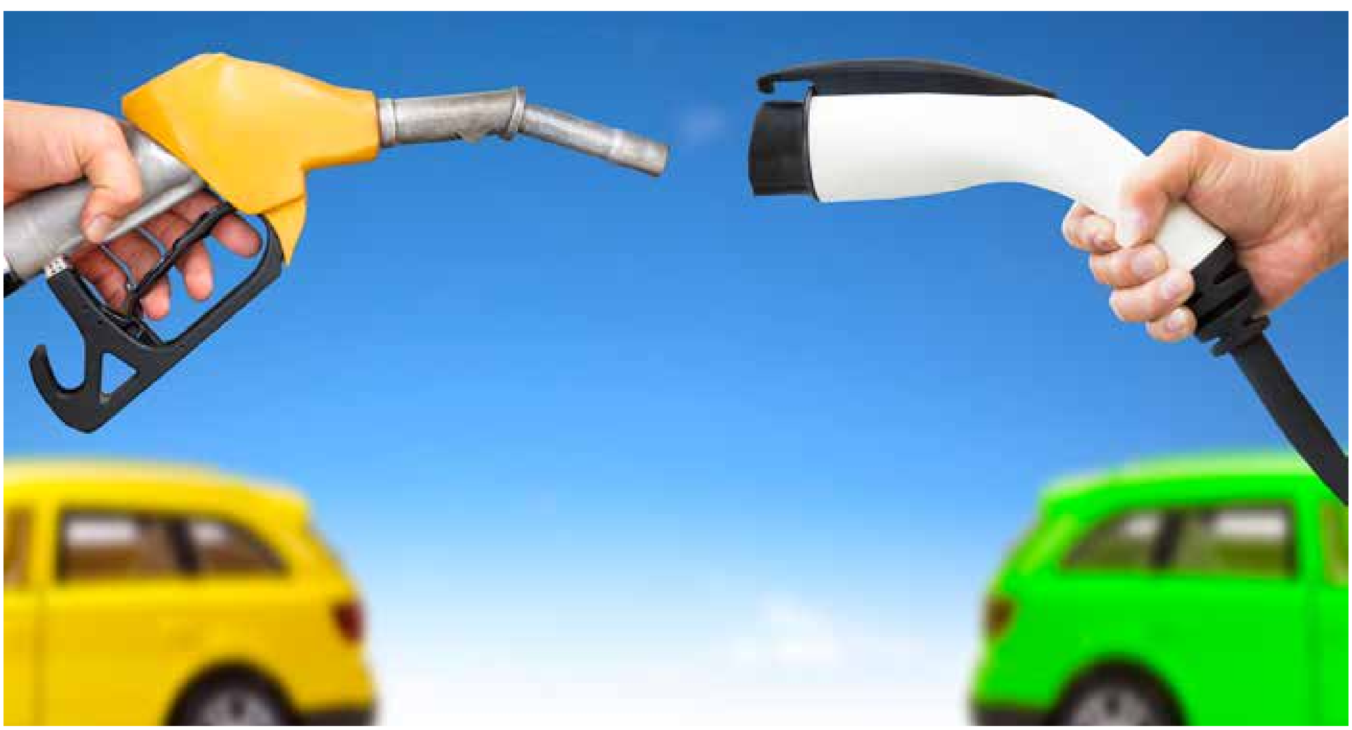
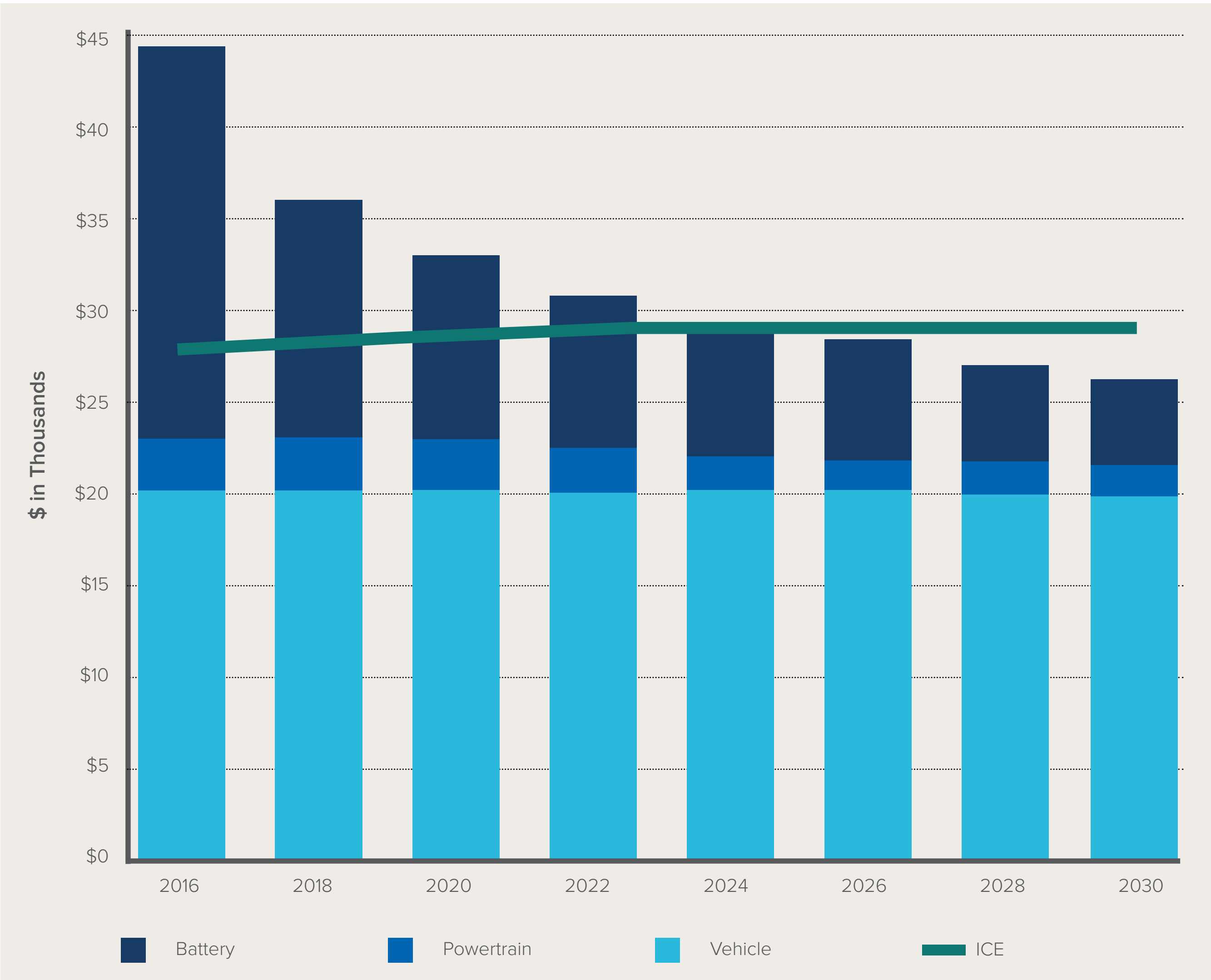


EXHIBIT 11

US Medium BEV Price Breakdown, ICE Price and Share of Battery Costs[20]



this cost decline, as the battery pack currently comprises 40% of the total EV cost. As battery manufacturing continues to scale up, battery costs are expected to fall below $100/kWh by 2025. As a result, the cost of the battery will comprise less than 20% of the total EV cost in the United States by 2025.

We expect EV costs to follow a similar trajectory in China and India, as they participate in the same global battery market and in some cases the same auto market. Price parity may be slightly delayed in these countries, since vehicle prices are on average lower than in the United States and thus more sensitive to high battery costs making up a large portion of the total vehicle cost. As a result, battery prices must be reduced even more to reach price parity or battery packs will remain relatively smaller in Indian and Chinese vehicles to keep overall costs competitive.

Nonetheless, we expect EVs to reach price parity in China and India by the mid to late 2020s for private vehicles and likely much earlier for high-utilization commercial vehicles.

These projections for price parity are based on assumptions around existing government support. Policy plays a critical role in driving the scale-up of battery manufacturing, as it provides confidence to the private sector to invest in these technologies and prepare for future EV demand. Loss of government support, such as the proposed rollback of fuel efficiency standards in the United States, will likely delay EVs from reaching price parity and achieving mass adoption.

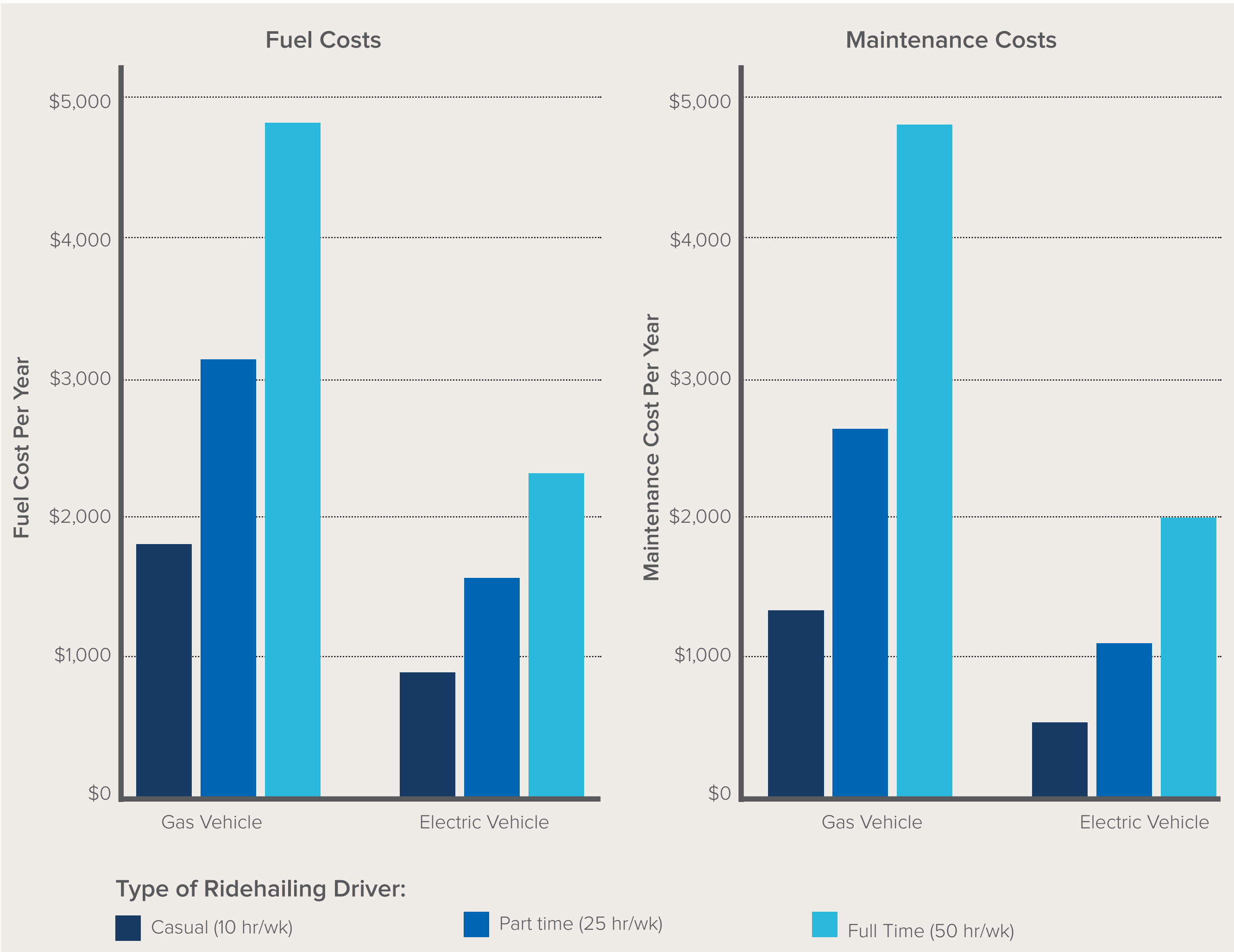
Operating costs

Price parity in the total cost of ownership (TCO), which takes into account operating costs, will be reached several years earlier than for the capital costs such as fueling and maintenance, and is already present for some drivers. This is because EVs are cheaper to operate on a per-mile basis, due to their lower fuel costs and maintenance requirements.

Vehicles used for ridehailing, which will be discussed in the following section, are strong candidates for electrification due to their high utilization rates. As demonstrated in RMI's previous **study**, full-time ridehailing drivers for ridehailing companies can save up to $5,200/year in fuel and maintenance costs with an EV compared to a gas vehicle.

EXHIBIT 12

Cost by Vehicle Type for Ridehailing Drivers[21]



Charging Infrastructure

In all three countries, mass adoption of EVs will be heavily tied to the availability of public and private charging infrastructure. In our previous RMI report ***From Gas to Grid***, we demonstrate that deploying charging infrastructure in a cost-effective and optimal way requires careful planning, appropriate government incentives, and a high level of coordination and collaboration between public and private sectors. Supporting a healthy electric vehicle ecosystem in any of these countries will require a properly adjusted mix of public DC fast charging, public Level 2 charging, private home charging, and dedicated fleet charging, working across a wide range of vehicle types. While China has made significant progress in deploying DC fast charging networks in particular, the United States and India are behind and require significant further investment from the private and public sectors. Uniquely, India is likely to invest in both conventional charging infrastructure and a battery swapping network because of a combination of electrical infrastructure constraints and the inability of many consumers to pay the full upfront cost of the battery and vehicle. Battery swapping enables a clean and simple way to decouple battery costs from vehicle cost, which effectively lowers the upfront price of vehicle ownership by shifting those costs to a per mile operation cost. It also potentially improves reliability in an environment with lower electricity grid reliability by creating depots of charged batteries that can be used even in the event of a grid outage.

The Chinese government has made significant investments in public charging infrastructure, while public chargers in the United States are mostly funded by automakers and private charging companies. This has resulted in under investment in charging infrastructure in the United States while China has created a robust and successful charging network to support the growing EV market. Through its FAME II scheme, India is also planning to build 2,700 public charging stations along major corridors across India. This is a good start, but India will need significant additional investment from the private sector and central, state, and municipal governments to meet the demand for charging services associated with the high levels of projected EV ownership.

Cultural Acceptance

Range anxiety is a common concern for drivers who need to travel considerable distances or who want to use a vehicle for travel outside cities. This can be addressed by developing an extensive network of public chargers, as discussed above. Strategically siting chargers along major corridors, similarly to gas stations, allows EV drivers to take longer trips without worrying about getting stranded.

The ease and speed of fueling is a major perceived advantage of gasoline vehicles, so any new technology must either match or exceed this standard of convenience or find other ways for drivers to use the time while charging, to be successful. The first generation of DC fast chargers in the United States and China can add about 80 miles of range in roughly 30 minutes, which is significantly longer than refueling a gasoline vehicle. However, DCFC stations between 150 kW and 350 kW are already entering the market for both personal and commercial vehicles, which will decrease charge times to between five and ten minutes for the same 80-mile charge. However, the rate of charging is not the only criteria for convenience. EVs offer an unprecedented level of convenience by charging the vehicle overnight at home or during the work day at the office instead of having to make a dedicated stop at a gas station. The ability to charge a vehicle while it is not in use allows users and owners to effectively spend no time on charging. For many EV drivers, it is possible for them to meet most of their charging needs at home or at work. While this level of convenience is surely better than driving to a gas station and waiting to fuel your vehicle, it will take a certain level of informational (knowing where to charge), behavioral, and mental shifts to overcome the status quo.

It is important to note that other zero-emissions vehicle technologies are available—in particular, hydrogen-powered fuel cell vehicles (FCV), which can be refilled as quickly as gasoline vehicles. We focus on battery electric vehicles because they have captured the majority of the market, locking in significant investment in charging infrastructure. Nonetheless, many consumer-focused policies are technology agnostic and can thus accommodate other forms of zero-emissions vehicles if the market shifts in those directions.

Recommendations

- Falling battery costs will bring EVs to price parity with combustion vehicles in the next 5–10 years across all three countries. While prices will naturally fall as scale and learning continues, supportive policies are needed to accelerate this transition and help overcome behavioral norms that bias toward gas vehicles and the advantages of already-built fueling infrastructure.

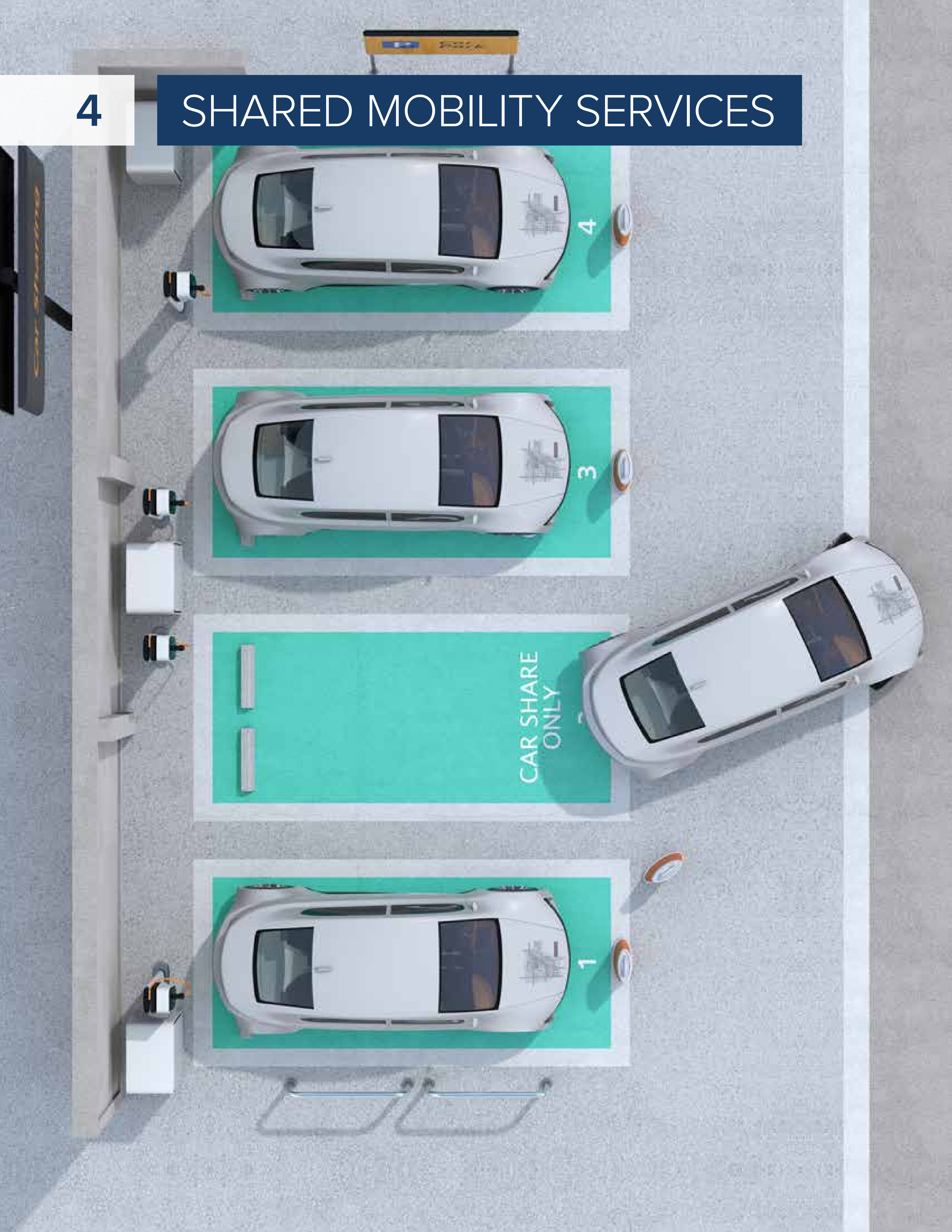
- A set of coordinated but distinct policies targeting both automakers and consumers with a healthy balance of rewards and punishments has proven to be most effective in China. However, each country has different capacities and appetites for top-down mandates versus subsidies and incentive packages.

- Adopting a uniform, national EV-sales mandate to send a clear message to automakers to scale up production—as has been done in China—can be effective across all countries.

- Focusing finite EV subsidies on high-utilization vehicles —as has been done in India—allows for the greatest leverage of public funds to increase electric vehicle miles while creating broad public exposure to EVs.

- A coordinated and collaborative approach to charging infrastructure investment and buildout that engages public and private sectors across both the transportation and electricity sectors is required for quick and efficient deployment of infrastructure at the level required to support rapid EV adoption.

4 SHARED MOBILITY SERVICES



SHARED MOBILITY SERVICES

Shared mobility services take on numerous forms, including ridehailing, carsharing, bikesharing, scooter-sharing, and van-pooling. Each of these services serves a different market segment and travel distance. We focus here on ridehailing, as it has the highest usage rates of all shared mobility services, and is perhaps most likely to replace the role of private vehicles given the barriers and geography dependence of other sharing models.

MOBILITY SERVICES ADOPTION

Ridehailing adoption has taken off in all three countries, totaling over 700 million customers, which comprise over 80% of all ridehailing users in the world.

United States

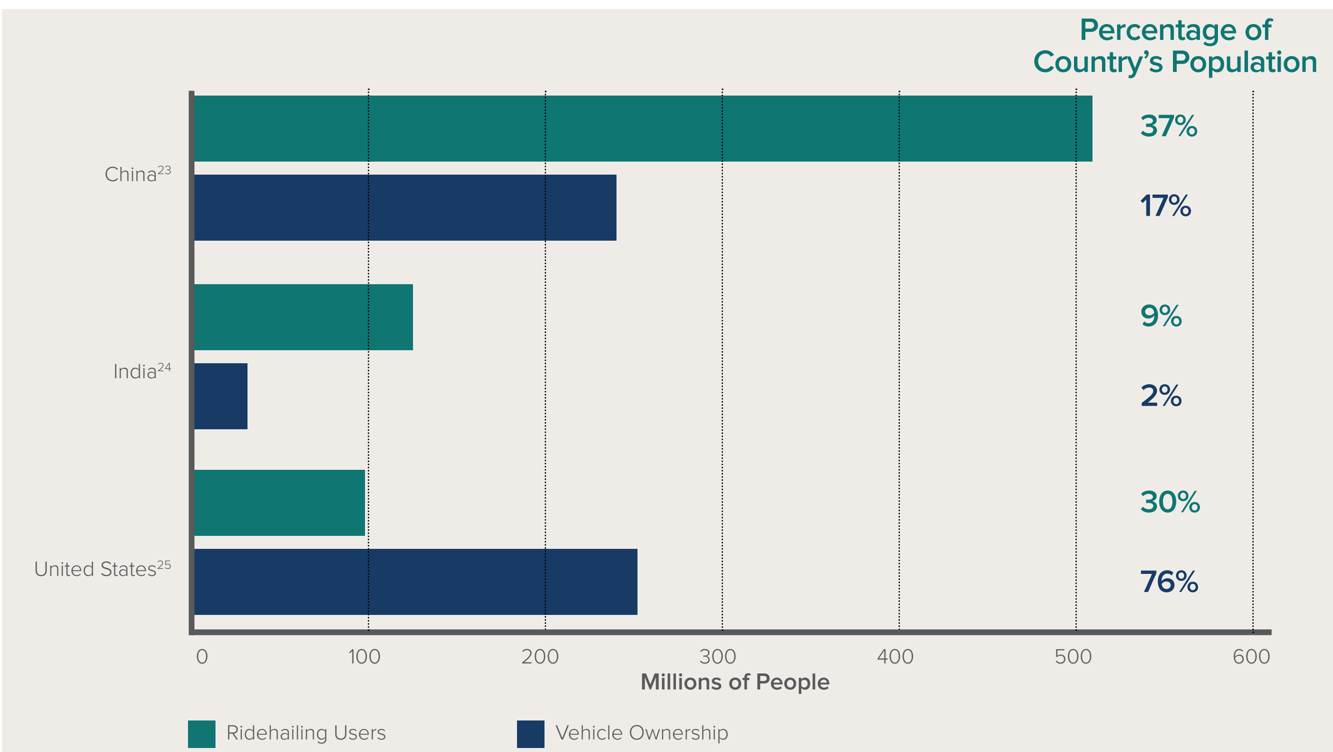
In the United States, where car ownership is the norm, ridehailing usage is growing rapidly as there is a strong supply of drivers. Currently, vehicle ownership rates are also slowly increasing, but there is potential for this trend to reverse as ridehailing and other services grow to replace the traditional function of personal vehicles.

China

In China, 37% of citizens are registered as ridehailing users, which is more than double the rate of vehicle ownership. This suggests that the growth of ridehailing has outpaced that of personal vehicles since 2010.[v]

EXHIBIT 13

Ridehailing Users Versus Vehicle Ownership[22]



[v] Not all registered users on ridehailing platforms are necessarily active. The optimal metric for measuring shared mobility usage is passenger vehicle miles traveled (VMT), but this data is not available. Thus, we use registered users as a proxy for passenger VMT.

India

The growth of both car ownership and ridehailing services is relatively nascent in India. However, ridehailing usage is currently quadruple the rate of vehicle ownership and growing rapidly, suggesting there is potential for India to leapfrog the Western car-ownership paradigm.

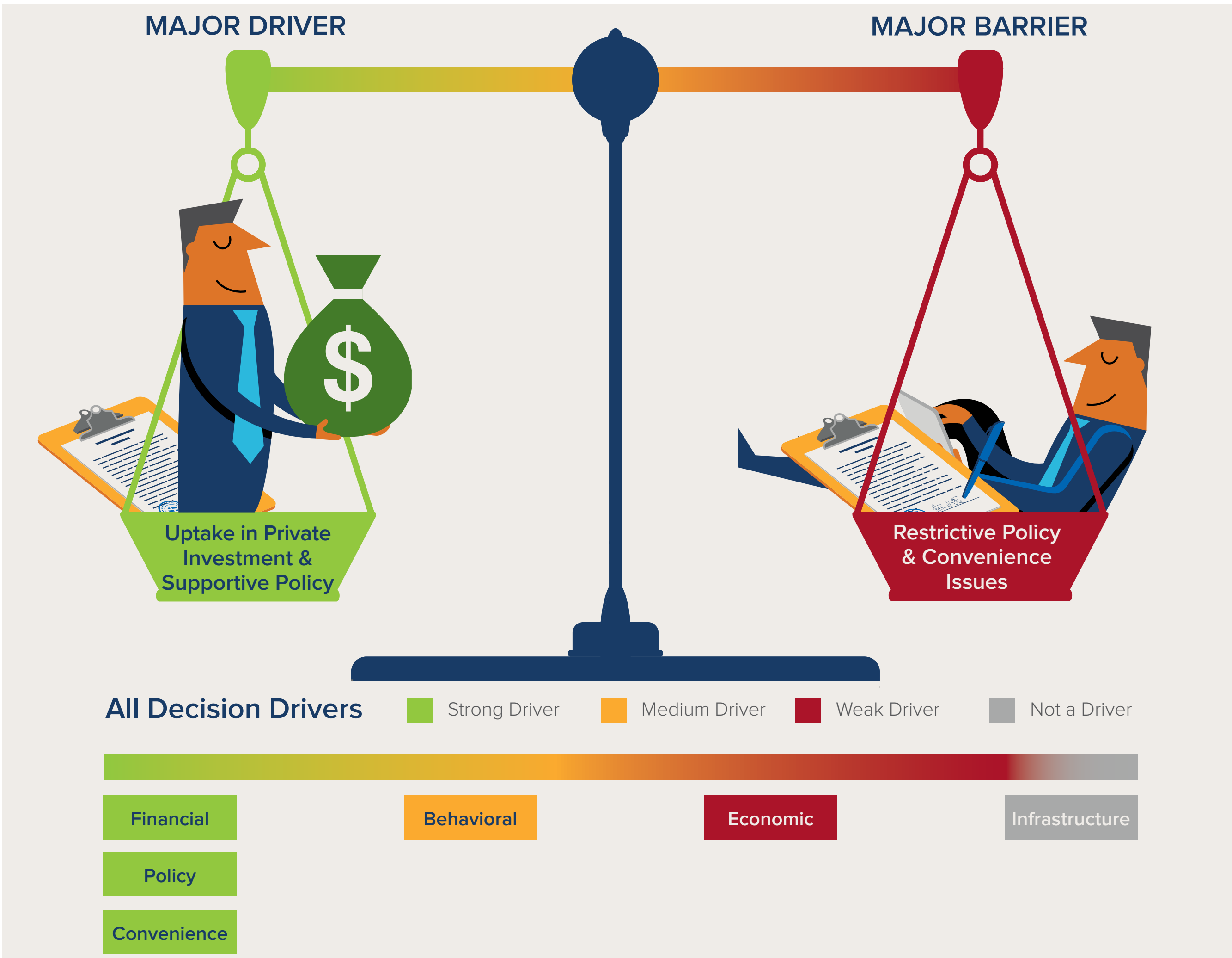
Globally, the majority of ridehailing trips are still single occupancy; for example, pooled rides comprise only 20% of all Uber trips worldwide. This has caused concern to both policymakers and the public around congestion and air quality issues because in the absence of pooling and efficient shared route optimization, TNCs can result in increased vehicle miles driven. As a result, it is essential that shared mobility services are pooled—to increase vehicle utilization and reduce congestion, and electrified—to avert worsening air pollution.

KEY DRIVERS

Mobility service companies are currently funded by private investors and many aim to implement AV technology to become profitable or more profitable, though this is not an immediate step given the current development of the technology and rules for implementing it. To gain ridership, mobility services must be competitive with other modes of transit in terms of cost and convenience. Policy can support or hinder the pace at which mobility services are able to integrate autonomous technology into their platforms and also inform the fraction of mobility services that are pooled and electric.

EXHIBIT 14

Key Drivers and Barriers Behind Shared Mobility Services



Shared Mobility Policies

Policymakers have begun regulating ridehailing services primarily in response to studies that suggest ridehailing is **worsening** congestion in cities and **cannibalizing** public transit ridership. However, models have shown that ride pooling can reduce the number of vehicles on the road.

Ridehailing policies can be designed to mitigate congestion (and associated air quality issues) by encouraging ridepooling and electrification. The resulting tax revenue can be used to bolster public transit, which can be integrated with other shared mobility services.

Through well-designed policy, cities have the opportunity to guide the evolution of ridehailing services to align with the city's goals of improving mobility. Below we highlight some municipalities within the three countries that have implemented ridehailing policies to encourage pooling, electrification, and integration with public transit.

EXHIBIT 15

Ridehailing Policies in the Three Countries

		China	India	United States
Encourage Pooling	Ridehailing taxes			
	Congestion pricing			
	Caps on ridehailing drivers			
Encourage Electrification	Emissions standards on ridehailing vehicles			
	Targeted EV subsidies for ridehailing vehicles			
Integrate with Public Transit	Multimodal services			

* Light blue indicates that there are select cities or municipalities within the country that have implemented these ridehailing policies, but they are not necessarily enforced nationwide.

Encourage pooling to reduce congestion

Ridehailing taxes and rebates

The first wave of ridehailing taxes were "blanket taxes," which charged a standard fee per ride regardless of ride type. Recently, cities have begun implementing tiered taxes that encourage pooling and electrification, which better align with city goals of reducing congestion and air pollution. Exhibit 17 shows some examples of tiered taxes that we believe align the interests of both cities and ridehailing companies.

It remains unclear who should bear the responsibility of paying these taxes—the driver, passenger, or ridehailing company. In some markets, excise taxes have been deducted from the driver's earnings. This has raised concerns from part-time drivers who can struggle to make a living wage from ridehailing work when driving inefficient and expensive gas vehicles. The allocation of costs across different parties should be clearly specified in the tax policy.

EXHIBIT 16

Examples of Tiered Taxes That Align the Interests of Both Cities and Ridehailing Companies

	Single-occupancy rides	Pooled rides	Rides in EVs
Manhattan	$2.75 tax	$0.75 tax	
San Francisco (proposed)	3.25% tax	1.5% tax	0% tax
Massachusetts (proposed)	6.25% tax	4.25% tax	
New Delhi (proposed)			10–20% rebate

* This is an illustrative list; not comprehensive

EXHIBIT 17

Proposed Congestion Pricing in Manhattan

	Personal vehicles	Trucks	Ridehailing vehicles	
			Single occupancy	Pooled
Manhattan	$11	$25	$5	$2

Congestion pricing

Another policy mechanism to encourage pooling is congestion pricing, which charges a fee to enter a designated high-traffic corridor. These fees are imposed upon all vehicles entering the congestion zone but vary based on vehicle type. Exhibit 17 shows an example of proposed congestion pricing in Manhattan.

Congestion pricing is considered a fairer implementation of fees, as it applies to all road users that may contribute to congestion —not just ridehailing vehicles. Ideally, congestion fees should be structured to reflect each vehicle's contribution to the problem. Beijing is currently considering a congestion pricing program for implementation in 2020.

In the future, taxes can be further tiered to adapt to real-time congestion at different times of day and in different regions. This level of granularity would allow tax structures to accurately reflect the market value of averted congestion.

Caps on ridehailing drivers

An alternative approach for reducing congestion is to directly cap the number of ridehailing vehicles on the road. Historically, India has had the strictest licensing processes for for-hire vehicles, due to its stage carriage permit laws. Recently, Nanjing and **New York City** became the first cities in their respective countries to enact registration caps for ridehailing vehicles, in order to better regulate and understand the impact of ridehailing services. We expect other cities to consider similar caps in the future.

Encourage electrification to improve air quality

Emissions standards on ridehailing vehicles

In September 2018, California passed the first legislation requiring ridehailing companies to meet **emissions** standards. The standards will be defined by 2021 and enforced starting in 2023. In response, ridehailing companies have begun taking voluntary measures to reduce their emissions.

We believe China would be well-poised to implement this type of regulation for ridehailing companies, as an extension to its strict emissions standards for automakers. Nonetheless, China is already leading the world in electrified shared mobility, with over 50% EVs in the ridehailing fleet (compared to less than 1% in United States and India). Thus, the direct regulation of ridehailing companies may not be necessary.

Targeted EV incentives

India's recent FAME-II program will only subsidize four-wheelers used for commercial or shared mobility services, not those purchased by private consumers. This ensures that the vehicles with the highest utilization are electrified first, maximizing the benefits of the subsidy.

Both China and the United States could potentially adjust their existing EV subsidy programs to prioritize vehicles used for shared mobility.

Provide equitable access to mobility services

There is significant concern that ridehailing companies are deepening urban inequality by providing services only in certain regions, pricing out lower-income residents and failing to accommodate disabled passengers. Unlike transit agencies, which are required to provide equitable mobility services for these underserved populations, ridehailing companies are not often subject to such requirements and often lack the profit motive to serve these communities. Cities like Vancouver, Canada—a holdout against ridehailing—are trying to find better policies to attack this issue before they allow TNCs.

These concerns are magnified in regions where ridehailing services have begun replacing underutilized transit lines, such as **Dublin**, California, and **Altamonte Springs**, Florida. There is fear that if public transit is completely replaced by private ridehailing companies, there would be no regulatory mechanism to ensure affordable rates and adequate coverage in low-income neighborhoods. As ridehailing becomes more ubiquitous, policymakers will have to decide whether to hold these companies to the same accessibility standards as transit agencies.

Integrate with public transit

The relationship between ridehailing companies and public transit agencies has been strained, as recent US-based studies have suggested that ridehailing services can cannibalize ridership from public transit. Mass transit is still the most efficient form of transportation along high-traffic corridors, for space utilization and mass-flow reasons among other things, and should not be displaced by shared mobility. However, mobility services can complement mass transit by offering first- and last-mile solutions to destinations not served by public transit.

Integrating ridehailing services as a first- and last-mile solution

There is potential for ridehailing services to complement and support public transit systems, by integrating services at existing transit hubs. Programs in Los Angeles, Charlotte, and Philadelphia are currently offering free or subsidized rides to and from light-rail stations. Didi recently introduced a **service** that allows users to book a full multimodal journey in their app, including mass transit and pooled rides to and from the train station.

Despite these programs, surveys from multiple American cities indicate that only **4%–5%** of Uber and Lyft customers are using ridehailing services to access mass transit. Better coordination between public and private sectors supported by thoughtful policy will be required to ensure that ridehailing services are well integrated into public transit planning and operation, leading to more streamlined and lower-cost multimodal transit ecosystems.

Multimodal transit models can be developed to align the interests of cities, shared mobility companies, and passengers. In one model, high-traffic corridors could continue to be efficiently served by bus and light-rail, while underutilized bus lines at the city periphery could be substituted by pooled ridehailing services, which essentially serve as microbuses with dynamic routes and schedules. This way, public transit agencies could continue operating their most profitable bus and rail lines, while cities can limit congestion in high-traffic corridors, and passengers can enjoy shortened transit connections.

Policy can encourage such an integrated multimodal approach by taxing or otherwise limiting rides that run parallel to existing transit routes in high-traffic corridors (tiered by number of passengers and time of day), subsidizing rides that start or end in existing transit hubs, and promoting mutually beneficial data sharing. Cities, for instance, could provide transit ridership data to assist ridehailing companies in planning for demand, while ridehailing companies could provide aggregated route data to assist cities in understanding if the program is adequately serving riders from underserved transit deserts.

Economics and Convenience of Shared Mobility

Our previous **behavioral economics work**, and that of others, suggests that consumers make travel decisions not only based on cost, but also considering convenience, reliability, travel time, and comfort.[26] In the United States and increasingly in China and India, personal vehicles are the gold standard that all new mobility services must meet or exceed. We find that dense cities provide the best environment for shared mobility services integrated with public transit to compete with personal cars in terms of both cost and convenience.

In rural areas, trips are typically longer and taken between more remote regions that would be poorly served by ridehailing services and public transit. Passengers may have to wait longer to hail a vehicle, and ride-pooling opportunities have been limited. As a result, traveling by personal car is often faster and more convenient, with few pain points—for now.

EXHIBIT 18

How Urban Form Influences the Feasibility of SEAMs

	Lower density, rural	Higher density, urban
Personal vehicles	• Longer trips to more remote areas • Free and convenient parking	• Shorter trips between dense regions • Limited and expensive parking
Ridehailing	• Few vehicles nearby; long wait times • Few riders nearby; limited pooling	• Many vehicles nearby; short wait times • Many riders nearby; efficient pooling
Public Transit	• Cost prohibitive to establish public transit connectivity in remote regions	• Better opportunity for public transit connectivity in dense regions

On the other hand, ridehailing operates more efficiently in dense urban areas, where many vehicles and passengers in close proximity allow for dynamic and rapid ride matching. Ridehailing can serve nearby transit hubs that connect passengers with mass transit. Car ownership becomes more of a burden than a freedom, as parking can be expensive and difficult to find. Shorter trips also mean the vehicle is likely underutilized, costing significantly more per mile to operate.

Thus, dense urban cities provide the ideal environment for shared mobility services to thrive and evolve in the near term, setting the stage to eventually evolve to serve the more challenging rural environment. By this criteria, China and India present huge potential for shared ridehailing services, as they are undergoing significant urbanization. China and India collectively have over 200 tier-2 cities (more than 1 million people) and 13 tier-1 cities (more than 10 million people), compared to just 10 tier-2 cities in the United States. China and India's rapid urbanization suggests shared mobility has huge potential to replace or perhaps avert personal vehicle dominance.

Financial Investment

Shared mobility services were initially dominated by technology companies seeking to disrupt the automobile industry. In response, incumbent automakers have entered the shared mobility space with their own ventures, partnerships, and acquisitions, in anticipation of large changes to the auto industry over the next decade.

Ridehailing companies are primarily funded by private investment because their business models appear to require AV technology or other innovations to reach profitability in countries with high labor costs. After raising $27 billion in 2017, ridehailing companies now have a combined valuation of over $160 billion. Lyft was the first ridehailing company to enter the public market in March 2019, with Uber following suit shortly after.

Global scaling potential

The two major players, Didi (China) and Uber (United States), have acquired or purchased **stakes** in many other independent mobility-as-a-service providers worldwide, including Ola, the leading ridehailing service in India. As a result, the growth trajectory of ridehailing in these three countries has significant implications for shared mobility in the rest of the world. If these companies can demonstrate successful operation in their home countries, their platform and technologies can be quickly scaled to other regions of the world.

Cultural Acceptance

Personal vehicles represent freedom

Ultimately, shared mobility adoption may be driven less by economics than by cultural norms and perceptions. According to a J.D. Power study, while 70% of **Chinese consumers** are willing to give up car ownership if effective mobility alternatives are available, only 26% of **US consumers** would be willing to do the same. This may speak in part to the incredible diversity of uses that Americans have for their cars—including using them as closets, offices, off-road freedom mobiles, status symbols, and objects of weekend affection.

Perhaps the reluctance in the United States arises from the belief that no mobility alternative could truly be as effective in serving individual needs as operating a personal vehicle. Private cars have dominated personal mobility for so long in the United States that the two concepts have become almost synonymous. There exist few options that can compete with private cars in terms of convenience, accessibility, and comfort. As a result, most Americans have had only limited or negative experiences with alternative forms of transit. Understandably, the concept of replacing an asset so core to the American way of life is inconceivable but not impossible.

Further, automobiles in the United States have come to represent the core American values of freedom and self-reliance. Vehicle models are often marketed not to fulfill a function, but to allow the purchaser to fulfill a lifestyle. Similarly, in China, car ownership has become associated with freedom and social status and represents an aspiration for many Chinese citizens as does both two-wheeler and car ownership in India. In contrast to the United States, and in line with most of the rest of the world, public transit has much higher utilization in Chinese and Indian cities. Passengers in China and India may be more accustomed to high-utilization mobility service vehicles such as rickshaws and shared autos, and may not view ridepooling as inherently less desirable. Thus, shared mobility services have the opportunity to demonstrate their convenience and comfort in these markets as an improvement over the status quo, without having to overcome preexisting notions (often negative) about shared rides.

Equity concerns

In each country, there is a stratification of transit mode by socioeconomic class. Certain modes of transit are stigmatized or perceived to be lower class. In the United States, as well as India and China, buses are often used by lower-income residents who cannot afford the costlier mobility services or the even costlier option of a personal vehicle. Many US cities run public transportation in the tradition of American social safety-net programs—so minimally as to encourage people to stop using them the moment they can afford to do so. Cycling has become a symbol of poverty in China, which was once deemed the "bicycle kingdom." In India, auto-rickshaws are predominantly used by lower-class citizens, who cannot afford a two-wheeler or car. In all three countries, private vehicles rest at the top of the mobility pecking order, serving as a target or aspiration for the majority of their populations that must be overturned if shared mobility services are to succeed in the global mobility transformation.

If shared mobility services are to not alienate lower-income segments of society, they must be accessible and affordable and integrate with public transit networks. Ridehailing companies will likely stratify their services to serve these different market segments. Regulators also have a role to ensure that shared mobility services are equitable and accessible to all residents.

Takeaways

- Encouraging pooling and electrification of ridehailing through tiered taxes and incentives can minimize the impact on congestion and air quality and can help overcome the strong behavioral preferences for single occupancy rides.

- Ridehailing services will thrive in dense, urban environments where they are competitive with the price and convenience of personal vehicles and can be integrated with public transit (buses, rail, and subways) and nonmotorized transit modes.

- China and India have the potential to leapfrog the American paradigm of car ownership, due to their rapid urbanization and less entrenched car culture.

- Ridehailing services have the potential to both reduce congestion (through pooling) and integrate with public transit systems to increase ridership and enable better transit services. Well-designed policies should encourage ridehailing companies to develop products that meet these goals, instead of emulating the single-occupancy private vehicles that they sought to replace.

- Shared mobility must be well integrated with existing public transit infrastructure and should be part of future transit planning processes. Increased use of public private partnerships should be encouraged to ensure an efficient use of public resources and private investment.

5 AUTONOMOUS VEHICLES

AUTONOMOUS VEHICLES

AV ADOPTION

Exhibit 20 illustrates where each country lies on the path to large-scale deployment of autonomous vehicle technology using road testing as a proxy for progress. Companies are granted more freedom in testing (moving to the right) as they prove their competence through different metrics (number of miles driven, frequency of disengagements, rate of accidents, etc.) and eventually are granted permission for full-scale deployment. Road testing is important because AV technology needs to prove it can perform in a complex real-world environment and instill confidence in all stakeholder groups that AVs will indeed benefit society rather than harm it.

We compare AV development in each country by looking at the number of companies with road testing permits as a proxy for AV development in that country. Due to national laws that prohibit AV testing in India, there are no testing permits in India.

United States

The United States has led the world in AV development and testing, with significant private investment and a rich talent pool of AI engineers. Waymo (part of Alphabet/Google) reports driving over 10 million autonomous miles, and has been allowed to test AVs without a driver present in California. However, the United States has patchwork AV regulation that does not provide consistent guidelines for AV companies across states.

China

China is proactively trying to catch up by enticing US companies and talent to move overseas. Unlike the patchwork state policies in the United States, China has implemented national guidelines for AV testing that provide a clear pathway for AV companies to bring their technology to market.

EXHIBIT 19

The Path to Large-Scale Deployment of Autonomous Vehicle Technology

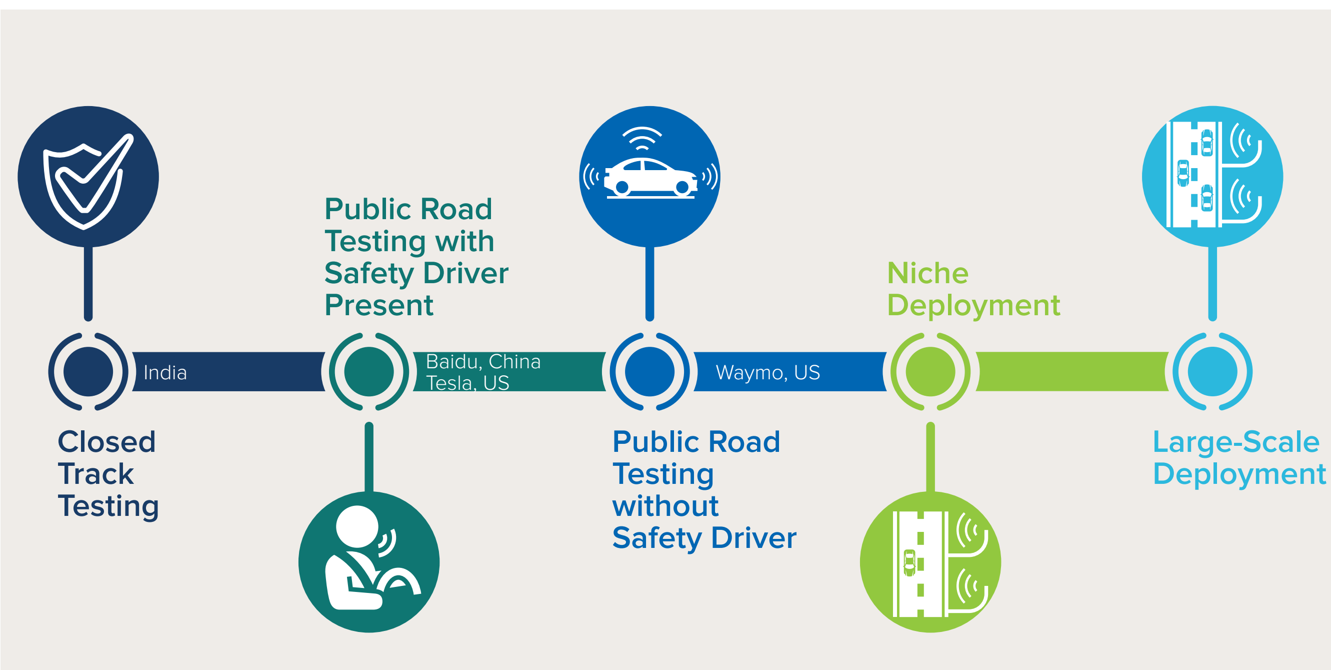
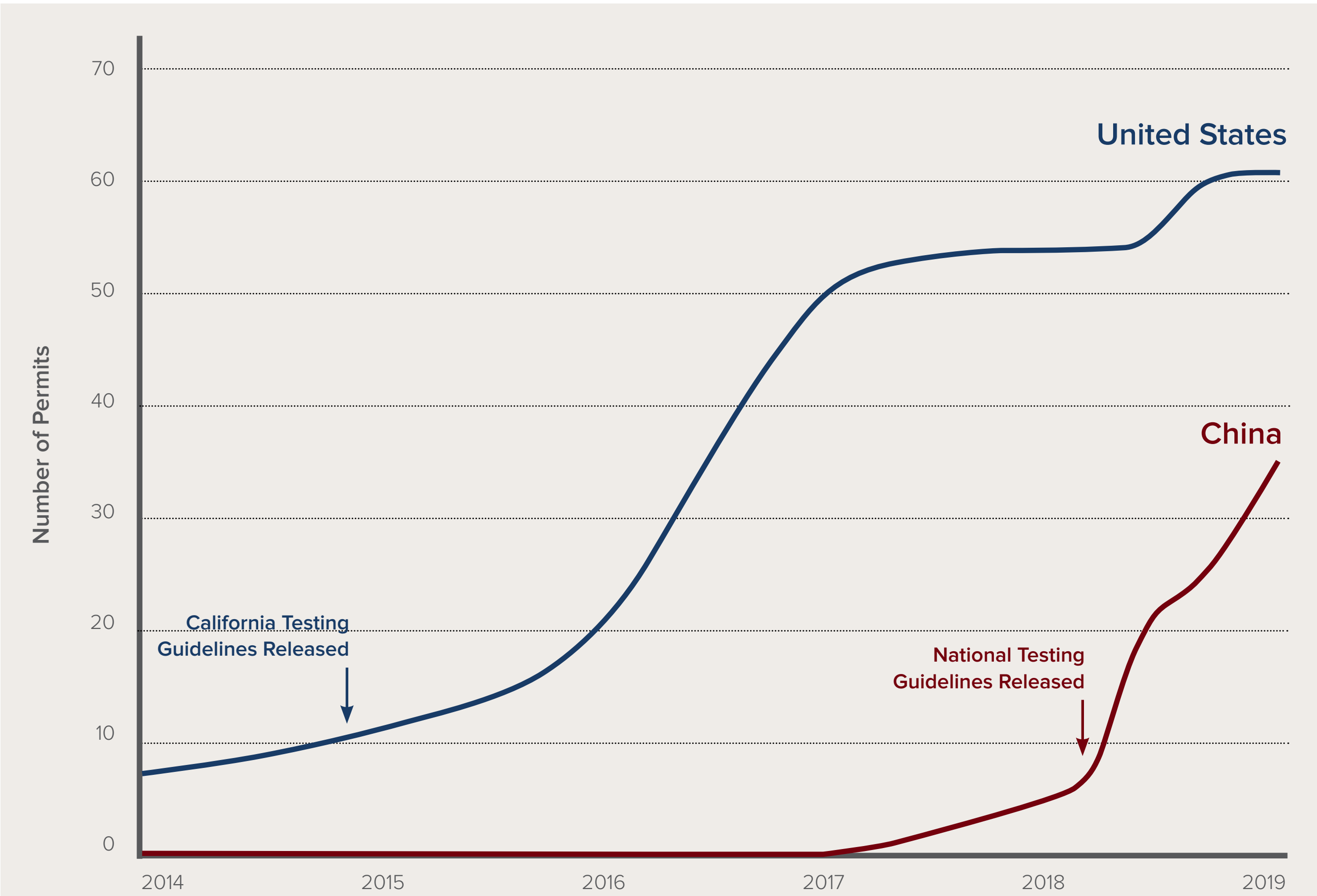


EXHIBIT 20

Number of Companies With AV Testing Permits[vi, 27]



[vi] We use AV testing permits as a proxy for AV development in each country. India is not shown due to current restrictions on AV testing.

India

India has expressly forbidden AV testing on public roads, so any AV testing is limited to closed test tracks due to labor market concerns. There are additional concerns from both policymakers and AV companies that the nature of India's roads may present a challenge for autonomous driving technology.

KEY DRIVERS

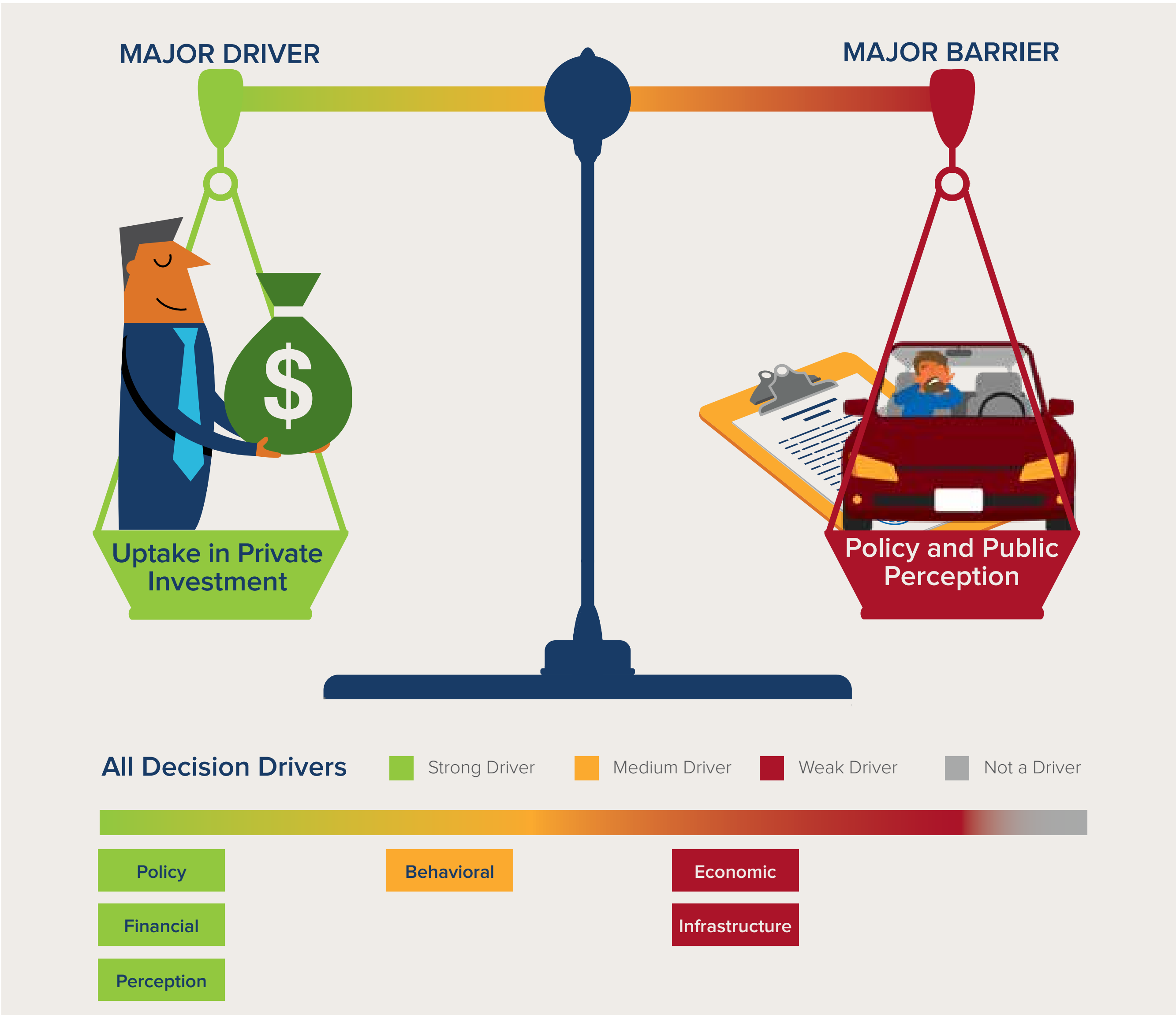
AV development is largely driven by private investment, but highly regulated by governments and scrutinized by the public.

Autonomous Vehicle Policy

Regulations around AVs are necessary because left unregulated, they can potentially cause significant public harm and contribute to congestion, pollution, and urban sprawl. Policymakers must balance innovation with public safety and wellbeing. Well-designed AV policy provides clear guidelines on

EXHIBIT 21

Key Drivers and Barriers for Autonomous Vehicles



how AV companies can demonstrate safe and clean operation while bringing their technology to market.

Public road testing is important as it indicates how vehicles detect and respond to real-world conditions such as complex intersections, illegally parked vehicles, and erratic pedestrians.

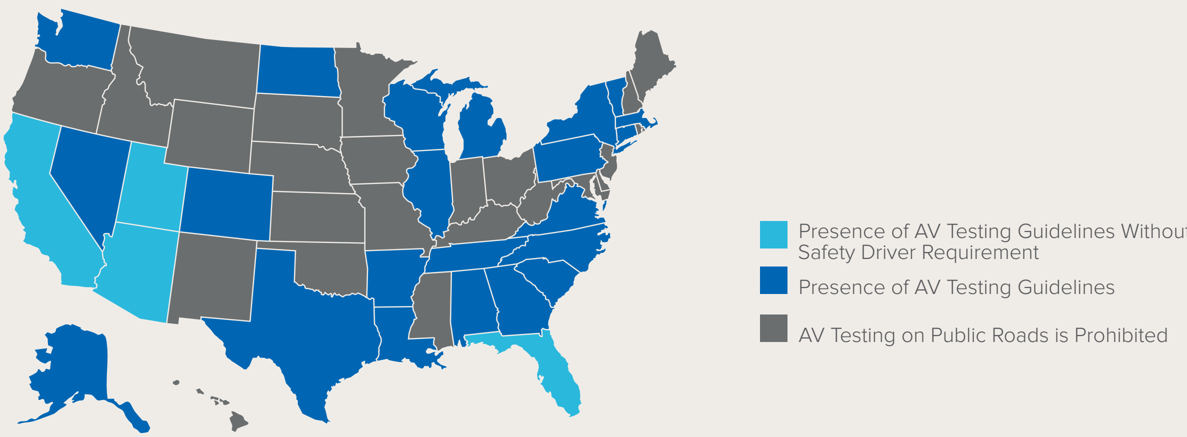
The United States has a complex, patchwork regulatory landscape that varies from state to state. Currently, 33 states allow AV testing on public roads. California has implemented the most comprehensive policies, requiring AV companies to apply for licenses and provide detailed reports on miles driven, disengagements, and accidents. Arizona, Utah, and

EXHIBIT 22

Road-Testing Regulations in the Three Countries[28]

UNITED STATES

A patchwork regulatory landscape that varies from state to state. As of mid 2019, four states allow AV testing on public roads without safety drivers



CHINA

Strong government support at both national and local levels

INDIA

Autonomous vehicles forbidden on public roads

Florida have also created permitting processes for AV testing on public roads without a safety driver, in an effort to attract AV companies and build public trust in autonomous technology. On the federal level, the Self-Drive Act passed through the House with bipartisan support but failed to pass in the Senate before the last term of Congress expired in 2018. Had the Self-Drive Act passed there would be significantly more clarity and uniformity on operational rules and regulations across the United States, creating more confidence in the private sector to take clear action in technology and business model development.

In China, AV development is at a more nascent stage, but has strong government support at both national and local levels. In early 2018, Beijing and Shanghai created the first regulatory frameworks for public road testing. Shortly after, China implemented Beijing's policy at the national level. These uniform national guidelines provide a clear pathway for AV companies to bring their technology to market. By making AV development a national priority, China aspires to be a global leader in AV production by 2025.

In India, AV developers have not been able to move beyond closed test tracks because the Minister of Transport and Highways publicly forbade autonomous vehicles due to the risk of taking away jobs from for-hire drivers. Neither the Indian government nor global industry players expect that AVs can be deployed on public roads in the near future due to the nature of India's road traffic. The wide variety of vehicles, roaming cattle, poor signage, and dense and unpredictable traffic patterns present a challenge for current AV sensors and software.

Encourage electrification and pooling

Autonomous vehicles have the potential to exacerbate congestion and air quality issues if allowed to operate inefficiently. Robin Chase famously describes a "**hell scenario**" in which privately owned AVs are tasked to run mindless errands and people commute hundreds of miles while sleeping, clogging up streets and choking the air. To avoid this scenario, AV policies can encourage or even require some degree of pooling and electrification.

In Massachusetts, self-driving vehicles are required to be electric. This type of policy would be far more effective at the federal level and would ensure that AVs lessen rather than contribute to greenhouse gas emissions. Since the EV and AV markets are moving forward somewhat independently, it cannot be taken for a given that all AVs will be EVs. Both AVs and EVs are more expensive than the average car; the price of the combination would be challenging for a while. There is a chance this combination may occur naturally due to market forces and vehicle availability as we expect EVs to reach mass market before AVs are widely integrated into the mobility paradigm. Once past the crossover point, market forces are in favor of EVs due to the favorable economics of highly utilized electric vehicles over gas vehicles. GM Cruise, a GM-owned driverless car company, is already testing on an all-electric fleet; Waymo, Google's driverless car company, has a mix of plug-in hybrids and electric vehicles; and Tesla Autopilot technology is a simplified approach to AV installed in an all-electric platform across all of their models.

AVs will also be subject to a per-mile tax in Massachusetts. To take this one step further, such taxes should be tiered and charge more for single-occupancy or privately owned AVs to encourage higher utilization and pooling. In Beijing, AVs are restricted to certain streets at certain times, which ensures that AVs do not contribute to congestion along high-traffic corridors.

Economics of AVs

The operating costs of autonomous vehicles have the potential to be far lower than human-driven vehicles, particularly in the United States, where the drivers' earnings represent the majority of the ridehailing fare unlike India where the fuel and other costs represent the larger fraction of the fare. This presents a compelling market opportunity for the transport of both goods and people. In a **previous report** published by Rocky Mountain Institute, autonomous vehicles in the United States are projected to reduce the operating costs of ridehailing by more than half, bringing autonomous shared mobility to price parity with personal vehicles, and in time possibly even lower.

The cost savings of replacing the human driver depends on the cost of labor, which is significantly lower in **China and far lower in India**. As a result, the relative cost savings will be lower in these countries. Nonetheless, self-driving technology will still reduce the cost of shared mobility services, making them more cost-competitive with personal vehicles.

Financial Investment

Private investment is the primary driver for AV development, with over $9 billion invested in autonomous vehicle companies in 2018. The AV landscape is a complex partnership of investors, automakers, and self-driving car businesses. Incumbent automakers like GM have invested in software and sensor companies in anticipation of an autonomous future. Technology developers like Baidu and Waymo have partnered with automakers to mass produce vehicles with their AV technology.

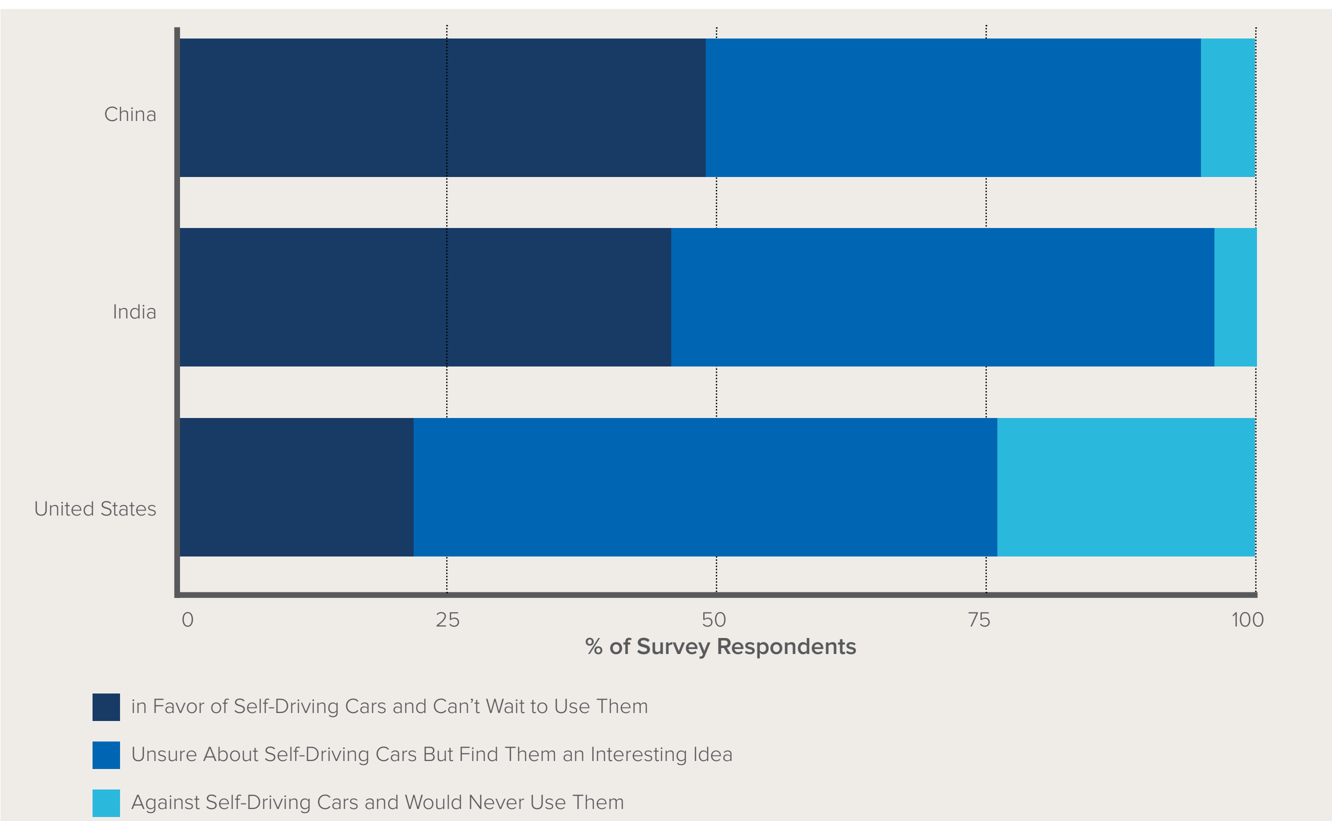
A significant portion of this investment is used to hire top talent in the artificial intelligence and machine learning fields, which has historically been concentrated in the United States. Recently, Chinese AV companies have opened offices in Silicon Valley to aggressively recruit US talent for their research and development. China is also encouraging US AV developers to set up satellite offices in China, where there is a more supportive testing environment. This will certainly encourage global competition in the AV market, which should accelerate development and bring AVs to production sooner.

Cultural Barriers

A global survey conducted by **Ipsos** exploring perceptions about autonomous vehicles indicates that people in India and China are more than twice as willing to adopt AV technology, while almost a quarter of Americans refuse to ever use them. The study found an interesting trend that faith in AV technology

EXHIBIT 23

Perceptions About Autonomous Vehicles[29]



is highest in developing countries, with India and China topping the list of 13 countries surveyed and the United States, Germany, UK, and Canada reporting the most negative or fearful public perception.

Fatal accidents spur public distrust

A series of fatal accidents involving AVs have spurred public distrust in AV technology. In March 2018, a self-driving Uber struck and killed a pedestrian pushing a bicycle in a complex intersection, who was classified as an unknown object by the vehicle's telemetry. Several days later, a Tesla Model X crashed into a concrete barrier while operating in Auto-pilot mode (not a fully autonomous mode) killing its driver. These incidents have resulted in an increase in negative public perceptions of the technology in the United States.

In response to these accidents, Arizona temporarily halted AV testing and Uber elected not to reapply for a California testing permit. However, if public skepticism continues to grow, regulators will likely respond more harshly and potentially halt or further control AV testing.

The **public** is far more favorable and accepting of AVs in China than in the United States, as shown in Exhibit 23.

In India, public perception is less well known due to the current laws restricting AV testing on Indian roads. There is however a commonly articulated barrier to AV use in India associated with lesser enforcement of road rules and more unpredictable driving habits, particularly the tendency of drivers to not drive in a single lane.

Establish liability standards in the event of an accident

Some have argued that fatal accidents will be unavoidable in the development of a technology like AV. If this is the case, there should be clear liability standards that protect the public in the event of an accident. China's national policy holds the human driver behind the wheel responsible for accidents caused by that autonomous vehicle, and requires AV companies to provide liability

insurance or a compensation guarantee of $800,000. Another legal **scholar** has argued that autonomous vehicles represent a shift from vehicular negligence to product liability, and thus automakers should be held liable for accidents, as is currently the case in Michigan. In either case, instituting clear liability standards can help protect the public in the event of an accident.

Establish vehicle monitoring standards to prevent accidents

Autonomous vehicle policy can also establish data-sharing standards to ensure safe operation. In Beijing, AV companies are required to collect real-time information about the location and status of every safety driver within an autonomous vehicle as a stop-gap measure to facilitate more safe testing. Using internal cameras and eye sensors ensures that drivers are not distracted and are actively prepared to assume control of the vehicle. Autonomous vehicles are also required to have third-party monitoring equipment installed, which will store data for at least three years to provide evidence in legal proceedings in the event of an accident.

In the United States, data-sharing requirements are less granular and well-defined. California has the most advanced guidelines, requiring AV developers to report their miles driven, disengagements, and accidents on public roads. While this provides some information to guide policymakers in assessing the state of AV development, this does not allow for preventative measures for accident avoidance.

Conservative driving angers human drivers

Another common complaint facing self-driving vehicles is their overly cautious driving habits. AVs generally travel at lower speeds, brake earlier, and yield more conservatively at intersections. In response, some impatient human drivers have swerved around AVs and caused accidents. Regardless of who is at fault, AV companies and drivers will have to reach some sort of compromise to prevent these secondary accidents as AVs become more ubiquitous.

Takeaways

- Establishing uniform, national guidelines around AV testing to provide a clear pathway to production by AV companies will create greater confidence in the market and improve public perception.

- Encouraging electrification and pooling for AVs through tiered taxes, to avert congestion and air quality issues, will help to avoid potential negative side effects of low-cost AV mobility services.

- Creating liability standards and vehicle monitoring protocols can help avoid fatal accidents and instill public confidence.

- China's funding and research into AV technology will likely accelerate the pace of AV development globally.

6 CONCLUSION

CONCLUSION

If adopted in isolation, each of these technologies can potentially create new problems and unnecessary additional external cost to consumers in the form of congestion, pollution, and added cost. Various policies have been implemented to minimize these issues and encourage synergistic benefits; however, current policy is insufficient. Ensuring that rides in autonomous vehicles are both electrified and pooled can mitigate these congestion and pollution issues and provide reliable, low-cost mobility for a rapidly urbanizing society.

- There is huge interest in AV development, due to cost savings in transporting goods and people. However if AVs are not electric, they will worsen pollution; if they are not shared or regulated, they will worsen congestion.
- MaaS companies are also battling to enter new markets globally. But if they are not electric, they will worsen pollution; if they are not shared, they will worsen congestion.
- Electric vehicles are quickly gaining market share in the United States and China with India in a position to follow fast, especially for two- and three-wheelers. Without adequate and collaborative planning among utilities, regulators, policymakers, and the private sector there is potential for inefficient or insufficient investment in charging infrastructure. If done in isolation of the needs of the electricity system, mass adoption of EVs could result in significant added costs that could easily be avoided with intelligent and forward-looking planning processes.

EXHIBIT 24

Policies and Industry Developments that Encourage the Co-Development of EVs, AVs, and MaaS

	Synergies			SEAMS Support
	EV + AV	**AV + MaaS**	**EV + MaaS**	
United States	In San Francisco, the proposed AV tax is lower for electric vehicles. Currently, 67% of testing miles are electric (Waymo, GM).	In Michigan and San Francisco, proposed AV taxes are lower for shared rides.	California has implemented ridehailing emissions standards.	Medium EV Mixed AV Mixed MaaS Minimal Pooling
China	AVs are likely to be electric due to a maturing EV market and registration restrictions.	NA	High EV penetration in existing ridehailing fleets due to registration restrictions.	High EV High AV Medium MaaS Minimal Pooling
India	NA (AV testing not allowed on public streets).	NA (AV testing not allowed on public streets).	EV subsidies are limited to 4-wheelers used for commercial purposes.	High EV AV Testing Prohibited High MaaS No Pooling

China, India, and the United States are at different stages of development in these emerging mobility technologies. As a result, they have the opportunity to share learnings and adapt each other's frameworks to accelerate the global mobility transition, as summarized below.

EXHIBIT 25

What Countries Can Learn From and Share With Each Other to Accelerate Adoption

Shared Learnings between Countries			
	EV	**AV**	**MaaS**
United States & China	China's national New Energy Vehicle mandate was modeled after California ZEV. The United States can adopt a more comprehensive policy framework from China with clear benchmarks for bringing EVs to market.	China's AV companies are opening US offices to attract talent while US companies are testing vehicles on Chinese roads to accelerate their technology development.	US ridehailing companies can borrow from China an integrated ride booking system that incorporates public transit and bikeshare as part of a multimodal journey.
China & India	India took a tip from China's national level EV policy approach. China can adapt India's prioritization of support for commercial EVs and include a component of ridepooling to encourage higher load factors.	India can look to China for guidance on implementing AVs if and when India lifts the AV ban. Public perception of AVs in China and India is more supportive than in the United States.	China and India have many rapidly urbanizing, dense cities that are well suited for mobility services integrated with public transit. A robust policy framework can shift the course of development toward pooled rides and away from personal vehicles.
United States & India	The United States can borrow from India's policy framework and target high mileage commercial vehicles for electrification first resulting in both favorable economics for the operator and more vehicle miles electrified.	India can borrow from the US experience of implementing AVs if and when India lifts the AV ban.	India can borrow from the US emerging tiered tax structures on MaaS providers to create market incentives that favor higher load factors.

ENDNOTES

ENDNOTES

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