ARK INVEST

Mobility-As-A-Service

Why Self-Driving Cars Could Change Everything

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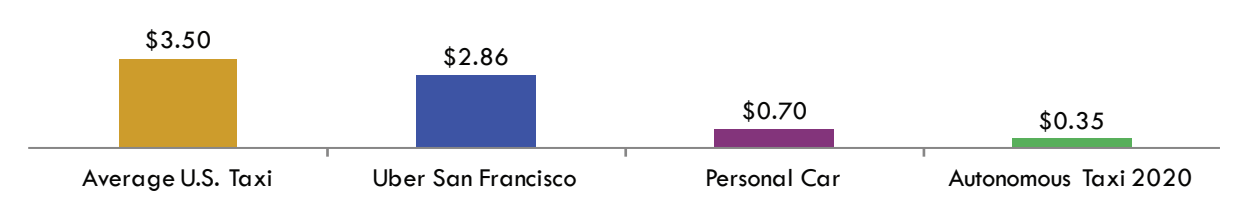
RESEARCH HIGHLIGHTS

ARK expects autonomous taxi services to be commercially available in 2019. By the late 2020s, autonomous taxis should be the dominant form of door-to-door mobility.

ARK estimates that autonomous taxis will cost consumers $0.35 cents per mile, or roughly half of the all-in cost car owners pay to drive today, thanks to much higher utilization rates. These compelling economics should drive widespread adoption of autonomous taxi networks.

All-In Cost Per Mile of Vehicle Services



Source: ARK Investment Management LLC

ARK expects traffic to increase almost three-fold by 2030. Autonomous taxi platforms will allow the non-driving population, which includes the blind, elderly, and young teens, affordable and convenient transportation options. While traffic likely will increase, autonomous cars should operate more efficiently and should give passengers a more pleasant experience than just sitting behind the wheel.

Autonomous cars should cause a shift away from personally owned vehicles, depressing global auto sales volumes in the coming decades. ARK's research shows that auto sales will fall by nearly half in developed markets. In the developing world, auto volumes will likely increase over the long term, but at a rate much slower than expected today.

While a loss in future auto sales may seem like bad news for the economy, **by 2035, ARK predicts that autonomous taxis will add more than $2 trillion to GDP in the U.S. alone.** Among these economic benefits, ARK sees additional service revenue, more discretionary time for passengers relieved of driving responsibilities, and higher capital returns from repurposing land once used for parking lots.

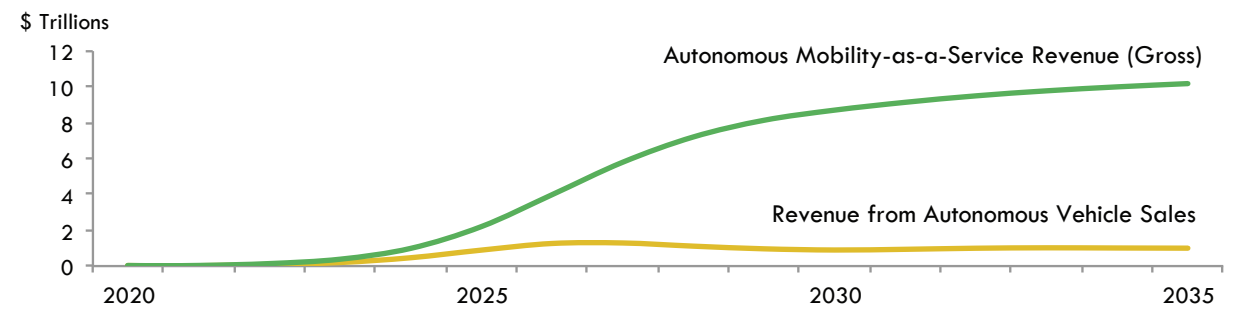
ARK's research shows that the global autonomous mobility-as-a-service (MaaS) market will exceed $10 trillion in gross revenue by the early 2030s.[i] Roughly a third of those sales will happen in China.[ii] In the United States, ARK expects the MaaS market to reach over $700 billion in sales

[i] ARK assumes that platform service providers will take a 20% cut of the $10 trillion gross sales. Net revenue for platform providers should reach $2 trillion.

[ii] Source: ARK Investment Management LLC

by 2030, or more than 30 times the size of the taxi industry today.[iii] The market for autonomous services should be roughly ten times the size of the market for autonomous vehicle hardware by 2030, as shown below.

Global Revenue For Autonomous Cars And Services



Source: ARK Investment Management LLC

ARK believes that investors may be undervaluing mobility-as-a-service severely today, and that in 5 years autonomous taxi networks could command a market capitalization of over $5 trillion.[iv] In comparison, the global automotive manufacturing industry probably will be roughly one third of that size. ARK expects autonomous mobility services alone will expand the total value of the $70 trillion equity market by 10%, as examined in this research report. The autonomous taxi market presents a massive growth opportunity for technology players or automakers that are able to piece together a successful autonomous strategy.

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SPECIAL THANKS to contributors: Catherine Wood, Brett Winton, Sam Korus, Dr. David Bodde

[iii] The taxi industry is a $19 billion market today. Source: http://www.ibisworld.com/industry/default.aspx?indid=1951
[iv] ARK has updated this figure since publication to include the latest estimate for 2022.

INTRODUCTION

Transportation—the moving of people and goods from place to place—serves a fundamental economic function, and historically transportation innovations have presaged and enabled fundamental economic transformations. In the late 1800s, Sears' catalog could not have transformed retail without the railroad.[1] Likewise, in the 1920s, in the absence of the tractor and the Model T, the agricultural workforce could not have moved to the cities. The internationalization of business required the jet turbine; the globalization of manufacturing necessitated standardized shipping containers; and the suburbs with their big box stores beckoned the highway system and relatively inexpensive automobiles.[2]

Transportation is entering another period of innovation. ARK believes that superior economics and increased convenience will encourage adoption of autonomous cars as early as 2019. As a result, autonomous taxis should accommodate a ten-fold increase in vehicle utilization rates, radically reducing the price of point-to-point travel and spurring a fundamental shift in consumer behavior. The taxi, heretofore a niche mode of travel, should grow to dominate personal mobility, with profound economic and societal implications.

Over the next 5-10 years, autonomous electric taxis could have a profound impact on global health, and will disrupt the auto industry dramatically, transforming the economy once again. ARK estimates that autonomous taxi networks alone will increase the value of the global public equity markets by 10% in the next two decades. Perhaps most importantly, consumers stand to benefit from cheaper, safer transportation …and fewer stranded assets.

1. AUTONOMOUS TECHNOLOGY IS NOT NEW

The road to autonomous cars began decades ago when automakers started introducing semi-autonomous technologies into personal cars. Chrysler (FCAU) first introduced power steering in 1951.[3] Toyota (TM) released a car with adaptive cruise control in 1998.[4] Audi (AUDVF) introduced the first car with automated braking features in 2006.[5] While helping to shoulder some of the driver's workload, these features fall far short of creating a fully autonomous car. SAE International defines five different levels of autonomy in vehicles, as shown in Figure 1.

While commercial cars today have some lower level features characterized by Levels (L0-2), L4—in which the human cedes all driving responsibilities to the robotic car—should create a step function change in the utility and economics of car travel. Taxis should become much cheaper and more convenient, and distributed taxi networks should form in suburbs as autonomous car owners share vehicles with their neighbors, giving taxi networks access to lower-density areas.

FIGURE 1
Levels Of Autonomy In Vehicles

SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/ Deceleration	*Monitoring* of Driving Environment	Fallback Performance of *Dynamic Driving Task*	System Capability *(Driving Modes)*
Human driver **monitors the driving environment**						
0	No Automation	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	Driver Assistance	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes
2	Partial Automation	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/ deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes
Automated driving system **("system") monitors the driving environment**						
3	Conditional Automation	the *driving mode*-specific performance by an *automated driving system* of all aspects of the dynamic driving task with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes
4	High Automation	the *driving mode*-specific performance by an automated driving system of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes
5	Full Automation	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**

Source: http://www.sae.org/misc/pdfs/automated_driving.pdf

2. MOBILE APP RIDESHARING IS TAKING SHARE FROM AUTO SALES

While autonomous taxis may be a few years away, mobile taxi hailing applications like Uber and Lyft already are changing the dynamics of transportation. The convenience, ubiquity, and relative economy of mobile taxi services present consumers with a viable alternative to buying a car. ARK sees evidence that mobile application-based ridesharing services already have taken a bite out of auto sales. Ridesharing services could have caused a cumulative loss of 640 thousand car sales globally through 2015 and may have caused another 1.9 million in forgone sales units in 2016, as shown in Figure 2.[6] China will experience the heaviest impact from car sharing, followed by India and Southeast Asia. ARK expects these markets to experience faster adoption of ridesharing services than more developed markets for three reasons:[7]

- Large percentages of developing market populations have yet to purchase a personally owned vehicle and, in effect, have not committed to a mobility option;

- Developing market populations are more likely to lack access to the upfront capital or financing required to buy a car; and
- In developing markets the ratio of hourly wages to vehicle prices is low, so a shared ride service is more compelling than owning a vehicle.

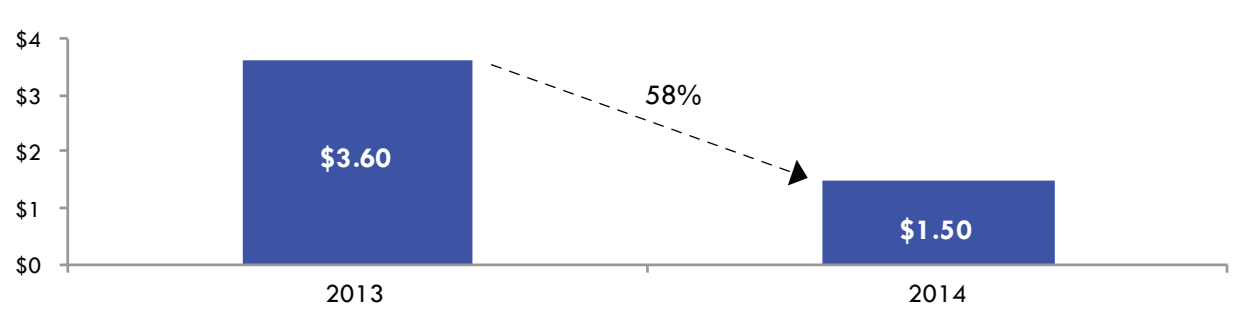
FIGURE 2
Auto Sales Lost Due To Mobile App Ridesharing

	2013 - 2015	2016	% of 2016 Car Sales
China	400,000	960,000	4%
India	100,000	540,000	15%
Southeast Asia	10,000	130,000	3%
North America	100,000	170,000	1%
Middle East & Africa	2,000	20,000	0.4%
Europe	30,000	50,000	0.2%
Rest of World	5,000	50,000	0.5%
World	640,000	1,900,000	2%

Source: ARK Investment Management LLC and OICA.com

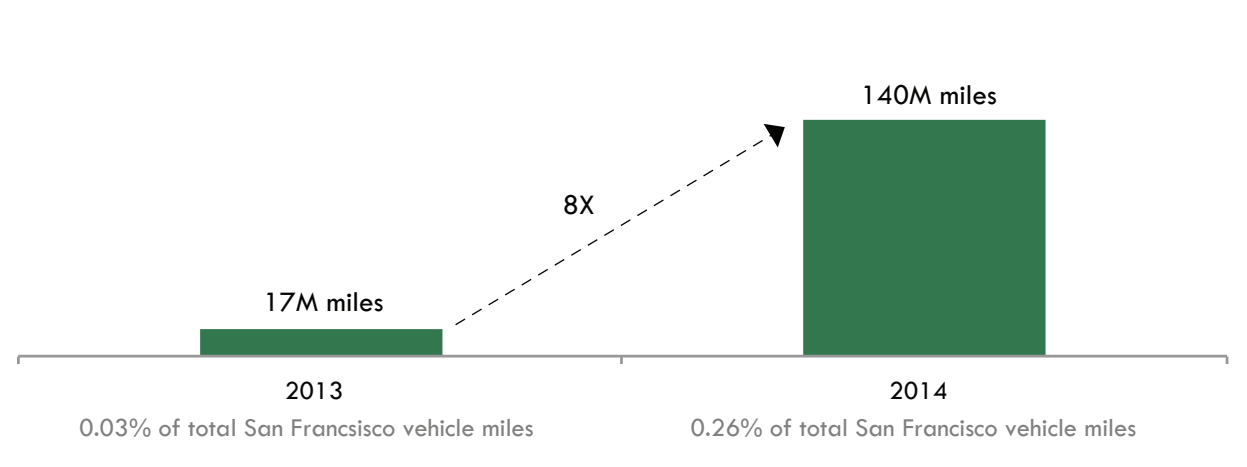
ARK believes the driving force behind ridesharing is the increased convenience at a lower price point that shared car services offer. Uber rang the bell for a radical shift in the transportation industry, adding lower prices to the convenience of the taxi model. Based on ARK's research, Uber's successful price cutting measures in San Francisco provide a gauge for the potential demand-response to autonomous taxis. As shown below, ARK estimates that when Uber lowered prices in San Francisco by a whopping 60% in 2014,[8] miles driven in Uber vehicles increased eight-fold.[9] Meanwhile, the average number of trips per traditional taxi declined from 700 per month to just 504.[10]

FIGURE 3
Uber Price Per Mile Estimate 2013-2014



Source: ARK Investment Management LLC

FIGURE 4
Estimated Uber Miles Driven In San Francisco 2013-2014



Source: ARK Investment Management LLC

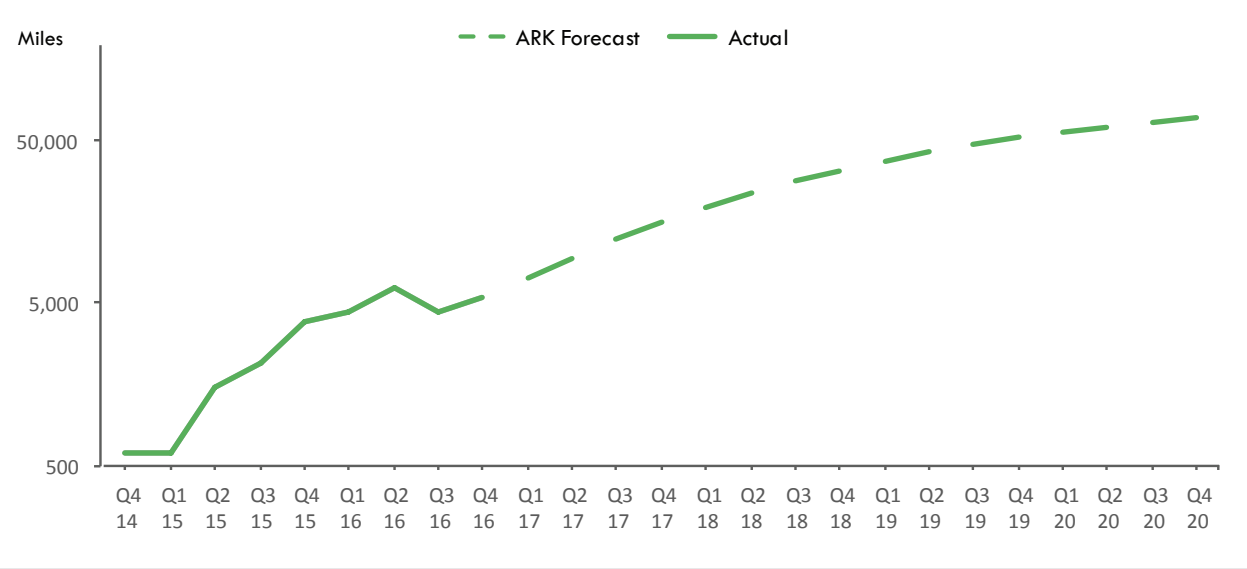
Uber has taken share not only from taxi drivers, but also from private vehicle miles and other transportation services.[11] By ARK's estimates, in San Francisco the miles traveled across all point-to-point MaaS offerings[12] as a percent of total vehicle miles traveled increased from 0.4% in 2013 to 0.6% in 2014.[13] As autonomous technology drives ride sharing prices down further, we predict that MaaS will take a much larger share of all miles.

3. AUTONOMOUS CARS SHOULD DEBUT AS SOON AS 2019

ARK believes that fully autonomous vehicles will be available to consumers by 2019. This estimate is supported by the improvement rate of Google's (GOOG) self-driving car system. In 2016,* Google's cars were traveling roughly 5,000 miles on average between safety-critical disengagements (when the engineer in the car needed to take the wheel either to ensure safe driving behavior or because the autonomous system otherwise would have failed). From 2015 to 2016, the Google system tripled the number of miles between interventions. If the car were to continue improving at that rate, factoring in a slight decay to account for the increasing difficulty of unsolved issues, the Google car could be ready for commercial deployment by 2019, as shown below. At that point, ARK estimates the car will be able to travel 50,000 miles between interventions, which is roughly how often personally owned cars break down today: or the failure rate that a "back seat driver" in an autonomous car would tolerate.

* ARK updated this section on Feb. 10th 2017 to include data for 2016. Note: Previously, ARK's estimate had included only disengagements where the Google autonomous system detected a failure and alerted the engineer. ARK has revised estimates to also include reported disengagements where the engineer took initiative to take control of the wheel, without receiving a notification from the vehicle to do so.

FIGURE 5
Autonomous Miles Between Manual Interventions



Source: ARK Investment Management LLC

4. AUTONOMOUS TAXI FLEET OPERATORS SHOULD GAIN FIRST MOVER ADVANTAGE

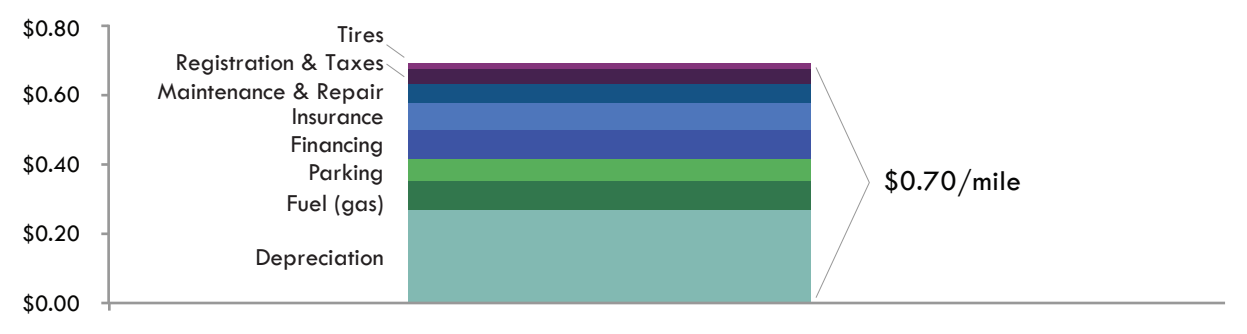
ARK believes that autonomous taxi systems will have third party operators that will control the car remotely when the autonomous system fails.[14] In the event that an autonomous car becomes confused by its surroundings, it will pull over safely to the side of the road and a teleoperator will direct the car to proceed. ARK also envisions that many of the first models of autonomous-capable cars will operate on autonomous taxi platforms because taxi travel will be much more economic than owning a personal car.

Further, the business owners of these taxi platforms probably will control geographic monopolies because they will use their fleets to collect the data necessary to create autonomous maps and train autonomous systems. This data reservoir will provide barriers to entry against competing service providers. Most importantly, ARK estimates that autonomous taxis will be extremely affordable, driving consumer acceptance and adoption.

5. THE COST OF MOBILITY IS LIKELY TO BE RADICALLY REDUCED

Even at a lofty $150,000 price tag for autonomous systems, if prototypes were ready today Google's Waymo could offer mobility-as-a-service (MaaS) profitably for roughly 70 cents per mile,[15] matching the cost to own and operate a personal car currently. As illustrated below, the current cost of auto ownership includes depreciation, gas, parking, financing, insurance, maintenance, registration, taxes, and tire replacement. Typically, consumers do not internalize all expenses in their calculation of annual transportation costs.

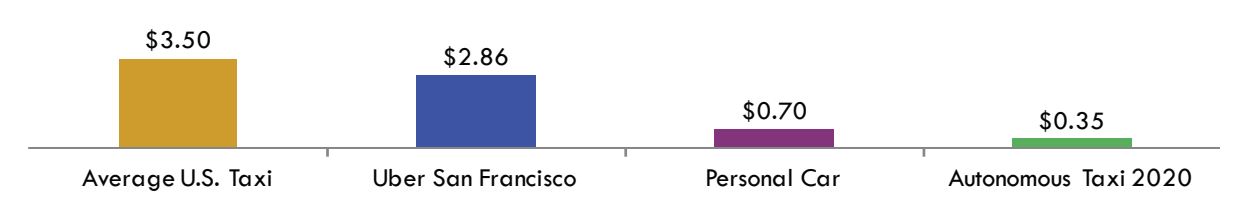
FIGURE 6
Cost Per Mile Of A Personally Owned Car



Note: Assumes an average gas price of $2.66 per gallon | Source: ARK Investment Management LLC

While autonomous taxis will be cost competitive with personal vehicles thanks primarily to higher utilization rates, they should be far superior to taxis given the elimination of labor costs. In the U.S., the average price a taxi charges per mile is roughly $3.50,[16] as shown in Figure 7. Given their much higher technology content, autonomous taxis will become more compelling over time as costs fall. Autonomous sensors and computer systems, which cost Google roughly $150,000 in 2012[17] and could be $10,000 – $20,000 now[18] should drop to $1,000 – $2,000 by the time autonomous cars are commercialized.[19] ARK's research shows that the higher utilization rates of autonomous taxis compared to personal cars will enable the feasible cost per mile of Google or a competitor's autonomous taxi to drop by more than half to roughly 35 cents per mile in 2020, as shown below.[20]

FIGURE 7
All-In Cost Per Mile of Vehicle Services

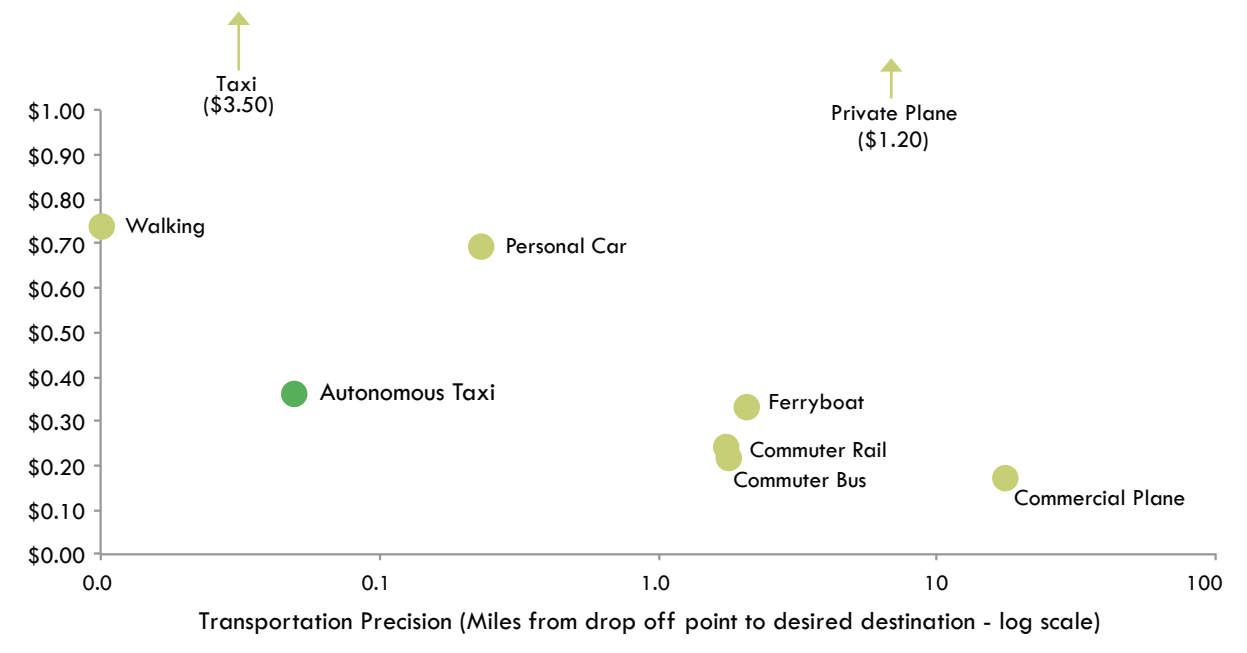


Source: ARK Investment Management LLC

6. AUTONOMOUS TAXI PLATFORMS' LIKELY COMBINATION OF PRICE AND CONVENIENCE SHOULD STAND OUT

While on a strict per-mile basis mass transit economics should beat those of autonomous taxi systems, the door-to-door convenience that autonomous taxis will offer should dramatically set the technology apart relative to other transportation options. Shown in the graph below is the per-mile price of transport versus the distance that a passenger still will have to travel to/from their pickup/drop off points. While a commercial plane, for example, offers the most-compelling per-mile economics, the location of airports themselves are not convenient and require as much as 34 miles[21] of additional travel to complete the journey. Autonomous taxis, in the lower left of the display, should stand apart, offering curbside-to-curbside convenience at an unprecedented price point.

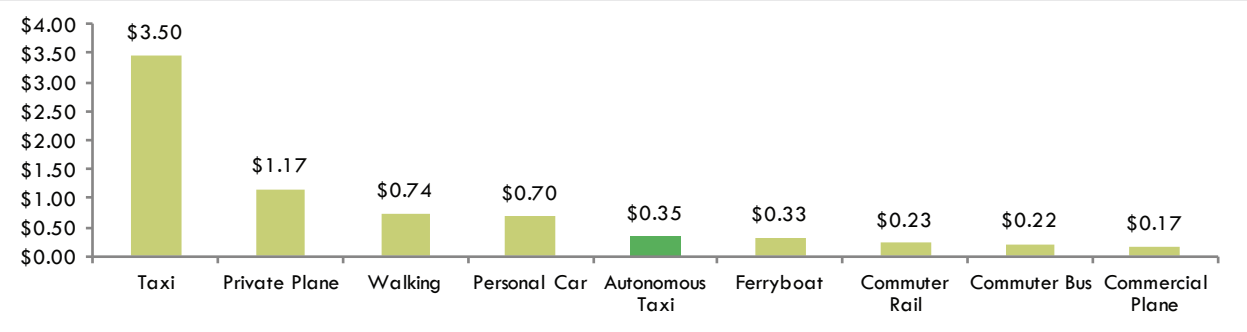
FIGURE 8
Price Per Mile vs. Transportation Precision



Source: ARK Investment Management LLC

To put the competitiveness of an autonomous taxi in perspective, ARK calculates that even walking–assuming a $3.99 Big Mac's worth of calories burned–could prove more expensive, as shown in Figure 9. This is not to suggest that people will cease walking from place to place. After all, a health-conscious consumer is unlikely to perceive the burned calories as a "cost" of walking; nor is the relative convenience of autonomous taxis likely to crowd out more traditional mass mobility solutions such as buses and light rail. Instead, a newly inexpensive last-mile solution that allows customers to

FIGURE 9
Modes Of Transportation Price Per Mile



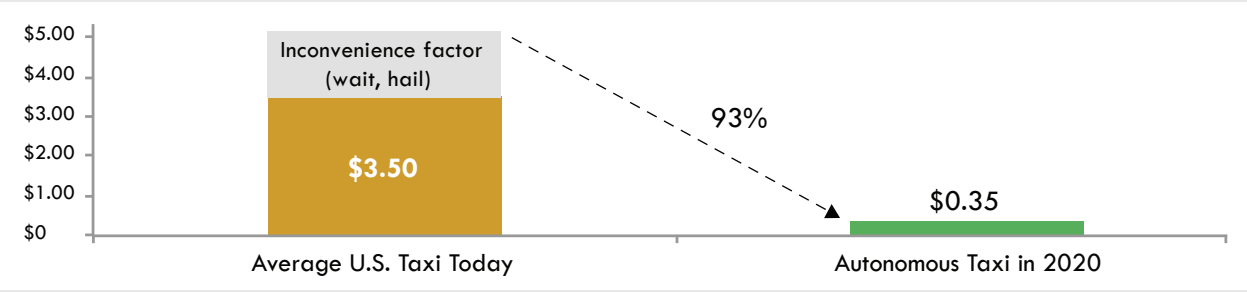
Source: ARK Investment Management LLC

get to and from a station easily should improve the relative utility of mass transit. Moreover, given anticipated rise in the number of miles driven, policy-makers likely will seek mechanisms to push riders into higher-density vehicles to increase the productivity of infrastructure.

7. COMPELLING ECONOMICS OF AUTONOMOUS TAXIS WILL ENCOURAGE ADOPTION

ARK believes that not only will autonomous taxis be an order of magnitude cheaper and more convenient than traditional taxis, in addition, hailing an autonomous car via a mobile app and then riding without a stranger in the front seat will be a much more pleasant experience. ARK estimates that the cost of the inconvenience associated with traditional taxis is roughly $1-$2 per mile.[22] Consequently, autonomous taxi services likely will be priced 93% below the average U.S. taxi today, as shown below.

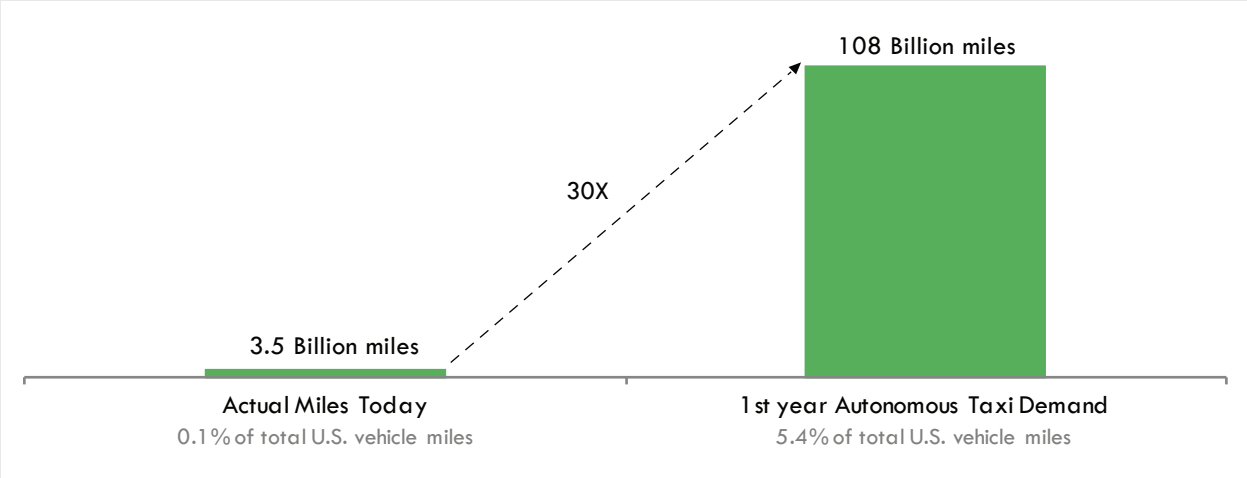
FIGURE 10
Per Mile Price Comparison



Source: ARK Investment Management LLC

Taxis travel 3.5 billion miles annually in the U.S. today[23], only 0.1% of 3 trillion total vehicle miles traveled.[24] ARK's analysis suggests that if autonomous taxi services were available in the U.S. at all times in all places, the demand would exceed 100 billion miles within the first year, as shown below.[25] This near thirty-fold uptick in demand within one year is consistent with the surge in demand that Uber caused in San Francisco when it cut its rates.[26]

FIGURE 11
Estimated Demand for Mobility-as-a-Service (MaaS) in the U.S. in Miles



Source: ARK Investment Management LLC

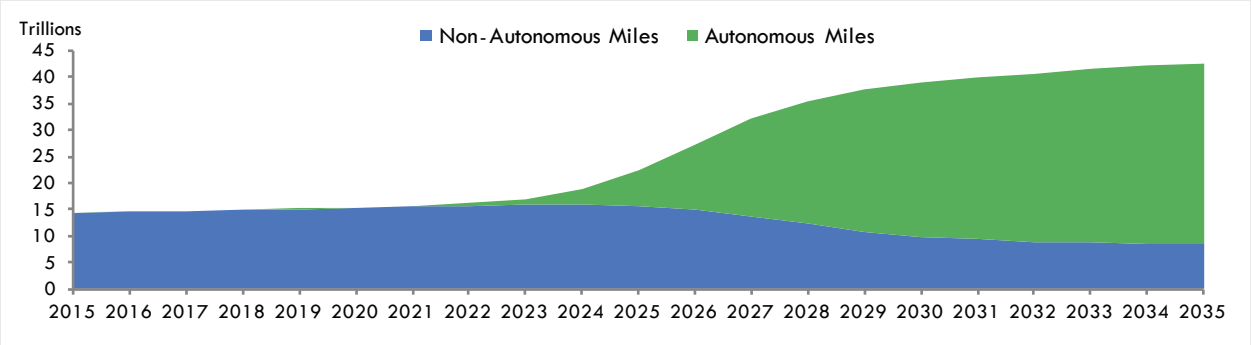
Practically, however, autonomous taxis will not be able to launch nationwide immediately upon commercialization. Instead, ARK expects that companies will require time to validate autonomous system performance and to build out networks of autonomous taxis services in different operating environments. Initially, these autonomous networks may roll out in select communities like college campuses or densely populated cities. Therefore, ARK forecasts that it will take about five years after commercial launch for U.S. autonomous taxis to exceed 100 billion miles driven.

By that time, the growth in demand could remain explosive as commuters and travelers opt for more convenient and lower cost travel. Some Uber customers already have foregone personal cars and driver's licenses.[27] Even today, vehicle owners—who effectively have prepaid for travel—leave their cars in the garage and use Uber, suggesting that the current system of mobility is inefficient and broken. Consequently, ARK believes that autonomous taxis are likely to become a dominant platform for point-to-point mobility in the U.S. and ultimately around the world.

8. GLOBAL VEHICLE MILES TRAVELED SHOULD INCREASE

ARK expects that vehicle miles traveled could increase dramatically, as shown in the chart below. For example, the non-driving population, including the blind, the elderly, and young teens, will have access to inexpensive, convenient transportation. In addition to this increased source of demand, the convenience of mobility-as-a-service (MaaS) also could prompt existing drivers to travel more miles.

FIGURE 12
Global Vehicle Miles Traveled



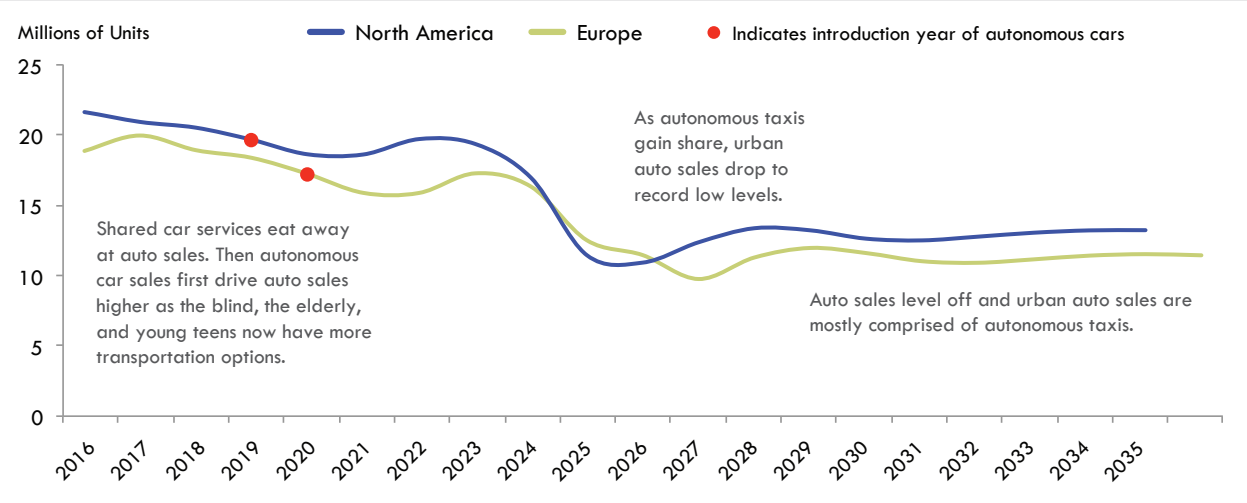
Source: ARK Investment Management LLC

Based on ARK's research, an increase in miles will not correlate perfectly with an increase in congestion: autonomous vehicles will operate more predictably, allowing higher throughput on existing infrastructure, and autonomous taxi services will reduce the need for parking infrastructure significantly, allowing more lanes of roadway to be devoted to driving. Even without shorter drive times, we think passengers may not mind waiting in traffic if they can watch online streaming services like Netflix (NFLX), browse social media, or catch up on emails while doing so.

9. GLOBAL AUTO SALES SHOULD BE LOWER THAN ANTICIPATED

Autonomous cars will likely accelerate the trend away from personally owned vehicles. As stated earlier, ARK believes that autonomous cars could be priced at 35 cents per mile, roughly half of what drivers pay for personally owned cars today. Consequently, while the demand for ride sharing will increase autonomous taxi fleet sales, consumers will forgo buying cars eventually selling or discarding the ones they no longer use. In North America and Europe, the net impact of autonomous cars could cut auto sales in half by the late 2020s, as shown in Figure 13.

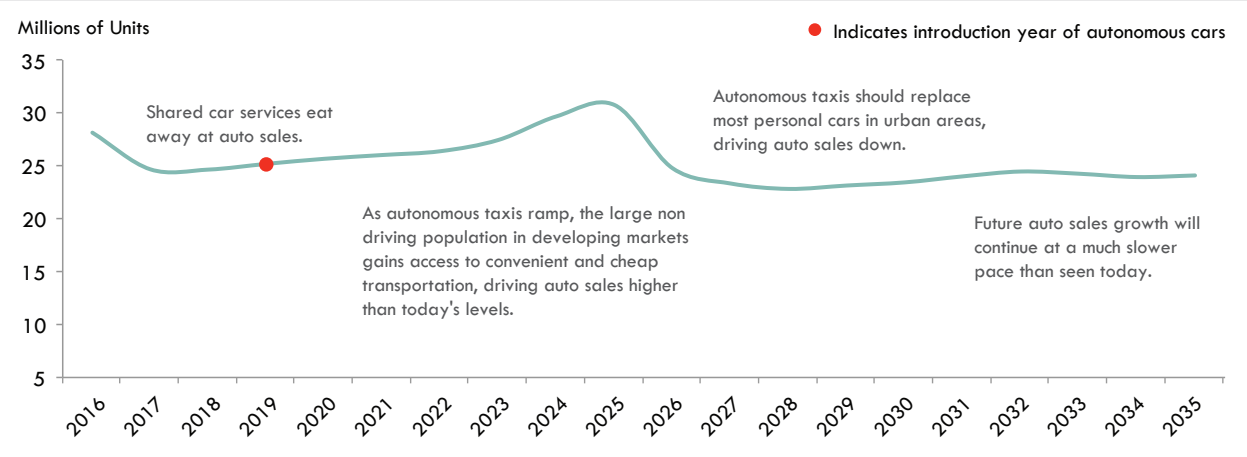
FIGURE 13
Annual Auto Sales In North America & Europe



Source: ARK Investment Management LLC

As can be seen in the graph above, car sales probably will increase modestly in North America and Europe after the introduction of autonomous taxis. ARK believes the acceleration in demand growth from the non-driving population should boost the number of autonomous taxis sold. Thereafter, total sales will descend precipitously as autonomous taxis gain share, obviating the need for personally owned vehicles in urban areas. Used car sales and prices are likely to plummet as drivers give up their personal vehicles.

FIGURE 14
Annual Auto Sales in China

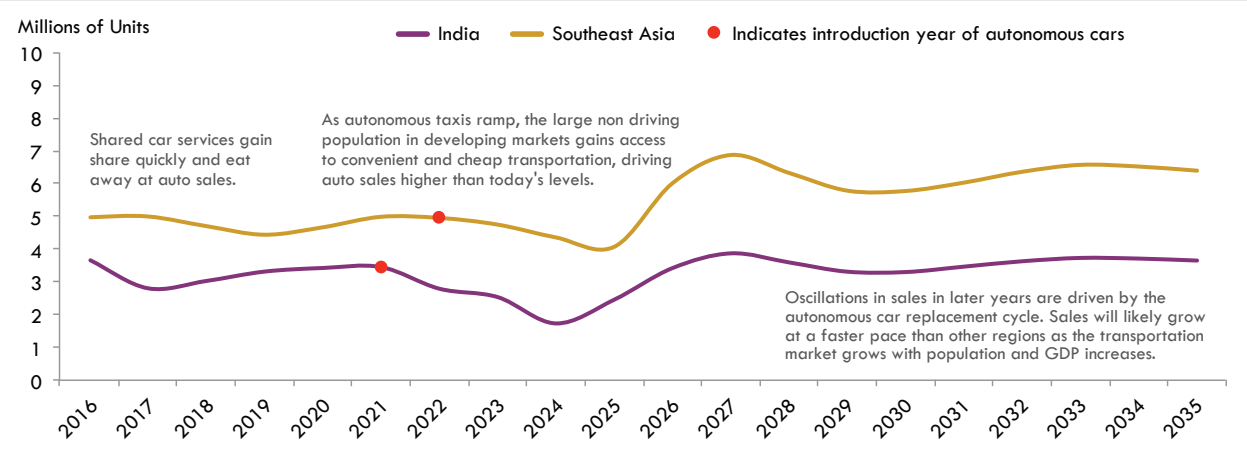


Source: ARK Investment Management LLC

In China, only 20% of the population has a driver's license, compared to 70% in the U.S.[28] Autonomous vehicles are likely to bring a substantial share of this population into the point-to-point mobility market given the much lower total cost of usage. Consequently, we believe growth in the demand for autonomous cars will drive auto sales upward in China, approaching 30 million units by the middle of the next decade, before downshifting to 23 million units in the 2030's, as shown in Figure 14.

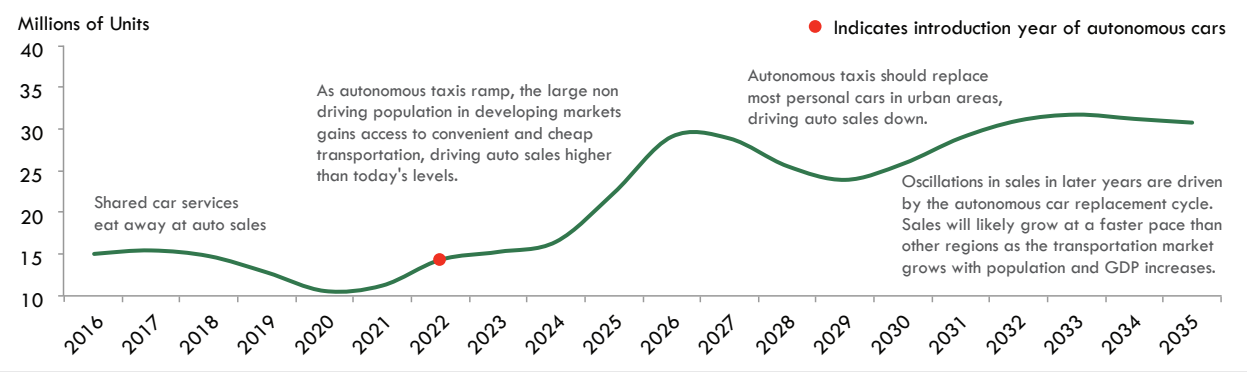
In other developing markets with a large proportion of non-driving consumers, we think the pattern will be similar to that in China, though stronger demographics will propel demand for autonomous vehicles even more in those countries, as shown below. Consequently, it is likely that automakers focused on the developing world should be in a better position to sustain growth than will players with significant exposure to the U.S. and Europe.

FIGURE 15
Annual Auto Sales In India And Southeast Asia



Source: ARK Investment Management LLC

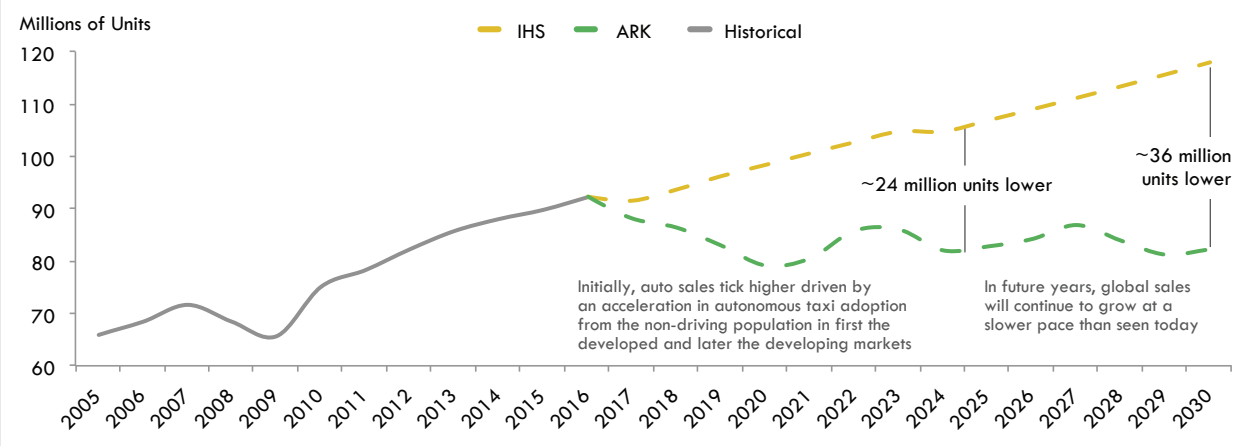
FIGURE 16
Annual Auto Sales In Rest of The World



Source: ARK Investment Management LLC

In sum, ARK expects global auto sales to be much lower than most forecasters anticipate, thanks to the initial adoption of shared car services and subsequent adoption of autonomous taxis. As shown below, the growth rates implied by IHS forecasts would suggest global auto sales will reach roughly 110 million units by 2025, 25% higher than ARK's estimate of 80 million units. Ten years later in 2030, ARK believes that auto sales will be a third lower than implied by IHS forecasts.

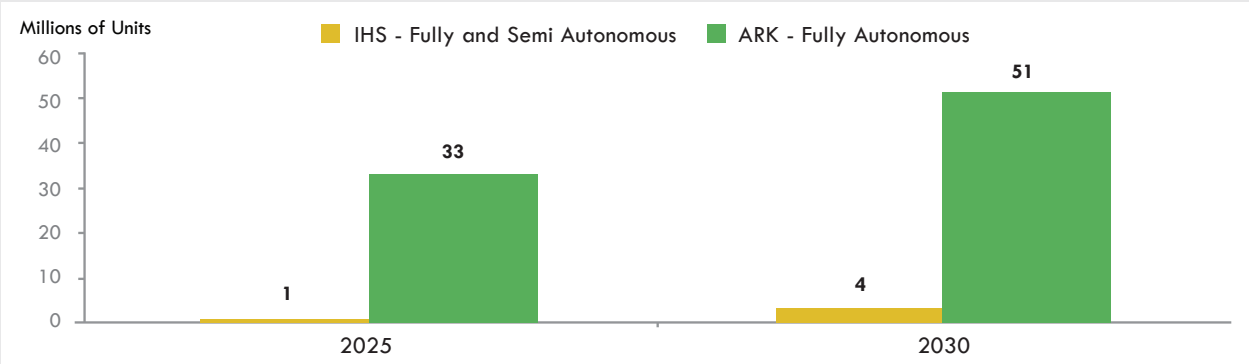
FIGURE 17
Global Annual Auto Sales



Source: ARK Investment Management LLC
Note: IHS figures for 2023-2030 were extrapolated by ARK Investment Management LLC based on growth rates.

By contrast, ARK anticipates that autonomous car sales will outpace current expectations significantly thanks to the demand likely to be unleashed by the substantial per-mile savings and convenience of autonomous taxi networks. The stark contrast between IHS's and ARK's forecasts of autonomous vehicles can be seen in the graph below.

FIGURE 18
Annual Global Autonomous Vehicle Sales

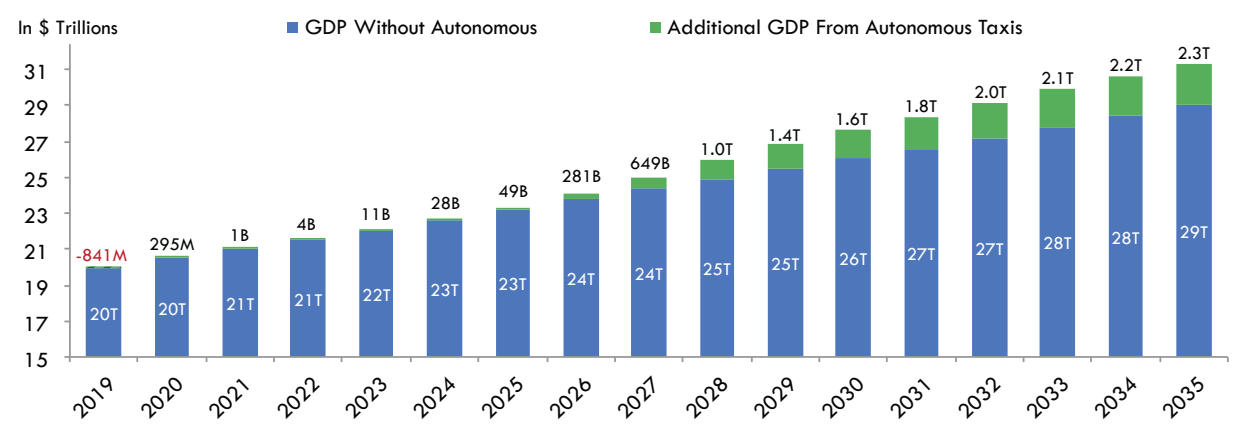


Source: OECD, ARK Investment Management LLC

10. AUTONOMOUS TAXIS SHOULD BOOST U.S. GDP

Given the macroeconomic importance of auto production in the U.S., losing auto sales would seem to be terrible economic news. Not so. Yes, in the year that the consumer decides not to purchase a personal vehicle, the economic impact will be net-negative, but in each subsequent year that decision will generate an economic surplus. In total ARK's research demonstrates that autonomous taxis could add roughly $2.3 trillion to annual economic output by 2035, as shown below.

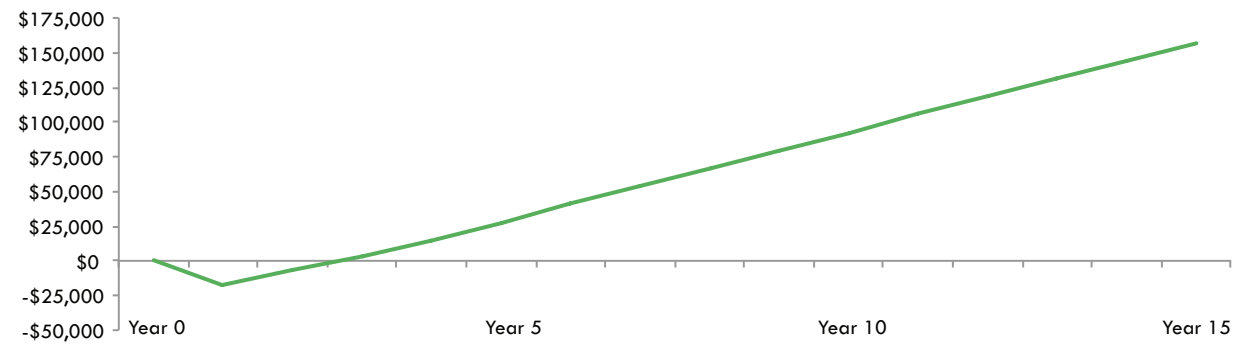
FIGURE 19
Forecasted U.S. GDP With Autonomous Taxis



Source: ARK Investment Management LLC

To illustrate this economic benefit, imagine a person decides not to buy a car and instead starts to use an autonomous taxi service from Google, Uber, or Tesla (TSLA). In the first year, there will be a net economic loss from the forgone auto sale, as shown below.[29]

FIGURE 20
Economic Impact Of An Autonomous Taxi Customer (Undiscounted Cumulative Cash Flows in Dollars)



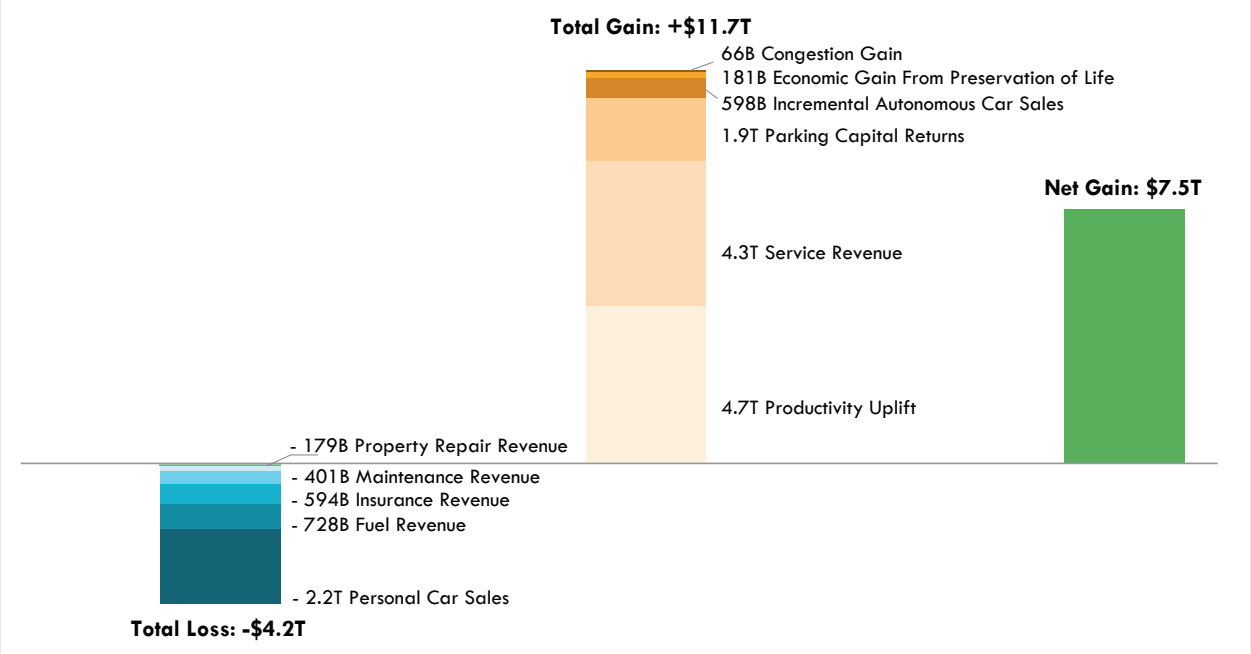
Source: ARK Investment Management LLC

The lost car sale will be offset partially by the following factors, pushing the cumulative economic impact positive within 3 years:

- A significant productivity boost as drive time—previously a non-market labor task for which the consumer received no compensation—shifts to leisure or compensated work time;
- Service revenue from, and sales of, autonomous taxis;
- Capital returns as unnecessary and unused parking spaces convert to offices, retail stores, or residences;[30] and
- A reduction in the $28 billion of annual costs associated with traffic congestion from car accidents, not to mention lives saved as the accident rate drops by over 80%.[31]

According to ARK's research, these benefits will offset the lost revenue from gasoline and insurance sales, as well as the medical and repair costs associated with car accidents every year. The net present value of the economic impact over 15 years associated with every driver in the U.S. who forgoes buying a personal car and instead rides in an autonomous taxi is roughly $120,000.[32] Incorporating expectations for the cumulative number of passengers that will enter the market as a result of autonomous accessibility, the net present value of the economic impact over the first 15 years will amount to roughly $7.5 trillion in the U.S., as shown below.

FIGURE 21
Net Present Value of U.S. Autonomous Taxis (All values shown are net present values over 15 years using a 3% discount rate)



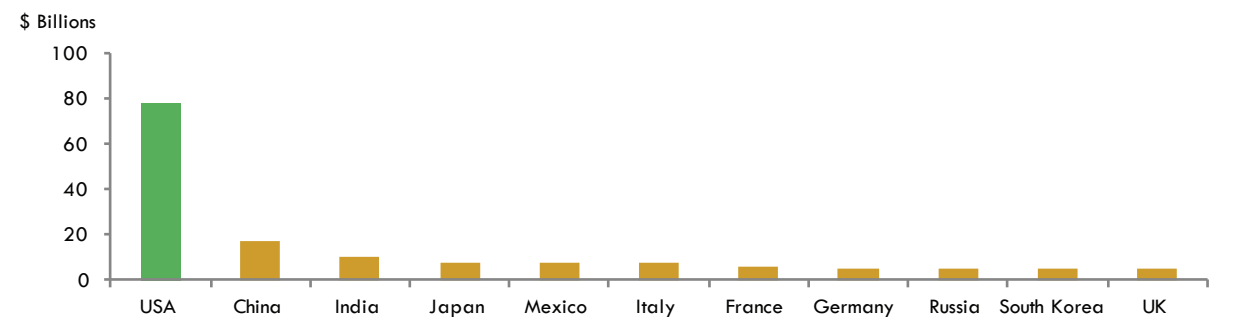
Source: ARK Investment Management LLC

Consumers should benefit from a shift to autonomous taxis in other ways as well. Driving a personal car costs roughly 70 cents per mile today. According to ARK's research, autonomous taxis could charge roughly half that cost, saving on average $4,700 per driver per year.[33] Moreover, while ordering an autonomous taxi on a mobile app and sitting in the backseat catching up on work or watching online streaming services, such as Netflix (NFLX), consumers should enjoy more convenience, productivity, and down time, not to mention safety.

11. AUTO ACCIDENT RATES COULD DECLINE BY MORE THAN 80%

Sadly, a majority of the tens of thousands of people who die in car accidents in the U.S. are young and full of potential. The total loss of life from traffic deaths is devastating, and on average costs America at least $77 billion per year in forgone economic contributions, as shown below. This amount is equal to the entire GDP of New Hampshire.

FIGURE 22
Annual Economic Loss From Auto Deaths By Country



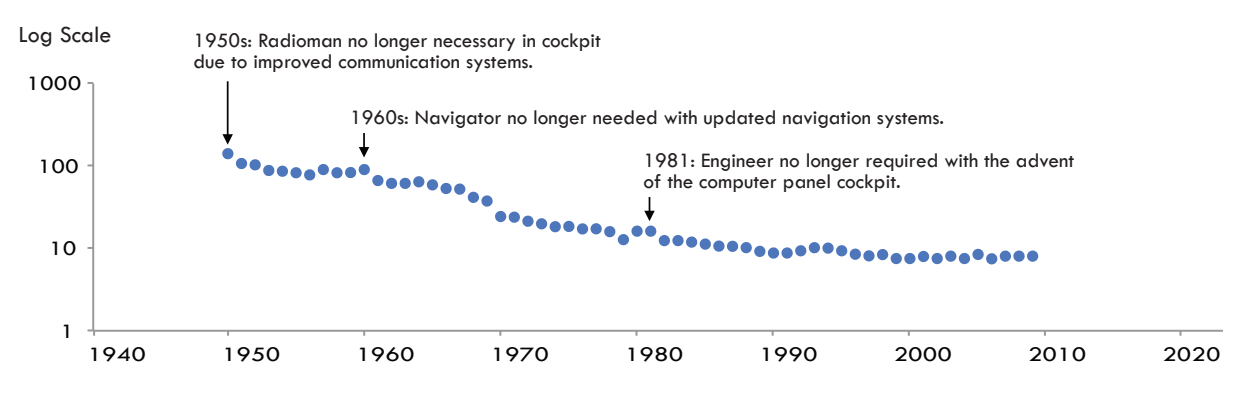
Source: ARK Investment Management LLC

Computers react more quickly than humans[34] as they do not text, drive while drunk, or daydream. As a result, robotic vehicles should be better drivers than their human owners. ARK estimates that autonomous vehicles ultimately will reduce accident rates by over 80%, contributing to a transformational public health gain. Every year automobiles claim more than 1.2 million lives globally at an economic cost of hundreds of billions of dollars.[35]

ARK has quantified the expected magnitude of this safety-advance by analyzing the introduction of another automation technology that has saved tens of thousands of lives: the airplane's autopilot. If autonomous vehicles contribute to a similar improvement in safety, the introduction of the autonomous car could be one of the great public health advances in history. ARK believes that autonomous technology platform providers and active safety integrators like Delphi (DLPH) or Autoliv (ALV) will drive this movement forward.

Over time, the introduction of autopilot technology has reduced pilot-attributable crash rates by 90%.[36] As shown in the graph below, automation system improvements and increases in cockpit efficiency from the 1960s through the 1980s dramatically improved flight safety. Although rudimentary autopilot systems were first developed in the early 20th century, the 1960s marked the first wave of electronic automation, which continued throughout the 1980s as digital computers made their way into the navigation and information systems of commercial planes.[37] Meanwhile, the number of people in the cockpit dropped from five to two, as communication, navigation, and information relay systems improved. Today automated commercial planes are considered the safest way to travel, but the aggregate human health impact of this automation has been somewhat limited to fewer than 10,000 lives saved per year because flying for most individuals is an infrequent activity, and commercial pilots are trained professionals, unlike most drivers on the road.

FIGURE 23
Accident Rate Per 100K Flight Hours (Adjusting for Number of People in Cockpit and % Accidents Due to Pilot Error)



Source: ARK Investment Management LLC

By contrast, in a completely driverless world, a reduction in driver-errors consistent with those experienced by the airline industry would reduce motor vehicle accident rates by 83%, from 1.1 deaths per 100 million vehicle miles traveled, to 0.2, as shown below. Given ARK's expectations for autonomous adoption, nearly five million fatal accidents are likely to be avoided by 2035.

FIGURE 24
U.S. Auto Fatality Rate Reduction Expected With Autonomous Vehicles (Units in deaths per 100M vehicle miles traveled)

Source: ARK Investment Management LLC

12. AUTONOMOUS TAXIS COULD HAVE FAR REACHING IMPACTS

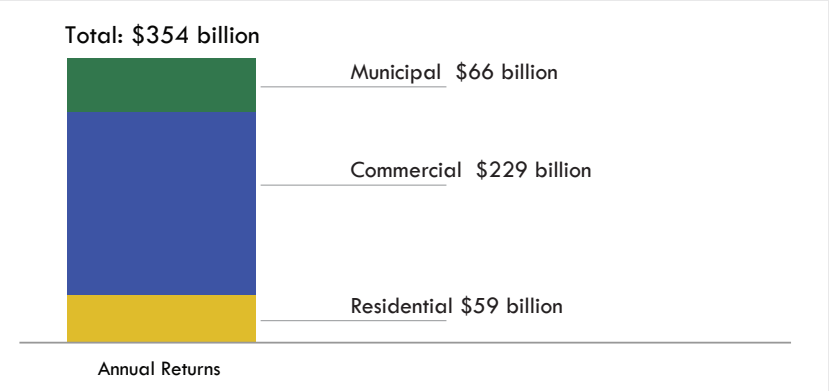
Given fewer traffic deaths, ARK believes insurance premiums will shrink. Anticipating historical liability tables as the transition to autonomous cars takes place, insurance companies like Allstate (ALL), Travelers (TRV), Metlife (MET), Chubb (CB), and Progressive (PRG) could enjoy a windfall in the form of much lower claims. Further, with more sensors on vehicles collecting data, accidents should be easier to predict, giving insurers the ability to adjust rates dynamically.

The addressable market for auto insurers should diminish because risks are likely to fall. Moreover, autonomous taxi service fleet operators should prove to be lower margin customers than are individual consumers, and the autonomous technology providers either will rely on their balance sheets to protect themselves in the event of technological fault, or will sell off any potential liabilities at the wholesale level.

Autonomous cars may be a boon for other industries as well. By 2030, autonomous taxis could add $28 billion[38] to the $1.5 trillion[39] global beverage industry, as the need for designated drivers disappears. Further, in 2030 autonomous taxi services could add roughly $100 billion[40] in advertising and subscription revenues to the global entertainment industry, a $1.9 trillion industry today, if autonomous taxis worldwide account for 4.8 trillion hours on the road (as ARK's forecast implies). ARK's forecast projects that passengers will use services like Facebook (FB) and Netflix (NFLX) 60% of the time in taxis.[41]

ARK expects autonomous taxi networks to have a profound impact on the telecom industry. Streaming and social media services could cause a massive increase in data usage. The $5.6 trillion[42] global telecom market could double over the next 10-15 years if those services were to use cellular spectrum. In all likelihood, however, the cellular operators will likely share the economics with autonomous service providers and mobile device manufacturers offering preloaded media content to passengers.

FIGURE 25
Annual Returns From Freed Parking Spaces In The U.S. In 2030



Source: ARK Investment Management LLC

Autonomous taxis also should impact infrastructure spending and economic returns: autonomous cars could add $354 billion in annual returns to the U.S. economy by freeing up unused parking spaces, as shown in Figure 25. Parking lots occupy a lot of otherwise productive space around the world, a problem that autonomous taxis will solve in large part. Spending eight- to twelve-fold more time on the road than traditional cars, autonomous taxis will likely require only one parking space in reserve per taxi, compared to the five in place today per personal car.[43]

By 2030, ARK expects autonomous taxis to free up roughly 250 million U.S. parking spaces worth $4.2 trillion at today's values. More than 80% of the benefits will accrue to commercial real estate owners and municipalities. Repurposed land and buildings would deliver significant incremental returns on invested capital. In a vibrant sharing economy, homeowners could turn garages into rooms or larger yards, while commercial real estate owners might build out more offices, retail storefronts, or apartments. Municipalities will potentially lose parking fees but could sell off their parking lots to compensate, ultimately turning parking fees into real estate taxes. By our estimates, converting parking spaces would add more than $350 billion to homeowner, commercial, and municipal real estate returns in the year 2030 alone.

13. DISTRIBUTED AUTONOMOUS TAXI NETWORKS MAY INTRODUCE NEW OPERATING MODELS IN SUBURBS

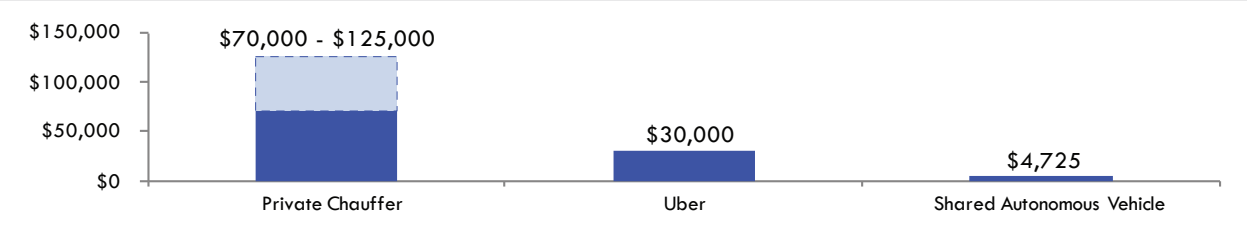
While individuals drive their cars for only one hour, or 4%, per day on average, they will be able to capitalize on the other 23 hours by renting out their autonomous vehicles. Uber, for example, could leverage its existing dispatch platform, giving auto owners the opportunity to rent their cars between the time they and their children are dropped off at and picked up from work and school, respectively. Tesla has already announced plans to launch such a platform. Owners with an unpredictable schedule could opt-in or opt-out on an hourly basis.

Given current economics, owners could recoup more than half the purchase cost of their autonomous vehicles within five years by renting them out part time. Today, a new car costs an average of roughly $30,000.[44] Autonomous technology could add another $1,000 – $2,000 by 2019, the year in which we expect autonomous vehicles to commercialize.[45] Theoretically, sending an autonomous car out for 11 hours per day and pricing rides at 35 cents per mile, a robocar owner could earn more than $10,000[46] per year, defraying the cost of the car.

Prices for suburban autonomous taxi services will vary based on competition and type of vehicle. For example, if multiple houses in a neighborhood were to own autonomous cars, pricing would be lower than if only one were available. Even if competition were to push prices down to about 20 cents per mile, owners still would profit.[47] As with Uber, an autonomous dispatch platform could incorporate a surge pricing mechanism, drawing in additional supply to accommodate demand and adding to profitability. Luxury vehicles such as the Tesla Model S or Cadillac (GM) CT6 also would command a premium.

In addition to the taxi model, autonomous vehicle owners could offer chauffer services part-time to a small, vetted customer base. Comparing the economics of autonomous cars to those of chauffeur services and Uber's current service offerings casts the value proposition of autonomous systems into stark relief. The cost of a personal driver ranges from $70,000 to $125,000 per year. The current cost of Uber's service would be at least $30,000 per year in New York City, based on the 13,500 miles per year that the Federal Highway Association estimates people travel per year on average. In contrast,

FIGURE 26
Annual Cost Of Chauffer Service



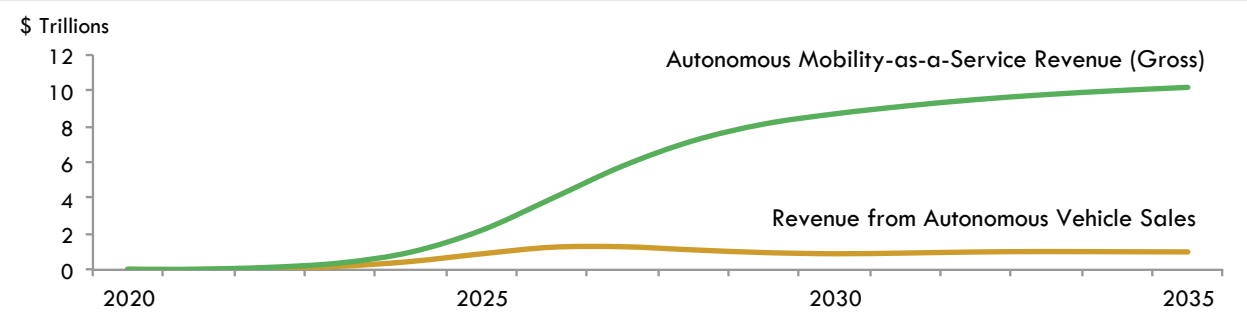
Source: ARK Investment Management LLC

the cost of an autonomous chauffer would be 84% lower, or $4,700 per year,[48] as shown in Figure 26. Autonomous technology should boost participation in the sharing economy as it eliminates many of the pain points in the current transportation system, chief among them parking and the stranded nature of most auto assets. Also, part-time autonomous taxis could speed the uptake of autonomous vehicles as the capital requirements can be distributed broadly and customer-financed. These suburban taxi networks also could benefit luxury vehicle producers, as auto purchasers veer toward quality name-brands which will provide higher autonomous vehicle income streams.

14. THE AUTONOMOUS MOBILITY-AS-A-SERVICE MARKET SHOULD EXCEED $10 TRILLION BY THE EARLY 2030s

As in the PC market, software and services should prove to be a more attractive part of the value chain than hardware. According to ARK's research and as shown below, the autonomous mobility-as-a-service (MaaS) market will exceed $10 trillion in gross sales by the early 2030s. Sales from autonomous vehicles will total about $900 billion at that time, or roughly one tenth of the services market. Autonomous taxis will enjoy substantially higher utilization rates than will personal cars, increasingly depressing the number of unit auto sales per year.

FIGURE 27
Global Revenue For Autonomous Cars And Services

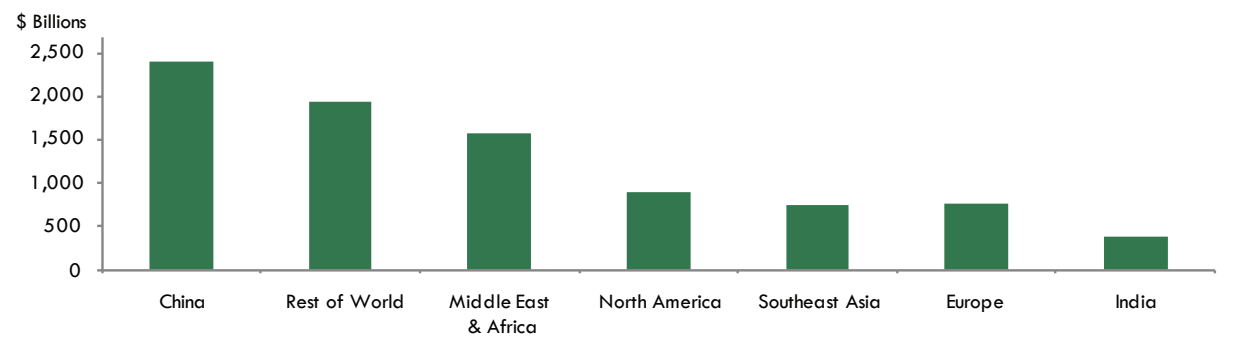


Source: ARK Investment Management LLC

ARK believes that the MaaS market will consolidate into regional monopolies due to the amount of driving data needed to train autonomous systems. Players with first mover advantage in various geographies will be well positioned to dominate markets.

On a geographic basis, ARK believes that China will be the largest market for MaaS by 2030, as shown below. China is in some ways the perfect geography for an autonomous service network: much of its infrastructure is relatively new, its government has proven willing to dedicate resources to new technologies, and the majority of the population has yet to commit to a personally owned vehicle. Increasingly that population is concentrated in urban areas. Indeed, similar to how cell phones obviated the need for fixed-line phone infrastructure investments in many developing countries, autonomous taxi networks may enable them to leap-frog technologies and garner the benefits of point-to-point mobility without the capital investment of a vehicle for every household.

FIGURE 28
2030 Mobility-as-a-Service (MaaS) Revenue (Gross)

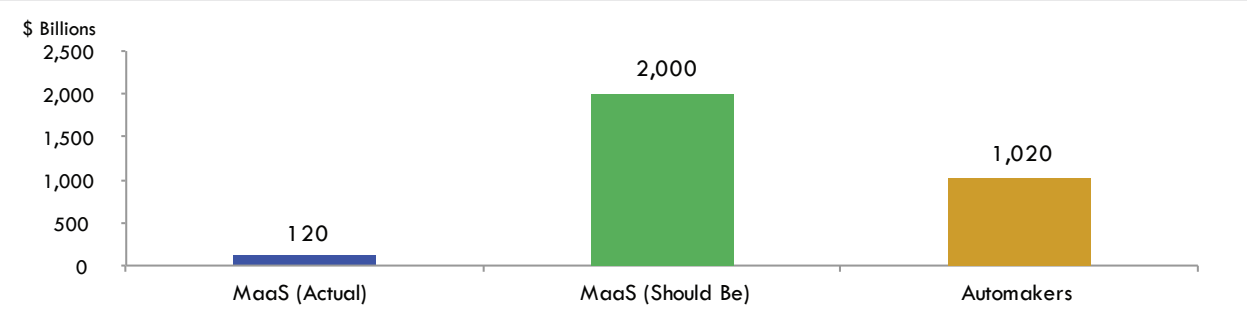


Source: ARK Investment Management LLC

15. MOBILITY-AS-A-SERVICE MAY BE UNDERVALUED BY INVESTORS

ARK believes that the net present value of the mobility-as-a-service (MaaS) opportunity is much larger than investors appreciate. As shown below, MaaS players, like Lyft, Uber, Didi, Grab, and Ola, share a market valued at roughly $120 billion today. ARK thinks that when accounting for the potential cash flow from autonomous taxi services, the market today should be valued somewhere between $600 billion and $3 trillion, depending on an investor's time horizon.[49] Of course, this opportunity may not accrue to the benefit of the Didi's and Uber's of the world. Google just announced its plans to partner with original equipment manufacturers (OEMs), both nuTonomy and Delphi have launched pilots in Singapore,[50] and several OEMs, notably Tesla, Volkswagen (VW), BMW (BMW), and Toyota, have detailed plans for both autonomous vehicles and shared autonomous services.[51]

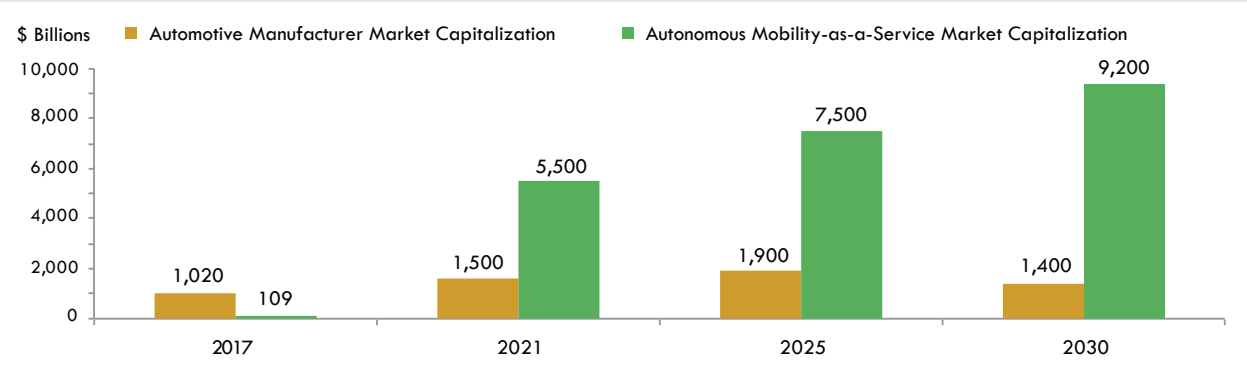
FIGURE 29
Market Capitilization Today



Source: ARK Investment Management LLC | Note: Mobility-as-a-Service (MaaS)

Although $2 trillion in net present value may seem farfetched for MaaS, ARK's research indicates that the opportunity actually will scale toward $9 trillion by 2030, further crowding out the traditional OEM model. As can be seen below, by 2021 ARK expects the equity market value of global OEMs to be roughly one third the value of the MaaS market, and by 2025, roughly one sixth. Part of the explanation for this growing gap will be the substantially higher vehicle utilization that autonomous taxis will enable. We think the average MaaS vehicle will service more customer-miles, depressing unit auto sales and constraining OEM growth. That said, OEMs could insinuate themselves into the MaaS market. In theory, an investor could buy all of the OEMs around the world today for roughly $1 trillion, and if just one were to take majority share in the autonomous taxi space, its return on investment would be four fold in five years. The likely alternative, of course, is that technology players like Google or Uber capture the majority of the service value.

FIGURE 30
Market Cap Of Autonomous Mobility-As-A-Service vs. Automotive Manufacturers



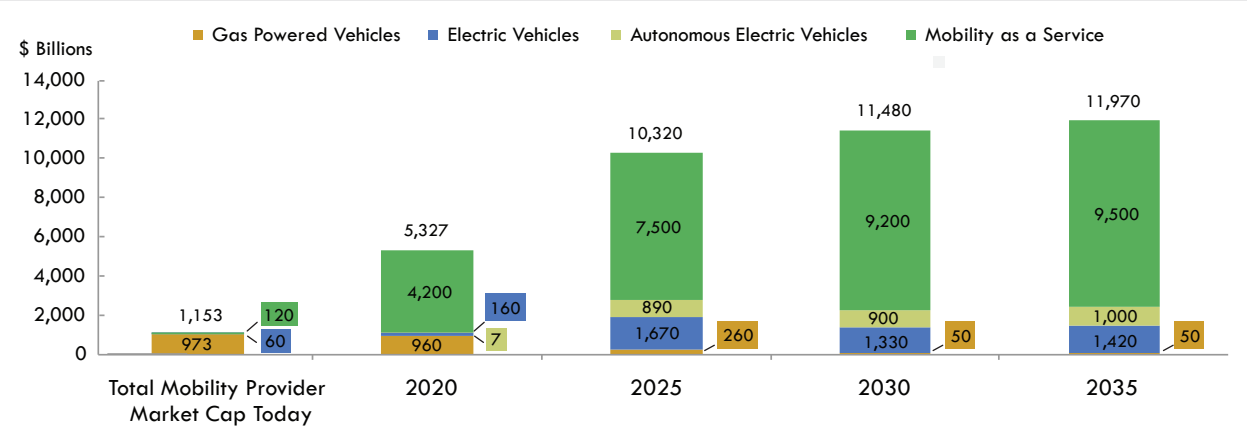
Source: ARK Investment Management LLC
Note: ARK has updated this graph since original publication.

As stated previously, ARK believes that the MaaS market will evolve into regional monopolies because of the deluge of driving data necessary to train autonomous systems. Tesla seems to have a first mover advantage and appears to be the leader in autonomous data collection around the world, as it is alone in selling vehicles equipped with the necessary hardware sensors to collect autonomous driving data.[52]

While services will become more valuable, hardware manufacturers still will be able to tap into growth opportunities as MaaS takes off. As shown in the previous graph, ARK expects the market capitalization (market cap) of traditional OEMs to nearly double by 2025, at which point it is likely to begin its descent as autonomous taxis cause a shift away from personally owned vehicles.

Automakers with successful electric vehicle (EV) and autonomous strategies should benefit disproportionately. ARK estimates that battery cost declines will drive higher EV and autonomous EV sales volumes, outpacing the growth of traditional gas powered car sales, as shown in Figure 31.[53] Electric vehicle manufacturers also may enjoy higher price to sales multiples than gasoline car manufacturers, as the industry will consolidate, resulting in better profitability characteristics.[54] Lastly, players like Nvidia (NVDA) and Mobileye (MBLY) that manufacture key enabling components for autonomous driving, as well as tier one integrators like Delphi and Autoliv that package autonomous sensor suites, may be well positioned to gain a share of the autonomous hardware market.

FIGURE 31
Market Capitalization of Mobility Types



Source: ARK Investment Management LLC
Note: ARK has updated this graph since original publication.

The shift to MaaS should create profound opportunities in financial markets. Relative to the $70 trillion in global equity market cap, MaaS could move the "needle" by more than 10% over the next decade. In other words, we think this previously unrecognized opportunity will evolve into a significant percent of equity allocations, providing appropriately positioned investors with outsized returns. The closest contemporary proxy is the computational software industry, not recognized as a

distinct portion of the value chain until the mid 1980s. It then increased its share of the S&P 500 to over 5% by the end of the 90s. In contrast to the software industry, which throughout the 90s was exposed to a small slice of the world's population, ARK anticipates that MaaS platforms will proliferate across the entire income spectrum as well as across all geographies quite rapidly. We may be at the cusp of a substantial transformation in the mode of transport throughout the world. Simple math suggests that such a transformation will prove substantial for investors who have anticipated it as well.

CONCLUSION

Autonomous cars could be the greatest economic transformation since the railroad, which changed the way cities were built, what foods were available, and most importantly what transportation channels were available. As a result economies flourished. It seems as if manufacturers like Ford (F) and GM already have seen the writing on the wall and made quick moves to gravitate towards an autonomous strategy. As a whole, merger and acquisition activity in the auto industry rose to $74.4 billion[55] this past year, or three times the annual average over the last ten years.

ARK views players like Tesla and Google as leaders in the autonomous space. Tesla is the only automaker currently selling consumer vehicles equipped with the hardware necessary to collect autonomous data, giving it an unparalleled data library and the ability to advance and teach its autonomous systems quickly. Google may have the best performing autonomous car from a technological perspective and is taking steps toward commercialization with its recently formed entity Waymo. Incumbent players still could play catch up. In fact, considering how much traditional automakers stand to lose, they may put up quite a strong fight.

Much like the railroad and the first highways in the U.S. gave many Americans freedom, autonomous cars will give freedom to people who cannot drive or cannot afford a car. The car was once a symbol of independence in the U.S. and status in China. Soon it will become more like an appliance, or a mobile device.

Autonomous cars also could dramatically alter urban landscapes as parking spaces are freed for more businesses or communal spaces. In short, the impact of autonomous cars will stretch far beyond transit from point-to-point. Our daily lives, our cities, and our economic structure will be changed forever.

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7. In China there is a fourth factor: Chinese regulations in some cities particular dissuade ownership as they allow a single vehicle to only drive on alternate days.
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18. ARK Investment Management LLC
19. ARK Investment Management LLC. ARK believes the autonomous sensor suite could consist of some combination of LiDAR, radar, cameras, GPS, odometry sensors, and sonar. There will likely be a central computing system such as Nvidia's DrivePX that will perform sensor fusion.
20. ARK Investment Management LLC
21. Median distance to an airport in the U.S. is 17 miles, so to and from would be 34 miles. Mark Pearson, 2012, "How Far Are People on Average from Their Nearest Decent-Sized Airport?" http://www.mark-pearson.com/airport-distances/
22. This is an assumption.
23. Calculated using state average taxi fares assuming a 5 mile trip, weighted by total vehicle miles traveled per state out of total. This was calculated by ARK Investment Management LLC using data from http://www.taxifarefinder.com/rates.php, Office of Highway Policy Information - U.S. Federal Highway Administration, March 2014, "Highway Statistics Series," http://www.fhwa.dot.gov/policyinformation/statistics/2011/vm2.cfm
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25. ARK Investment Management LLC

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29. Assumes a $30,000 car. Net loss includes partially offsetting gain of incremental share of an autonomous taxi sale.
30. There are roughly 5 parking spots for every car in the U.S.. An autonomous taxi will only need one.
31. ARK Investment Management LLC
32. ARK Investment Management LLC
33. This was calculated by ARK Investment Management LLC using data from the U.S. Federal Highway Association
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