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4 June 2019

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Sustainable & Thematic

Cutting the car ownership cord

When will ride-hail, micromobility and robotaxis drive consumers to "cut the cord" on car ownership? Before we reach #*Disruptive Mobility* or level 5 robocars, the interim will be multi-modal, with 'traditional' (that is, human driven) rideshare and increasing micromobility. While MaaS (mobility as a service) is growing rapidly, there is little evidence so far of a dramatic switch away from car ownership. In today's report we look at the tipping point when consumers will find MaaS cheaper than ownership and how cutting the car ownership cord can open up dramatic growth in terms of VMT (vehicle miles travelled) for alternative mobility. Even without robotaxis, we estimate about 25mn vehicles in the US are vulnerable to replacement by ride-hailing, adding 23bn VMT to the near-term serviceable market for rideshare as those households give up their vehicles, a significant increase over the ~10bn miles Uber and Lyft posted in 2018. By the late 2020s, when robotaxis can address a portion – but not yet all – of urban and suburban trips, a total 42mn vehicles and 64bn VMT could be in play.

MaaS is now incremental to car ownership – but at some point may be a substitute. Currently, rideshare and micromobility usage appears to be incremental to car ownership– much as many consumers layered streaming video on top of cable subscriptions. But as households look at their monthly car expenses vs. the cost of MaaS, they may move to 'cut the cord' on car ownership. We note the decision process behind mobility mode is often more intangible than cost alone but we think for multi-car, low-mileage households and lower income commuters, monthly vehicle cost is key – meaning they could cut the cord first. New household formations and emerging markets may never see the need for a car (or second car) at all.

Traditional rideshare alone could lead to cord cutting on 25mn vehicles unlocking 23bn additional VMT for MaaS: If cost were the only consideration, even before the advent of level 4 autonomy, 17-19% of the current vehicle parc in suburban and urban areas could be at risk of a switch from ownership to MaaS. While the variable cost of an owned vehicle is only $0.18/mile, fixed costs such as urban parking costs, taxation, depreciation, insurance, drives a total monthly auto bill for someone driving 3600 miles/year to ~$600-900. At an average $3.50/mile for ride-hail we see anyone driving less than 200-300 miles/month at risk of switching from ownership to MaaS, i.e. many households with two or more cars.

The MaaS uptake dynamic accelerates with geofenced robotaxis, opening from 43-64bn additional VMT for MaaS: As geofenced Level 4 autonomy accelerates in the mid-to-late 2020s we see an even more distinct tipping point when household economics flip from car ownership to MaaS.

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EXECUTIVE SUMMARY

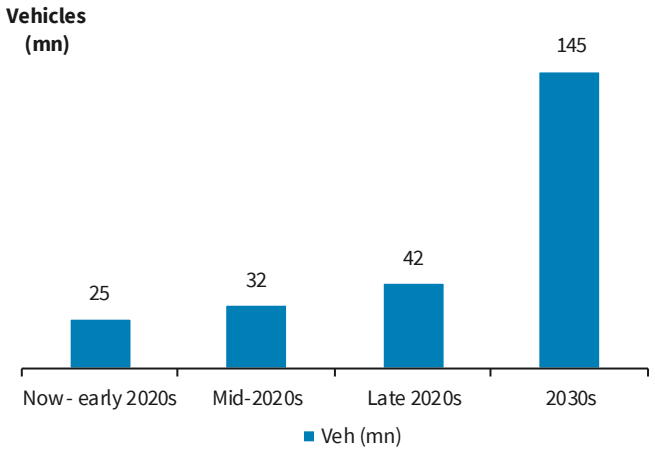
By now, investors know well the 'cutting the cord' story for cable TV (and before that landline phones). Consumers start by layering on new modalities (e.g., wireless phones, streaming video on demand) on top of their current services – but at some point, frustrated with rising monthly bills for the 'legacy' service, abandon the legacy service. And younger consumers and many in emerging markets never subscribe to the legacy services in the first place. Our TMT colleagues have explored this dynamic at length in *OTT Video: the best of times, the worst of times…*(24 July 2017).

We see the potential for the same dynamic with regard to automobile ownership vs. use of Mobility as a Service (MaaS) offerings ranging from traditional ridesharing to micromobility (such as shared e-bikes and scooters, see *Sustainable & Thematic Investing: Micromobility: Fast, Cheap and Good Solution for 'Smart Cities'* (20th March 2019) to robotaxis. Consumers without cars start using rideshare, while consumers with cars start by layering on rideshare. But at some point the economics of rideshare – depending on the fixed costs of car ownership and miles driven – can become more compelling.

In today's report we look at the cost of driving through the lens of monthly consumer vehicle spend to compare car ownership costs to a monthly mobility budget for MaaS (mobility as a service). In other words, at what point might a consumer decide to "cut the cord" on car ownership in favour of other more flexible forms of mobility such as Micromobility, ride-hail, car-share or rental.

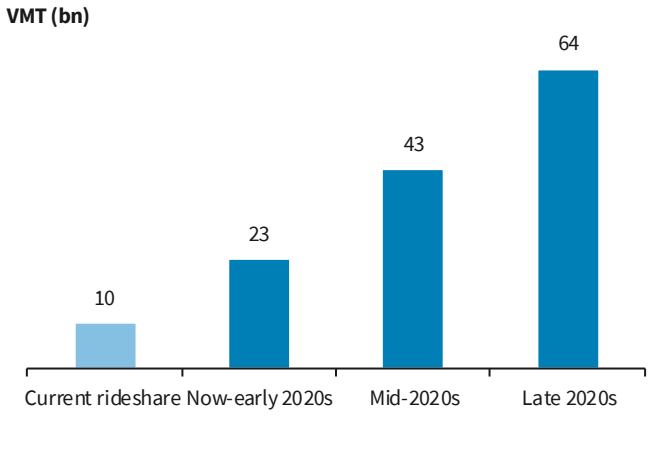
Based on our analysis of the 2017 National Household Travel Survey (NHTS) data, we have built a model to calculate total vehicles at risk as MaaS offerings expand in many urban areas. The model clusters the US vehicles in operation into 248 segments based on annual miles driven and population density. This model suggests that, even without robotaxis, about 25mn vehicles in the US are vulnerable to replacement by ride-hailing, adding 23bn VMT to the near-term serviceable market for rideshare as those households give up their vehicles, a significant increase over the ~10bn miles Uber and Lyft posted in 2018. By the late 2020s, when robotaxis can address a portion – but not yet all – of urban and suburban trips, a total 42mn vehicles and 64bn VMT could be in play.

FIGURE 1
Vehicles in play (US)



Source: NHTS, AAA, Barclays Research

FIGURE 2
Vehicle Miles Travelled (VMT) in play (US)



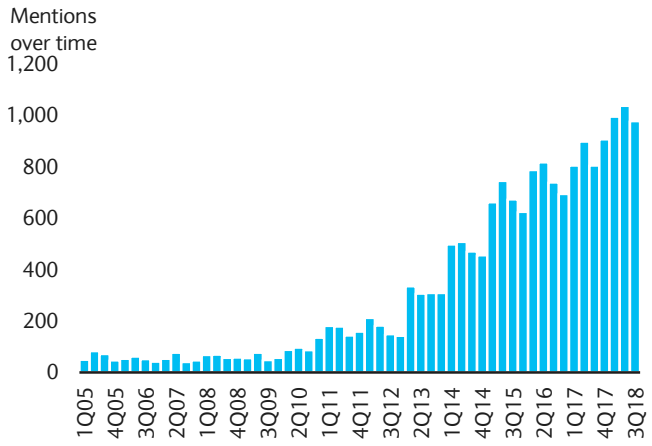
Source: NHTS, AAA, Barclays Research

Cord cutting in cable shows a pattern for gradual but significant disruption

Uber started operations in 2009, not long after Netflix started streaming in 2007 and Hulu in 2008. Not surprisingly, cord cutting was not even on the horizon for legacy cable companies in 2009, just as ride-hailing was not on the radar screens for legacy OEMs. Since then, cord cutting has become one of the dominant topics of conversation for cable managements. Given the proliferation of "skinny bundles" and non-linear over the air (OTT) services since then, 10mm consumers have cut the cord over the last 5 years and Virtual Multichannel Video Programming Distributors (vMVPD such as Sling TV), which did not exist until 3 years ago, now account for more than 7mm subscribers in the aggregate

FIGURE 3

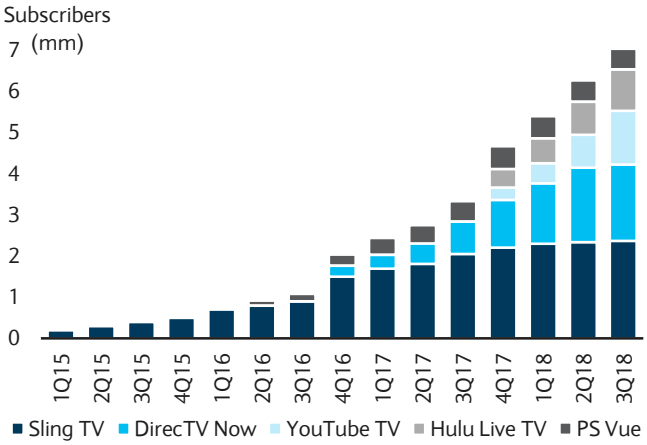
Cord cutting has become an important part of management focus as proxies by mentions during company events (US)



Source: Alphasense

FIGURE 4

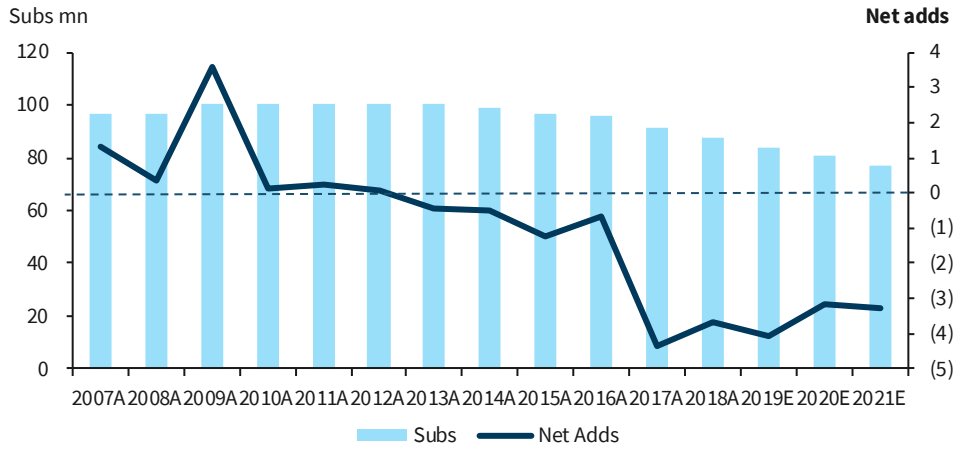
vMVPDs are seeing high subscriber growth (US)



Source: S&P Global Kagan, Company Reports, Barclays Research

Our TMT colleagues believe that despite the growth of internet platforms, this process is still in the early stages when it comes to premium video given that platforms like Facebook, YouTube, and Amazon are still just scratching the surface of what is possible with their platforms. They forecast continued decline in full-bundle cable subscriptions through 2021…

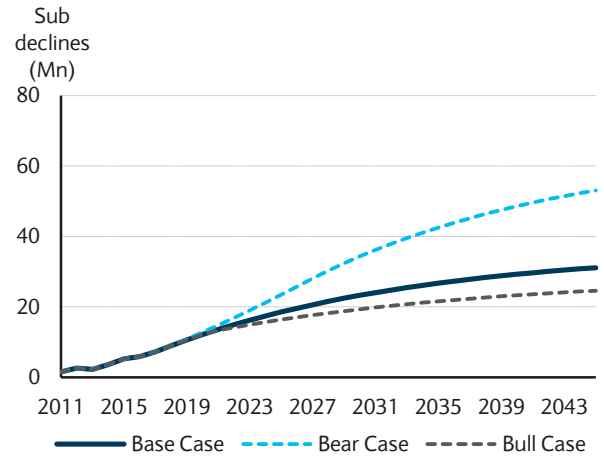
FIGURE 5
Multichannel video subscription trends (mn subs) (US)



Note: excludes skinny bundles
Source: Barclays Research

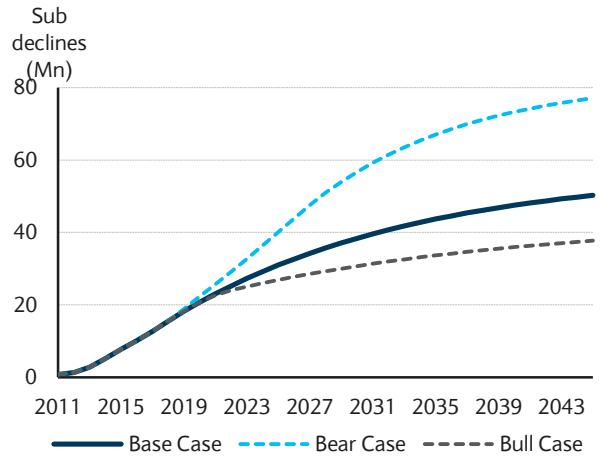
… and longer term their analysis of upside-downside scenario for both Pay TV as a whole and ESPN implies ongoing relentless pressure. For Pay TV, upside would imply 12mm additional subs lost in the next 10 years, while downside would be over 22mm. ESPN declines would total an additional 18mm subs in their upside scenario and their downside scenario would imply over 37mm additional subs lost.

FIGURE 6
Pay TV Sub Declines – Base, Bull, Bear (US)



Source: Barclays Research

FIGURE 7
ESPN Sub Declines – Base, Bull, Bear (US)



Source: Barclays Research

Cord cutting in Auto starts with human ride-sharing displacing low-mile urban and suburban cars and deepens with robotaxis

In today's report we look at the cost of driving through the lens of monthly consumer costs in light of the growing popularity of ride-hail and the rollout of robotaxis and micromobility. In particular, we focus on the monthly costs of vehicle ownership and when it makes sense for a household to decide to ditch their car because other forms of mobility prove more cost-effective and convenient.

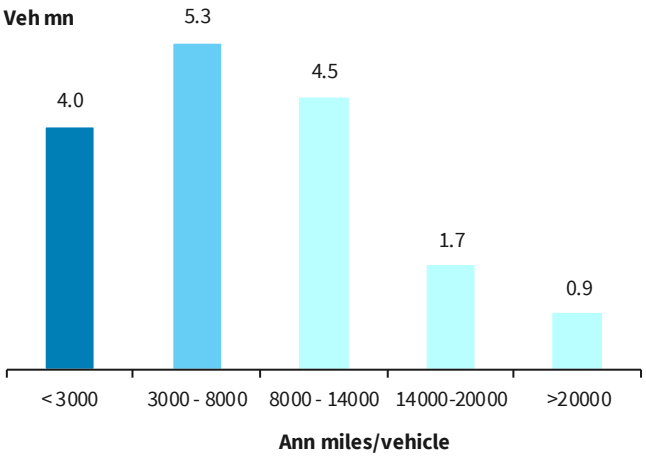
We are aware that the choice of travel mode is often highly subjective and differs widely by geography and demographic. While some consumers think about cost above all else, others consider factors such as convenience, habit, pleasure of driving and of course status (or virtue) signalling.

But if cost were the determining factor, we look to explore in today's report where the tipping point to MaaS is under four scenarios:

- **Baseline:** Now – Early 2020s: ride-hail is widely available, with limited micromobility and no robotaxis
- **Limited robotaxi**: Mid 2020s: where ride-hail and micromobility are widely available but Level 4 robotaxis are only available in selected, geofenced areas in some urban and suburban areas
- **Moderate robotaxi**: Late 2020s: where level 4 robotaxis can handle more (up to 40%) but not all urban/suburban journeys
- **Full robotaxi:** 2030s: where level 5 autonomy is 100% available for SAVs (shared autonomous vehicles)

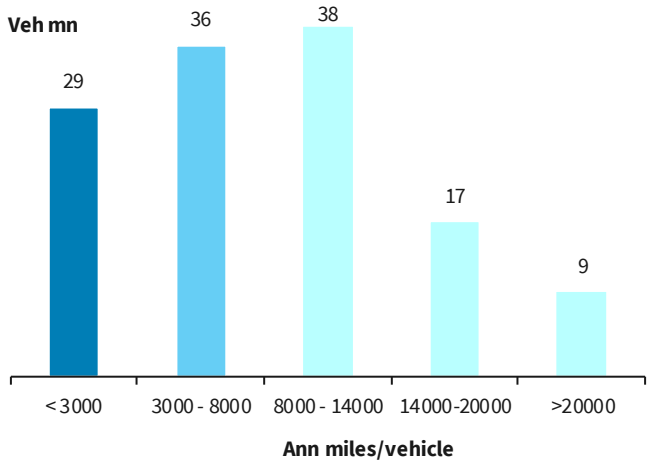
Our key findings for the US are that lower mileage cars in suburban and urban areas are at risk. Human rideshare puts at risk vehicles driven under 3k miles per year, while the rollout of geofenced robotaxis during the 2020s that can accommodate ~40% of urban and suburban miles would potentially take out vehicles with <8k miles. Note for urban areas, the breakevens are similar to suburban areas, because of the higher per mile cost of rideshare:

FIGURE 8
Distribution of US urban vehicles by annual miles/vehicle



Note: Dark blue = at risk in baseline and limited robotaxi, medium blue at risk in moderate robotaxi
Source: NHTS, Barclays Research

FIGURE 9
Distribution of US suburban vehicles by annual miles/vehicle



Note: Dark blue = at risk in baseline and limited robotaxi, medium blue at risk in moderate robotaxi
Source: NHTS, Barclays Research Source:

Specifically, in each scenario

- **Baseline:** Even before robotaxis and with only very limited micromobility, US households owning ~25mn lightly driven vehicles (~ under ~3k miles per annum) in urban and suburban areas would find cutting the cord and shifting to rideshare (and limited Micromobility) cost effective – which would open up ~23bn vehicle miles travelled (VMT) for rideshare operators even before robotaxis– significant growth over the ~10bn VMT rideshare posted in 2018.

- **Limited robotaxi (**Mid 2020s): With limited geofenced rollout of robotaxis in denser suburbs and urban areas, the monthly mobility bills for most would come down somewhat so moderately higher mileage vehicles become less economic – enough to put into play 7mn additional vehicles and 20bn additional VMT (for a total of 32mn vehicles and 43bn VMT).
- **Moderate robotaxi** (Late 2020s): As level 4 robotaxis can handle more rides (we estimate c40% of miles capable of travelling autonomously in urban areas by the late 2020's), households with vehicles that are moderately driven (roughly between 4k to 8k miles) will find ridesharing and micromobility more cost effective – which could put into play a total of 42mn vehicles and 64bn VMT.
- **Full robotaxi:** 2030s: This is when disruption becomes significant, both for the potential miles available for rideshare and robotaxi operators and for the impact on vehicle ownership and vehicle sales (as we explored four years ago *Disruptive Mobility 5/19/15*). Were level 5 autonomy available everywhere, at estimated robotaxi costs dropping from $0.50/mile (mid-2020s) to $0.30/mile (2030s), 145mn vehicles and 1.7tn VMT (out of ~2.8 total light vehicle VMT, excluding motorcycles, fleet LVs and trucking) could be at risk.

While the potential additional rideshare (both human and robo) miles are significant relative to today, it is worth noting that even with a moderate level robotaxis it's a miniscule percent of VMT, as vehicles with average to higher mileage remain in traditional use.

FIGURE 10
Vehicles and VMT in play by scenario (US)

		Vehicles at risk		VMT in play	
Scenario	**Time frame**	**Vehicles mn**	**% of VIO**	**VMT bn**	**% of VMT**
Baseline	Now - early 2020s	25	10%	23	1%
Limited robo-taxi	Mid-2020s	32	13%	43	1%
Moderate robo-taxi	Late 2020s	42	17%	64	2%
Full robo-taxi	2030s	145	59%	1,691	59%

Source: NHTS, AAA, Barclays Research *VIO = vehicles in operation

From the point of view of auto OEMs, its useful to note that rural cars are not at risk in any scenario – and those account for ~100mn of the ~250mn private light vehicles in operation (we are excluding commercial fleets, heavy trucks etc.) – favouring perhaps the Detroit 3 and their truck franchise and dealer networks. Note rural areas also account for ~1tn of the total ~2.8tn VMT we are modelling.

FIGURE 11
Vehicles in play by scenario in rural vs. suburban vs. urban areas (US)

	Vehicles at risk					
	Vehicles mn			% of vehicles		
Scenario	**Rural**	**Suburban**	**Urban**	**Rural**	**Suburban**	**Urban**
Baseline	-	22	3	0%	17%	19%
Limited robo-taxi	-	28	4	0%	21%	24%
Moderate robo-taxi	-	38	4	0%	29%	26%
Full robo-taxi	-	128	16	0%	99%	100%
memo: vehicles in use	*101*	*130*	*16*			

Note: Rural <999 population per sq. mile, urban >10,000 population per sq mile
Source: NHTS, AAA, Barclays Research

And further risk to OEMs/upside for rideshare from "leapfrogging" by younger generations and in emerging markets

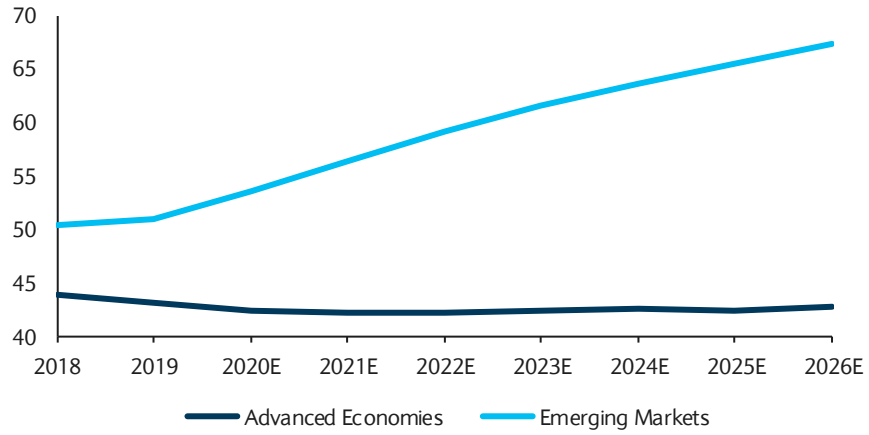
While we have full granular data for trip lengths, mode and purpose for the US from the National Household Transport Survey (NHTS), the data for the rest of the world is much more fragmented. But in order to build an addressable market for ride-hail and other MaaS options globally, it is important to understand the different global trends as a result of geographic differences in demographics, wealth, infrastructure and cultural trends.

In our report European Autos & Auto Parts: Dinosaurs vs. Disruptors (14th May 2019), we explored the growing trend towards MaaS and estimated global vehicles at risk from switching. We found that while the number of households globally with cars should continue to rise for the next decade, driven by macro-economic growth, it will be at a much slower pace. And the contraction in private vehicle sales growth driven by the rise of mobility services, will only partially be counteracted by the more frequent purchase of new shared vehicles for use by ride-hailing and car-sharing operators. In addition, mobility services may lead to a sales mix deterioration as the shared vehicles used in ride-hailing and car-sharing are generally lower spec than the typical privately owned vehicle.

We expect to see a strong divergence between growth in developed markets (where car sales growth is limited) and stronger opportunities in emerging economies, where urbanisation, economic trends and current low car density is more supportive of growth:

FIGURE 12

Annual vehicle sales (m) advanced vs. emerging economies

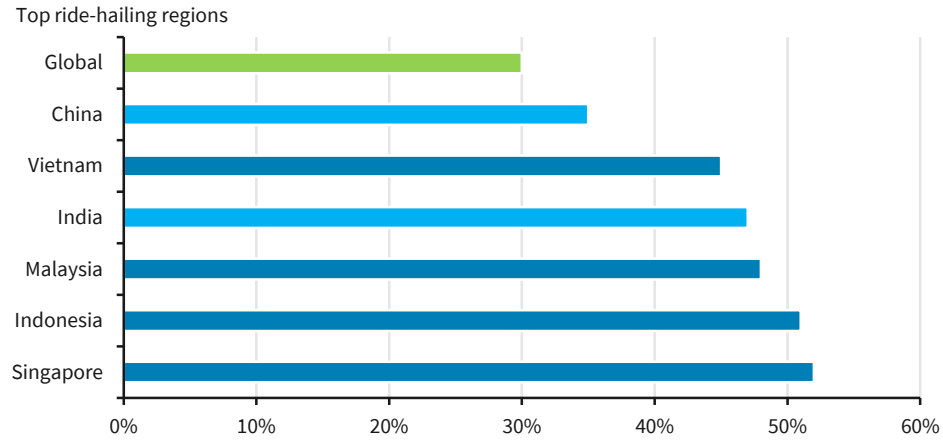


Source: Barclays Research, IHS, IMF

However, it is worth bearing in mind that while the "cord-cutting" analogy holds true for developed markets, lower car ownership levels in developing markets may see these markets leapfrog entirely the car and move directly to MaaS. As we will explore later in the report, many of these developing markets are already highly penetrated by users of mobile banking and e-commerce and already regularly utilising ride-hail:

FIGURE 13

Grab has helped Singapore lead the way globally in ride-hailing (% of internet users who use taxi/ride-hail apps at least once a month)

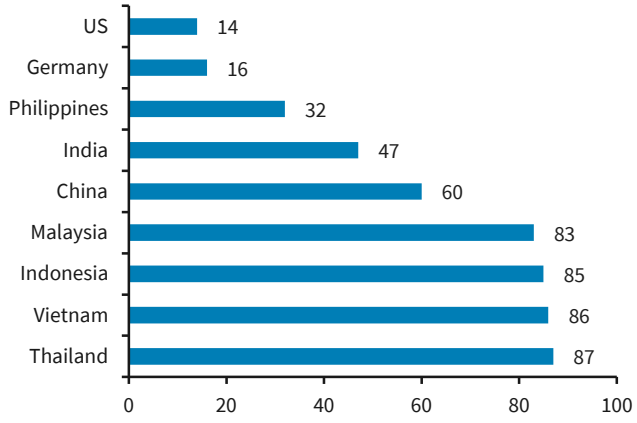


Source: We Are Social, Hootsuite

When taken in combination with already high two-wheel penetration and low car density, we see many markets like SE Asia, India and Africa at risk of leapfrogging the car and vehicle ownership commitments and moving directly to MaaS, with a heavily weighted proportion of micromobility in the mix:

FIGURE 14

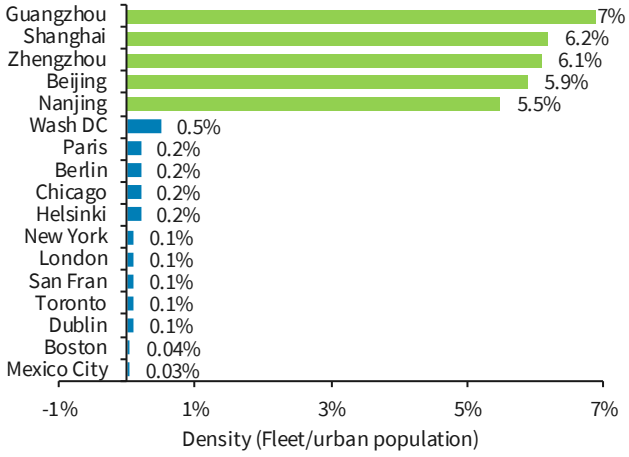
Percentage of households owning 2-wheelers (%) implies SE Asia and India may shift fastest to micromobility



Source: Roland Berger (based on 2014 data)

FIGURE 15

In China, non-electric bikeshare is already popular

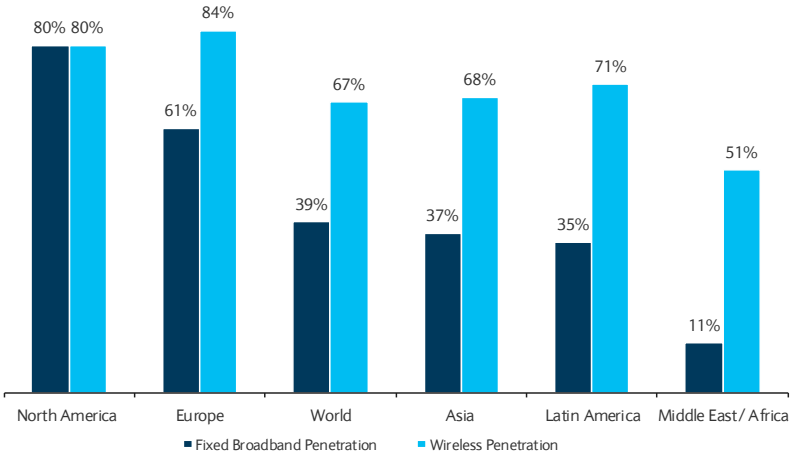


Source: Country statistics

Given such a heavy focus on two-wheeler and three-wheeler vehicles and low car infrastructure in many emerging markets, we wonder whether just as wireless penetration leapfrogged fixed broadband, MaaS will leapfrog car ownership.

FIGURE 16

Fixed broadband penetration in many parts of the world is lagging wireless penetration resulting in a transition to wireless first penetration. The same may easily be the case for car ownership vs MaaS



Source: SNL Kagan, GlobalWebIndex, World Bank

Note: Global Fixed Broadband penetration has been computed using total occupied households as the denominator

Demographic changes also point towards lower car ownership

As our colleagues discussed at length in Sustainable & Thematic Investing – Generation Z: Step aside Millennials (28.06.18), the next generation of consumer is not as tied to car ownership as the older generation. Gen Z may display more propensity for the security of ownership than their older Millennial peers, but given their equal focus on the environment, the concept of multi-modal mobility incorporating as much active and micromobility as possible, might become the default option over the car. We will discuss these trends further in today's report.

WHAT ARE THE ECONOMICS OF MAAS VS VEHICLE OWNERSHIP TODAY?

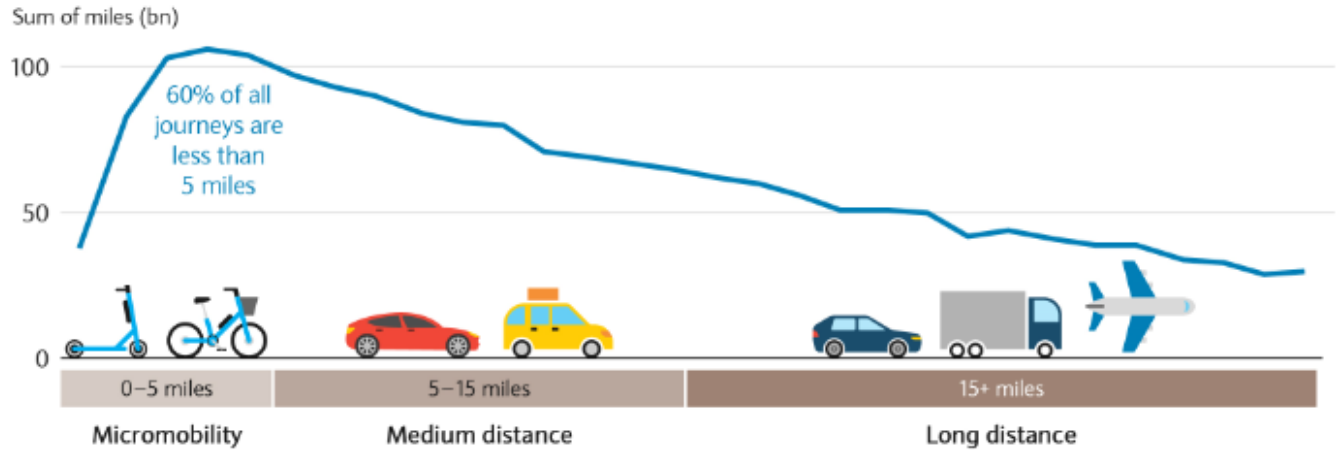
What would it take to persuade more consumers to switch to Maas?

Why are 70% of short distance trips taken by car?

In our recent report on micromobility - Micromobility: *Sustainable & Thematic Investing: Micromobility: Fast, Cheap and Good Solution for 'Smart Cities'* (20th March 2019), we argued that it does not make sense that 70% of all short-distance trips (i.e. those less than 5 miles in length) in developed markets are travelled by car. We discussed why other forms of new mobility, and in particular micromobility (smaller, electric vehicles), should make sense for many short, urban journeys, assuming such vehicles were made more widely available. However, we are well aware that a consumer's decision on whether to own and drive a car is based to a large degree on subjective elements that are often hard to quantify. It may be faster or cheaper to travel by public transport (or even e-scooter) but you might still choose to take your car or be driven by taxi/ride-hail.

FIGURE 17

With 60% of all journeys less than 5 miles in length, why are 70% of those journeys taken by car in developed markets?



Source: Barclays Research

How to quantify modal choice of mobility?

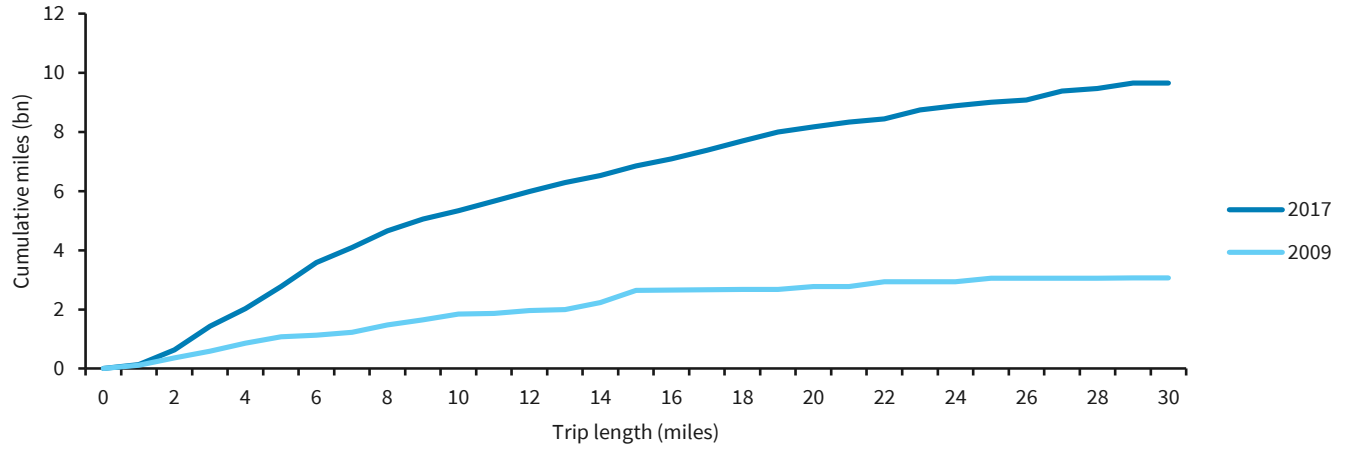
The choice of which mode of transport to take may be a combination of both quantifiable (cost, speed) factors as well as subjective or intangible decisions such as ease of mobility, need to transport goods/children, weather considerations, wish to avoid strenuous activity, habit of using a certain mode, love of driving, or any number of other (sometime less rational) considerations.

In today's report we will look at whether it makes sense for consumers to continue to own their own vehicle, given the advent of MaaS (mobility as a service), a dynamic we already discussed in detail in our EU Autos report: European Autos & Auto Parts: Dinosaurs vs. Disruptors (14th May 2019). We will touch on both speed and "hassle" factor as a determinant of travel mode but we want to analyse in detail the idea that monthly *cost* of vehicle-use may to many consumers provide a tipping point to drive a switch from car ownership to MaaS. We do not expect the switch to happen overnight. In fact, we note that despite 12.1bn additional taxi miles being travelled in the US between 2009 and 2017 (which could be taken as a proxy for the impact of the advent of ride-hail), global

population growth and economic growth have been strong enough to mitigate any obvious impact on car ownership levels to date:

FIGURE 18

Cumulative US miles travelled for taxi/limo trips have increased substantially from the 2017 NHTS survey 2009[1] and 2017

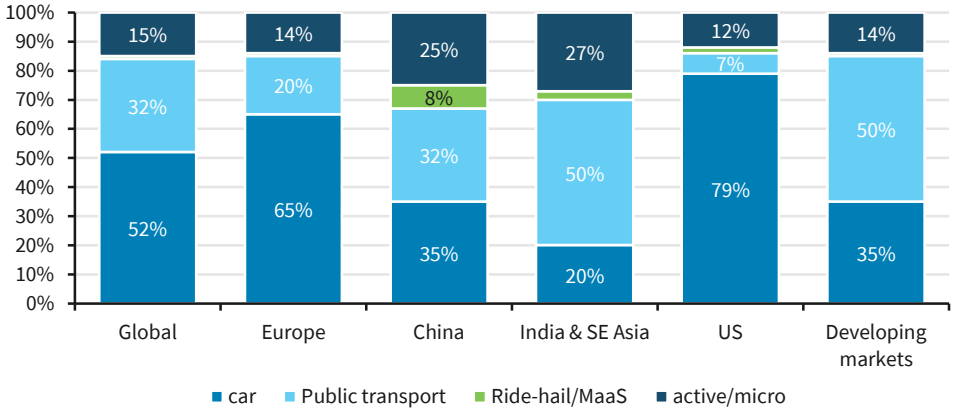


Source: NHTS, Barclays Research

Despite strong uptake in ride-hail miles, the personal car remains a favoured mode of transport today in many regions globally:

FIGURE 19

Mode of transport (trips) globally differs by region but the car dominates in all developed markets, with the US still the most car-centric geography



Source: Barclays Research, NHTS, national statistics * currently the majority of active/micro is 'walking' e.g. in the US 11% of trips are on foot versus 1% using bicycles or mopeds as per 2017 NHTS data

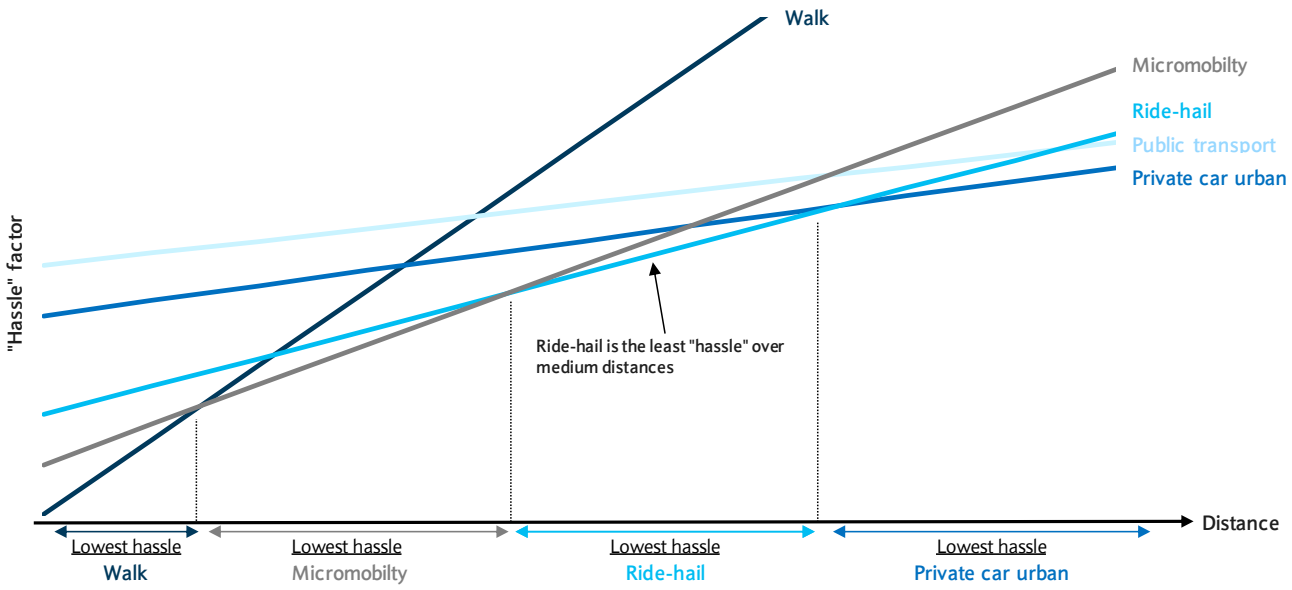
"Hassle factor" often as much a commuter consideration as cost

It is worth highlighting that many commuters choose travel mode based on less tangible factors than cost and also think about weather, infrastructure, the time spent looking for a parking space, distance of pick up/drop off to destination, etc. These factors are much more difficult to analyse but we have attempted below to show how we think trip distance has a significant impact on these "hassle factor" considerations:

[1] Federal Highway Administration. (2009). 2009 National Household Travel Survey, U.S. Department of Transportation, Washington, DC. Available online: https://nhts.ornl.gov.

FIGURE 20

We believe that directionally not only cost but also "hassle" is a key consideration for commuters and in dense, urban environments, a private car is more hassle to use and park for short/medium-distance



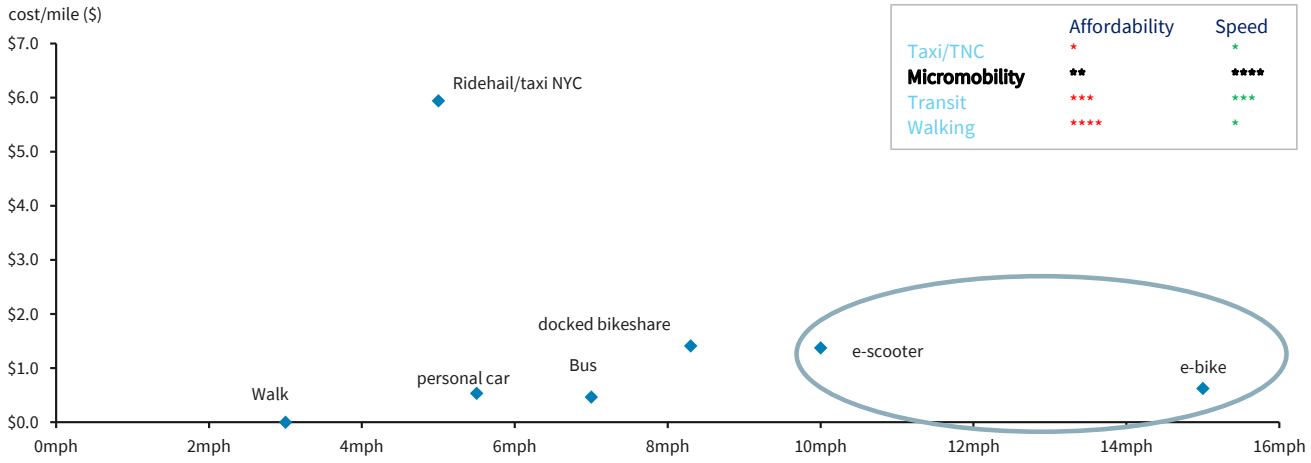
Note: based on discussions with Micromobility industry participants
Source: Barclays Research

Speed is also important in determining transportation mode

Another important consideration for mobility mode is speed, particularly in urban areas where congestion means average speeds often drop below 10mph. It is clear that where available, micromobility is often the fastest mode of transport, although many riders might consider the "hassle" factors of weather, experience on vehicle, potential requirement for a helmet to negatively outweigh the faster commute times. So whilst in theory a large proportion of commuters should choose on the basis of speed to switch to micro-vehicle if such a vehicle were made available, they might still decide to take a car due to increased "hassle" factor considerations:

FIGURE 21

We think speed is one of the greatest benefits of micromobility, especially if urban infrastructure is adapted to improve safety



Source: Barclays Research, Uber, Lyft, Yellow taxi, Citi Bike, JUMP, Bird, NY Transit, AAA

How do consumers actually think about the cost of owning a car?

Should consumers think about "per mile" and "per month" costs when choosing mobility mode?

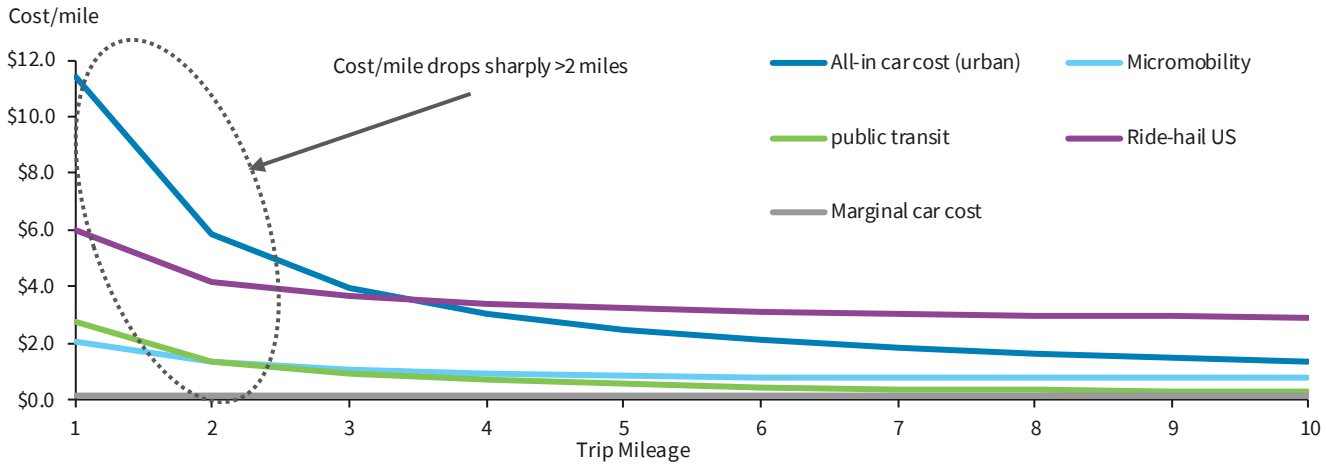
We show in the following section that car ownership costs/mile in theory drop drastically after the first few miles of a commute (Figure 22), if you factor all-in costs of car ownership. Similarly, other urban mobility modes are also the most expensive for the consumer in the first few journey miles (given either minimum fare costs, upfront base rates or flat rate costs per trip).

Our analysis of current per mile costs by transport mode shows that were the average consumer driven solely by cost-constraints, they should travel by micromobility (e-bike, e-scooter, e-moped) for the first mile or so of any journey, and public transport for all journeys above 2 miles.

However, were a car the preferred mode of transport and cost the only consideration, an urban commuter should currently choose to take ride-hail for journeys below 3.5 miles in length (were they looking at all-in car ownership costs including full fixed cost absorption) and use their own car only for lengthier commutes. Of course, on a marginal cost basis (i.e. only considering the variable costs of fuel and maintenance), a personal car is always the cheapest mode of transport:

FIGURE 22

The first two miles of any one-way commute are the most costly to the consumer. The tipping point between a fully loaded personal car (including fixed costs) and ride-hail in an urban area is c3.5 miles. But the marginal/variable cost is always lower



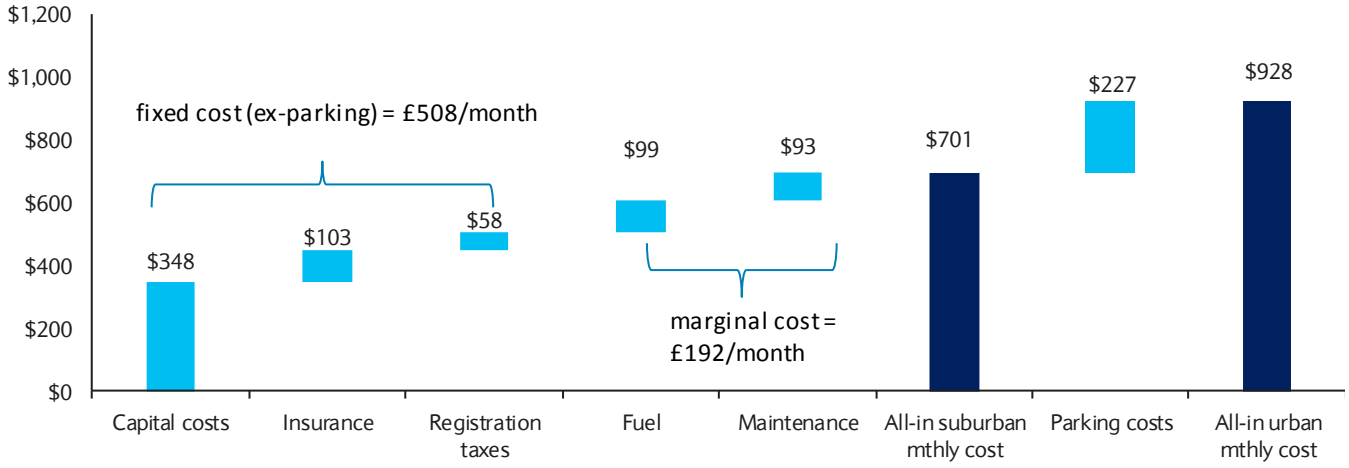
Source: Barclays Research, AAA, NY Transit statistics, Lime, Bird, Ford GoBike, JUMP, Taxify, Neuron

How much does it cost per month to drive a car?

Even where cost does come into consideration for a consumer (more notably in the lower income brackets), does that driver think in terms of marginal cost/mile, monthly vehicle-expenditure or all-in car costs over the period of vehicle ownership (i.e. total cost of ownership, TCO)? We think it depends on the individual but with leasing growing in prevalence in developed markets, many consumers have likely already switched to thinking of a car purchase in terms of monthly expenditure, as opposed to up-front cost. But do they include fixed costs such as up-front capital spend, depreciation, registration fees, etc. into that monthly spend; or do they just think in terms of the ongoing monthly spend on vehicle-related items such as insurance, interest, taxation, fuel and maintenance? We believe many drives may just think merely in terms of the marginal cost of using their vehicle, that is already bought (and in some cases fully paid down), for an individual trip. This marginal cost would just be the variable cost of fuel and potentially also maintenance (c$0.18/mile or $192/month for the average US sedan driver).

FIGURE 23

Average US monthly expenditure for a mid-sized sedan driving ~13k miles a year in the US is all-in $928 (or in terms of cost/mile this equates to $0.86 all-in and $0.65 excluding parking costs)



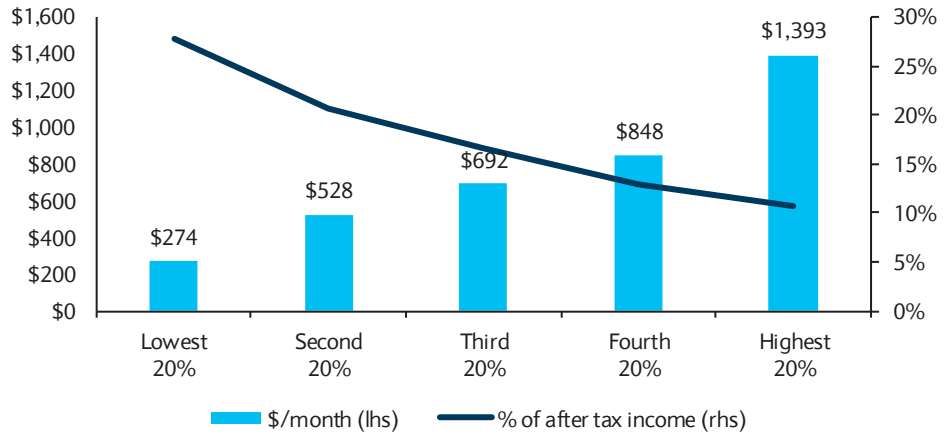
Source: Barclays Research, AAA

Car-related costs are a much larger proportion of total income for lower-income earners

Cost may be less of a consideration for someone in the higher income bucket, where monthly vehicle-related expenditures are just 10% of post-tax income, but for someone in the lowest income quintile it becomes a much larger proportion of the household budget – 30%. And for the 60% of consumers in the middle, the car on average costs ~17% of after-tax income. Could these monthly costs be reduced by the advent of alternative mobility modes?

FIGURE 24

Vehicle related expenditures (ex-parking) by income quintile, 2018 (US)



Source: BLS Consumer Expenditure Survey

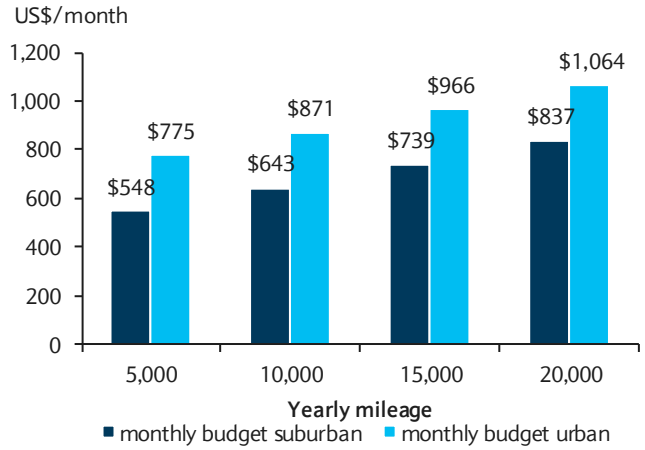
Costs vary based on annual mileage and parking-related costs

When thinking about costs in terms of monthly spend, which correlates most closely with the idea of a subscription based model for MaaS, based on AAA costs for the US market, vehicle-related expenditure (including depreciation, fuel, maintenance, insurance,

registration fees but excluding parking costs) for a mid-size sedan costs the average US household $701/month for anyone driving the US average of 13k miles per annum ($928 including parking for urban consumers). Factoring in a depreciation adjustment for different mileage, this cost drops to $548/month for anyone driving just 5k miles/annum and rises to $837/month for 20k annual miles. This expenditure also increases if you factor in urban parking costs, which can vary from $706/annum in Phoenix to $8,088/annum in NYC. We take the US average parking cost of $2,728/annum when scaling up driving costs for anyone driving and parking in urban areas. Costs are roughly equivalent in the European market too.

FIGURE 25

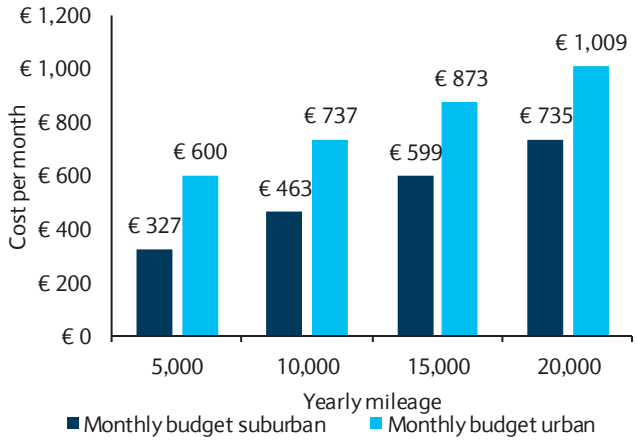
Monthly vehicle-related expenditure for a mid-size sedan in the US varies based on annual mileage (given the depreciation impact and variable cost/mile) and parking costs*



Source: Barclays Research, AAA *we assume no monthly parking costs in suburban regions, and US average costs ($2,728/annum) in urban areas

FIGURE 26

Average monthly vehicle-related costs are similar in Europe too (EUR/month)



Source: Barclays Research, Leaseplan

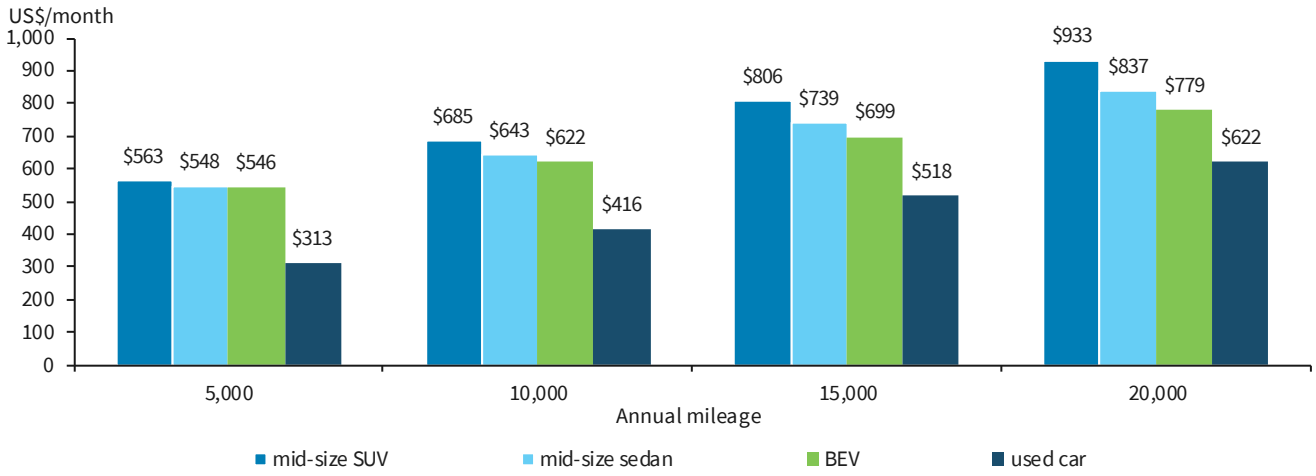
Cost also vary depending on the type of vehicle driven

Monthly vehicle-related expenditure also varies based on the type and size of car driven. For instance, the monthly vehicle-related cost in the US of $739 to own a mid-size sedan and drive 15k miles/annum rises to $806/month for a mid-sized SUV and falls to $699 for anyone choosing to drive a BEV (battery electric vehicle).

Despite higher variable costs for used cars, the reduced depreciation and fixed costs means the monthly vehicle outgoing is significantly lower:

FIGURE 27

Monthly US auto-related expenditure varies depending on the size, age and powertrain of a car (as well as miles travelled)



Source: Barclays Research, AAA

Average US urban car ownership costs $659/month ($887 with parking costs)

While the average American drives ~13k miles each year, according to the AAA[2] the average urban driver travels only 10,841 miles/year (of which 1,476 miles are for vacation road trips and the remainder the average daily commute, which we calculate as roughly equivalent to 26 miles/day, or 13 miles one-way). For a mid-size sedan driver, this would equate to a monthly cost of $659 (or $887 factoring in urban parking charges), rising to $705 and $932 respectively for a mid-sized SUV driver.

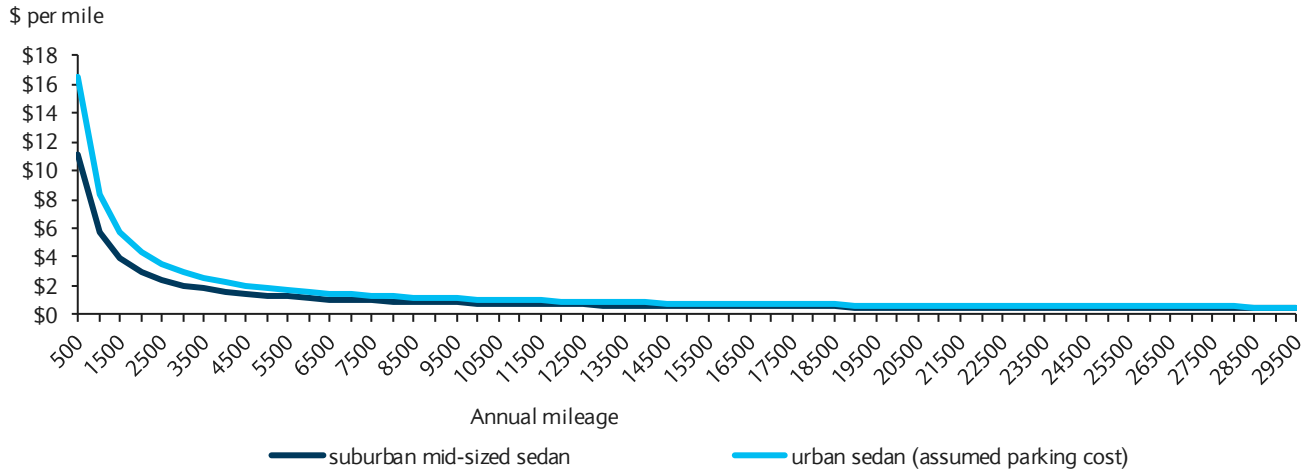
Monthly mileage is a key determinant of cost

While we believe the majority of drivers think in terms of monthly mobility costs, per mile costs are in theory significantly higher when a driver commutes less far, given fewer miles over which to cover fixed costs. For instance, someone travelling only 500 miles/year (the equivalent of a daily one-way commute of just 0.7 miles) would see their car ownership cost $11/mile ($16.5 including parking costs), or a monthly charge of $462 and $689 respectively. Monthly mileage in theory should be a key determinant of propensity to own a vehicle versus utilising other mobility services (MaaS), but it is also worth remembering that given the sunk upfront cost of buying and registering a car, when a driver is making a decision about monthly vehicle costs, only ongoing costs such as fuel, maintenance, insurance and taxation often come into consideration (as per Figure 23).

[2] *https://newsroom.aaa.com/2018/08/ride-hailing-double-cost-car-ownership/*

FIGURE 28

Car ownership costs drop sharply as annual mileage increases. The average cost/mile of a mid-size sedan driving 15k miles/annum is $0.50/mile (or $0.64/mile including average US urban parking charges)



Source: Barclays Research

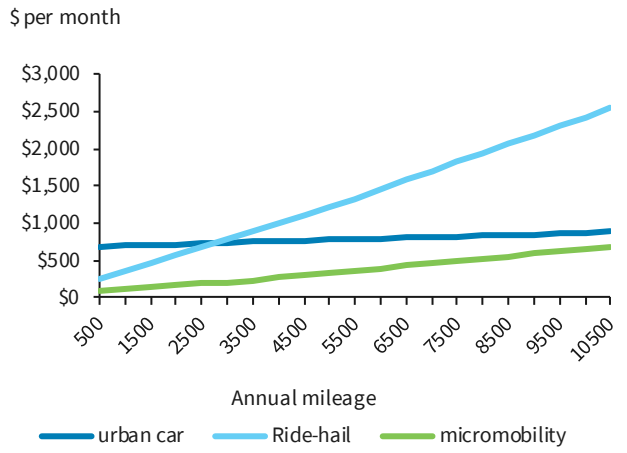
When do MaaS economics look more attractive than car ownership?

Even before the advent of autonomous driving, we can see a transition period for some drivers away from car ownership and towards MaaS, driven in part by these cost dynamics. We think those commuters conscious of cost, or where a car is used for very few annual miles, could increasingly consider a switch to multi-modal mobility, paid for potentially as a monthly subscription, as opposed to upfront car ownership costs. We see MaaS accelerating most notably in dense, urban areas where car ownership costs are at their highest and the "hassle factor" of owning a car is already high (given lack of parking, congestion and local authority regulations to discourage car ownership). However, these are also the regions where car ownership statistics are already at their lowest (for instance according to the 2017 National Household Transport Survey for the US, there are 10mn cars in the fleet in the most densely populated cities in the US, versus 50mn in the most rural locations (with population density less than 500 people per square mile).

Car ownership costs differ based on location

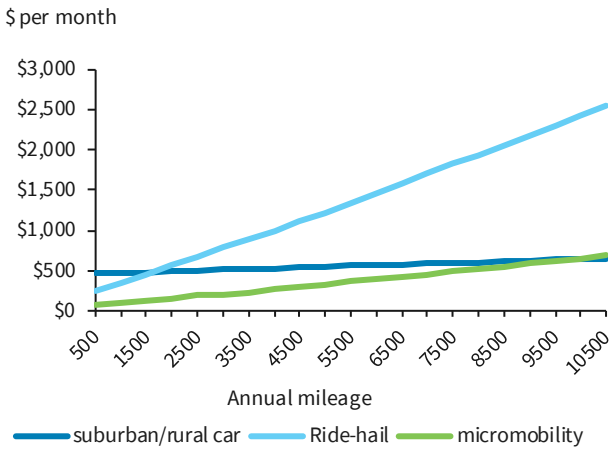
In denser urban regions, where parking is at a premium, it costs more to own a car, given average US urban annual parking costs of $2,728. It is currently cheaper to use ride-hail for all trips below 3.5 miles in length in urban regions but in regions where parking costs are negligible, ride-hail is a costly option for all trips over 2 miles in length. Or if looked at in terms of monthly all-in mobility costs, ride-hail costs trump car ownership in urban areas where monthly mileage is <3,000 miles. If you overlay micromobility, the urban car appears even more expensive for lower mileage vehicles (Figure 29). But in suburban areas, with minimal parking costs and where the chances of finding a micro-vehicle or even ride-hail are significantly lower, car ownership seems like the more obvious solution currently, apart from for vehicles with a low mileage of <2,000 miles annually (Figure 30):

FIGURE 29
High US urban parking costs means monthly all-in costs of car ownership are higher for urban vehicles and where both ride-hail and micromobility have made inroads…



Source: Barclays Research, AAA, US transit statistics

FIGURE 30
… but where parking costs are minimal (and vehicles less available), in suburban and rural areas in the US, car ownership is almost invariably cheaper and more convenient

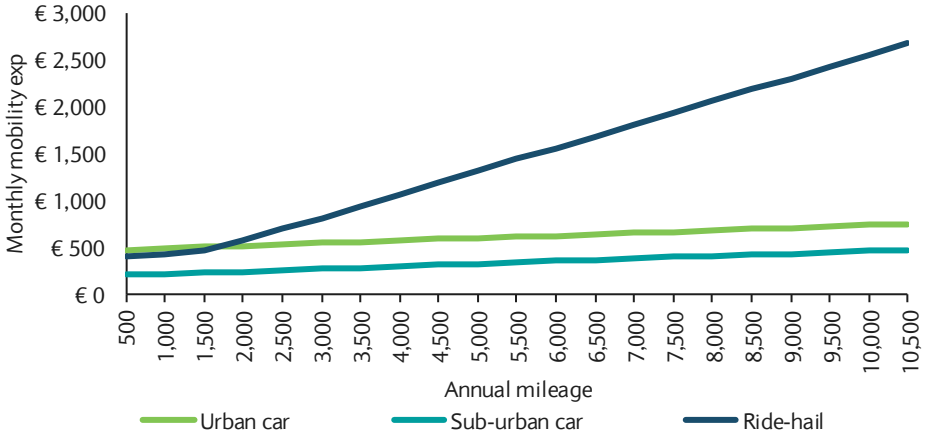


Source: Barclays Research, AAA, US transit statistics

Ride-hail more costly in Europe

The same data but with European prices for car ownership and ride-hail costs to the consumer averaged across major European cities show that only for the shortage urban mileage is ride-hail cheaper than car ownership. However, as we discussed earlier, cost is not the only consideration for consumers choosing transport mode and with more and more European cities introducing parking restrictions or extra congestion charges to discourage personal car usage, ride-hail could still offer strong growth opportunities, particularly when combined with other transport modes such as micromobility and public transport. And as we will discuss in the next section, car ownership statistics are very different in Europe than in the US with a higher proportion of households owning no cars and therefore already reliant on alternative modes of transportation.

FIGURE 31
Ride hail vs car ownership costs in Europe



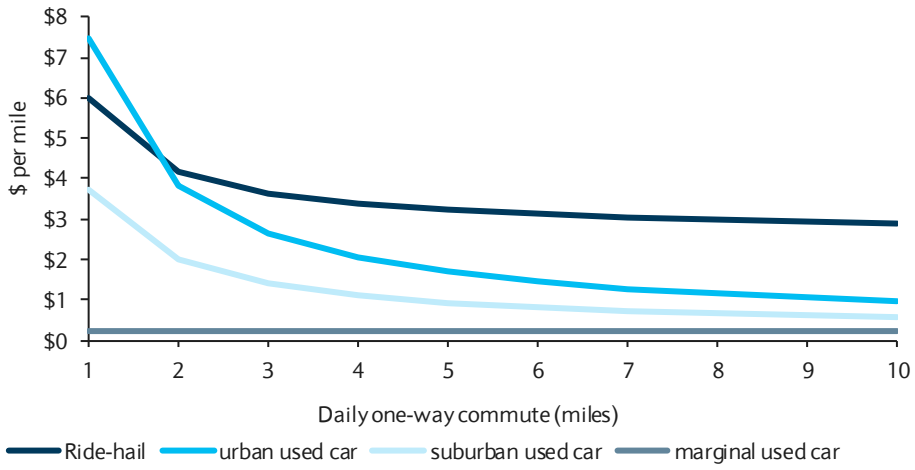
Source: Barclays Research, Leaseplan, Uber

Cost dynamics favour second-hand car ownership

We calculate significantly reduced fixed and variable costs/mile for used car ownership, such that in a region where parking costs are negligible (suburban or rural areas), it is always cheaper/mile to own a second-hand car than to utilise ride-hail. Even factoring in high urban parking charges, used car cost dynamics mean that all trips over 2 miles in length are cheaper by owned car than ride-hail. Of course, if you only factor in the margin cost of used car ownership, it always looks more attractive than ride-hail:

FIGURE 32

An average US used car is cheaper on a cost/mile basis than ride-hail, apart from the first 2 miles of an urban commute



Source: Barclays Research, AAA, US transit statistics

Are current micromobility and ride-hail costs sustainable?

The discussion above is based on current ride-hail costs in the US (we also have data available on request for comparable costs across a range of European cities). However, when talking about a future potential switch in car ownership, it is worth considering whether current ride-hail costs are sustainable or unprofitably low in order to gain network. If consumer prices are set to rise, or even if consumers were just to think they might rise in future, this could obviously affect any decision to give up car ownership.

We expect this partly explains the fact that despite 12.1bn additional taxi miles having been taken in the US since the advent of ride-hail (Figure 18), the impact on car ownership levels have so far been negligible – the average household in the US still owns 1.97 cars/household versus in Europe where the number is 1.2. It would seem that while the addressable market for MaaS is clearly growing, to date the impact on car ownership is not so stark (possibly because where ride-hail penetration is highest, in dense urban regions, is exactly where car ownership trends are already at their lowest). However, we do see this evolving as consumers become more and more reliant on alternative mobility forms.

Monthly ride-hail subscription could attract new users

Equally, if ride-hail companies were to start to offer newer forms of pricing structures – such as monthly subscription packages (similar to Netflix or Amazon Prime for TV streaming) – to attract a user more at ease with such subscription usage, some households might make an earlier decision to "cut the cord" on car ownership and rely solely on alternative forms of MaaS. Such subscription packages would likely encourage loyalty to ride-hail companies and also reduce cost/mile or monthly mobility payments to levels more attractive to current car owners.

Demographic considerations could play a role in mobility choices

While many consumers who drive regularly rely on their car often out of habit or comfort and are likely to need both monetary persuasion and less tangible inducement to change their favoured mode of transport, others may be less loyal to a particular mode. The youngest generation of car drivers (Gen Z) may be yet to buy their own car and currently still rely on usage of a car from their parents' household. Such consumers would need less incentive to "cut the cord" with a car ownership that they have never possessed and feel immediately comfortable with the concept of MaaS.

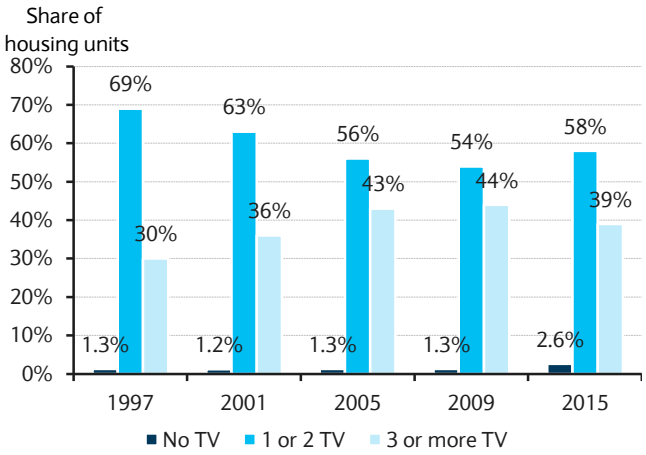
However, as our colleagues discussed in their report: Sustainable & Thematic Investing – Generation Z: Step aside Millennials (28.06.18), the Gen Z consumer is environmentally conscious and willing to act on their environmental beliefs. Therefore, even if they choose not to own a car, they might prefer to utilise "greener", healthier and more active forms of transportation, where possible, such as walking, cycling, public transport or micromobility, rather than switching from car ownership to ride-hail usage.

Demographics clearly at work in video cord cutting

Demographic shifts should contribute to cutting the car ownership cord, much as they have created dramatic shifts in the media landscape, where the average number of television sets in the US is actually falling as 32% of the US population has not known a world without the internet and 13% hasn't known a world without the iPhone or Netflix.

FIGURE 33

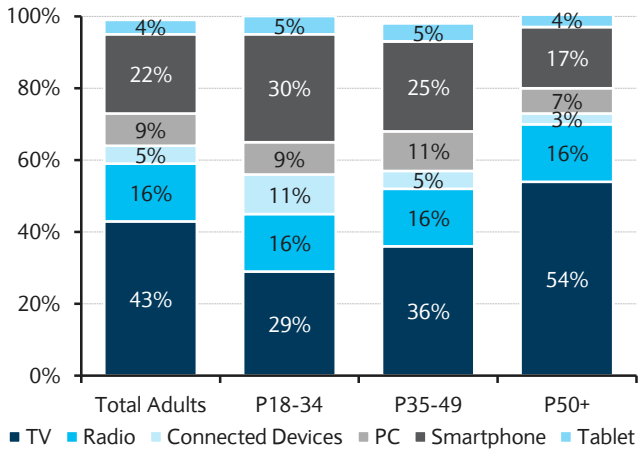
Average number of TV sets in U.S. homes are falling



Source: U.S. Energy Information Administration, Residential Energy Consumption Surveys

FIGURE 34

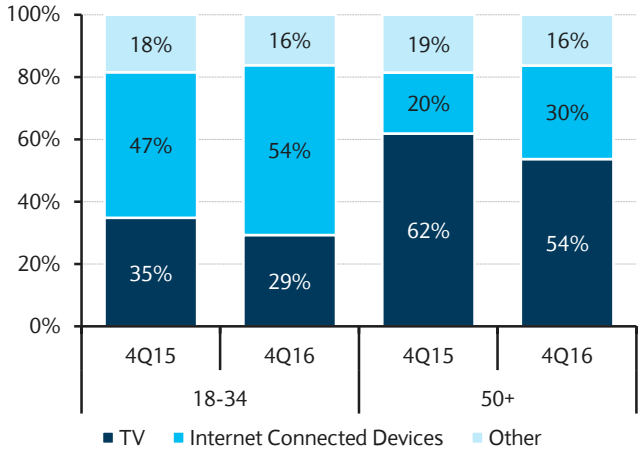
More US P18-34 are using internet-connected devices (55%) than television(29%) on average



Source: Nielsen Comparable Metrics 4Q16 Report

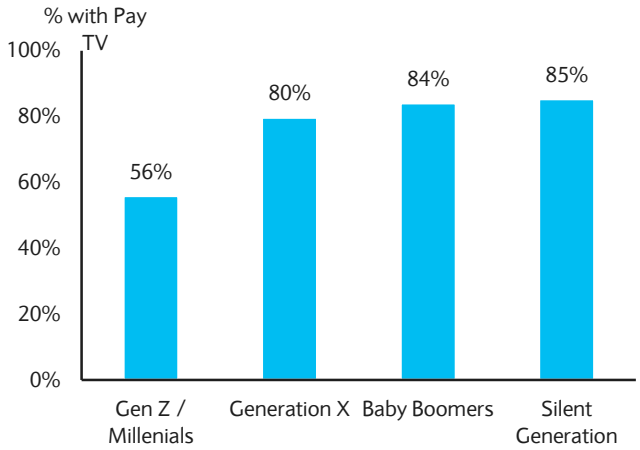
Not surprisingly, an entire generation is growing up with TV as the second screen instead of the default for entertainment. As seen in Figure 34, a higher proportion of adults 18-34 watch video on computers and increasingly on phones than on TV. Looking across age groups, we note that millennials (A18-34) spend more than half their media time on connected devices vs 30% for boomers. It is not surprising therefore that pay TV penetration for Gen Z/Millennials is well below older generations.

FIGURE 35
Millennials spend more than half their media time on internet-connected devices vs. 30% for baby boomers



Source: Nielsen Comparable Metrics 4Q16 Report

FIGURE 36
% of households with pay TV by generation

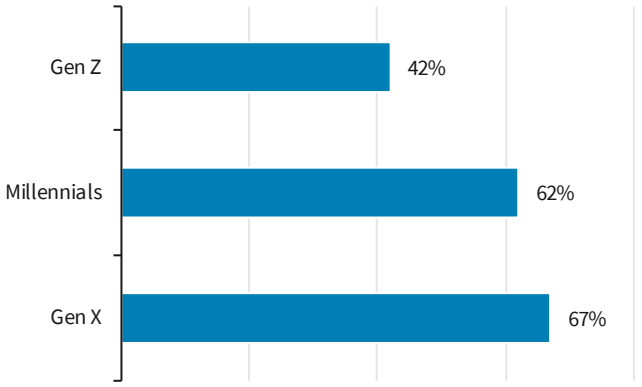


Source: Nielsen Total Audience Report 4Q14

Gen Z are the least-likely to visit car-related sites or apps

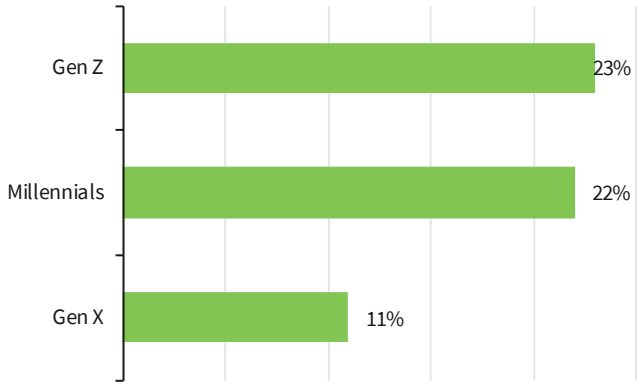
In mobility, according to a report from Comscore[3], Gen Z consumers (aged 18-24 years) are much less likely to visit an automotive site than their older peers. While it is hard to gauge whether a Gen Z consumer might change their habits drastically as their purchase power becomes more on a par with their older peers, the car industry clearly has some work to do to engage this generation in a passion for cars. However, the same report found that Gen Z and Millennials show a roughly similar propensity for usage of alternative forms of mobility (MaaS), but almost the double the usage of their older Gen X peers.

FIGURE 37
% of online audience that visited an automotive-related site or app



Source: comScore

FIGURE 38
% who used a car rental site or ride-sharing app



Source: comScore

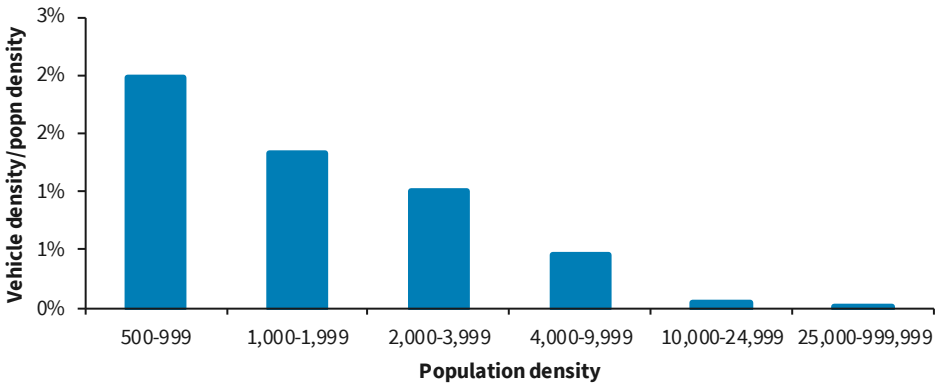
[3] Engaging car buyers of the future, May 2019, Comscore

Vehicle ownership is highest in the US

In today's report we focus largely on the US, where we have the most granular data on how people travel today (2017) versus how they travelled in 2009 via the NHTS, National Household Transport Survey. However, we are of course aware that travel mode, distance and propensity to own a car differ greatly by geography based on different demographics, economic growth, population density, infrastructure, regulations and many other variables. But it is clear from the US data that we have, that car ownership density is highest in the least population dense locations:

FIGURE 39

Vehicle ownership (millions) in the US is highest in regions where population density (people/square mile) is lowest



Source: NHTS 2017, Barclays Research

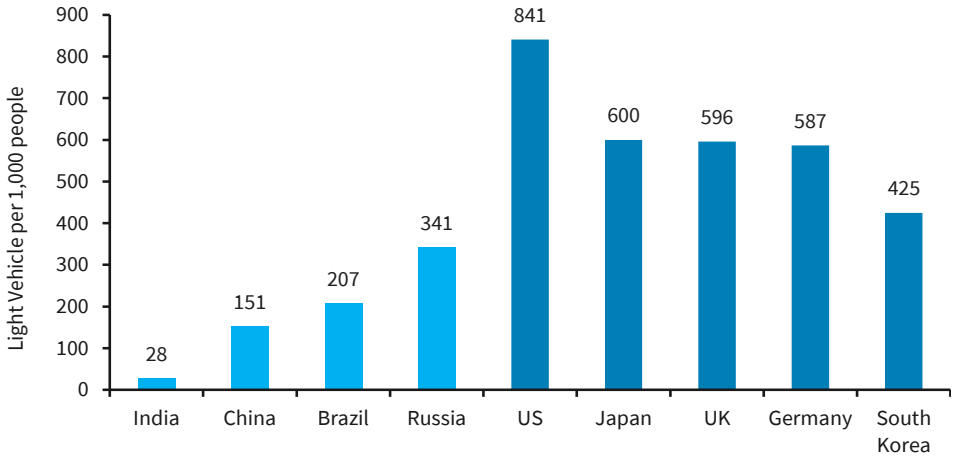
But multi-car households could shed excess cars sooner

While the above analysis, highlights that there are many occasions when car ownership is cheaper (let alone more convenient) than MaaS, there may be a growing number of consumers that still choose MaaS over owning their own vehicle. This dynamic may also change depending on number of cars owned/household.

Car ownership levels differ greatly by geography, with a car-centric country like the US not only having higher car density (cars/1000 people) than the rest of world but as a result also owning more vehicles/household than other regions.

FIGURE 40

Car density (ownership/1000 inhabitants) in developing markets is significantly lower than in mature markets

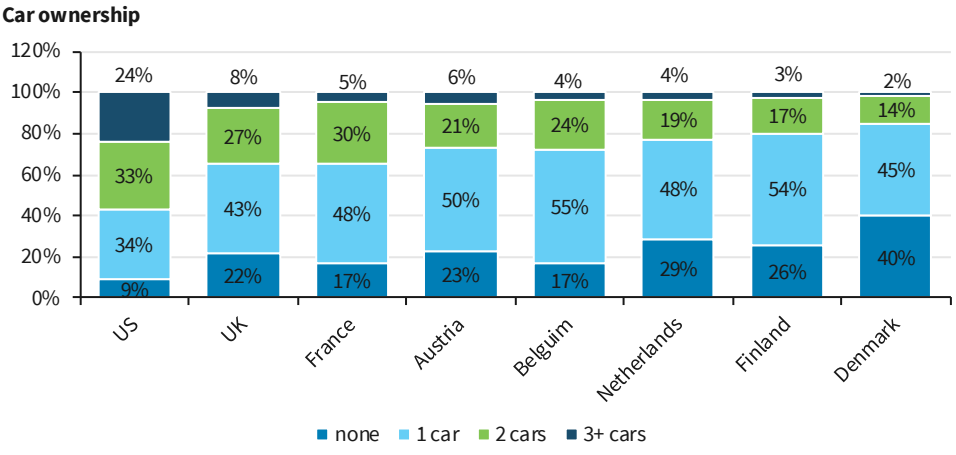


Source: IHS, Barclays Research

Many developed countries have markedly fewer car owners than in the US and therefore fewer households to be persuade to "cut the cord" and switch to MaaS. And while we do not show the statistics below, ownership levels are even lower in developing markets. Therefore, will a growth in availability of MaaS globally mean that some of these regions that might otherwise have been expected to reach economic growth levels commensurate with higher car ownership, actually skip over the ownership phase entirely? As we already discussed in our deep dive on micromobility, many regions of Asia ex-China, such as India and SE Asia, and also Africa where an urban demographic explosion is forecast over the next few decades, already have significantly higher ownership of 2 or 3-wheel vehicles than of cars, and might therefore be more amenable to utilising a combination of micromobility and ride-hail, than ever increasing the car parc density:

FIGURE 41

In the US, 24% of households own >3 cars versus only 8% in the UK



Source: ACEA, NHTS, national statistics

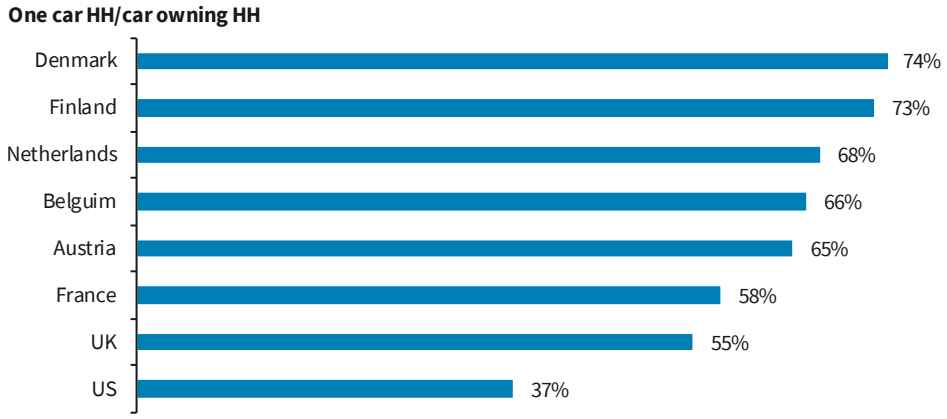
Local, regional and national policymakers globally are showing more appetite for discouraging car usage entirely in urban areas

When comparing those households that only own one car, Scandinavian countries show fewer cars/household than elsewhere in Europe – highlighting that consumers do give up

car ownership when governments start to actively discourage car usage and encourage alternative forms of mobility. However, many of these households might switch to non-car forms of MaaS, which might limit the TAM for ride-hail growth in these regions.

FIGURE 42

European households are more likely to own just one car than their US peers which are frequently multi-car households

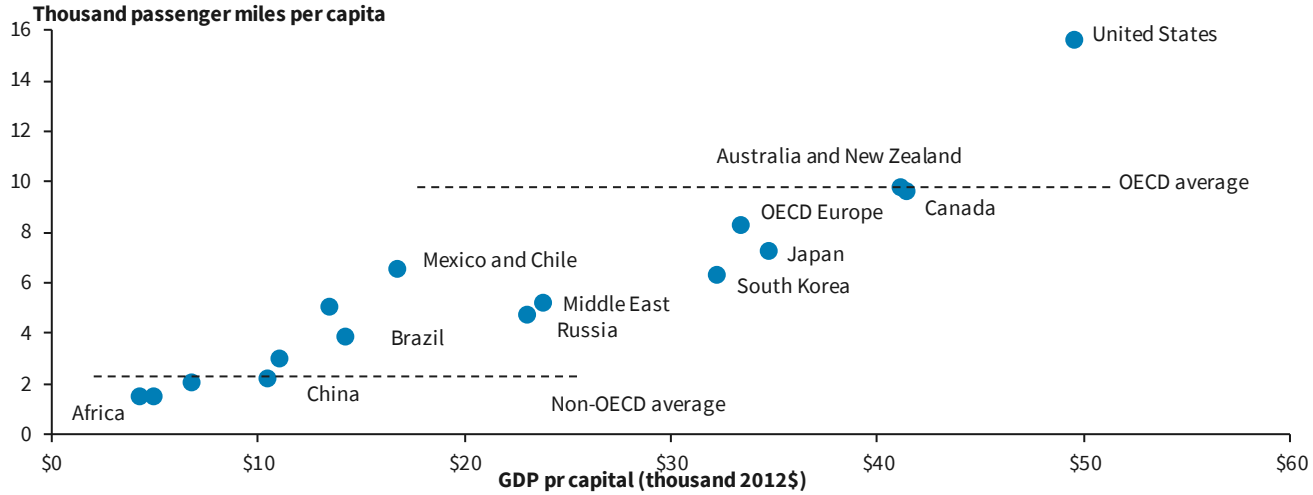


Source: ACEA, NHTS, Barclays Research

While the average US driver travels ~13k miles per year (or 11k miles/year for the average urban driver) – there is obviously a wide distribution of miles driven per vehicle both globally and within each region.

FIGURE 43

Passenger miles travelled by region differs greatly depending on economic dynamics



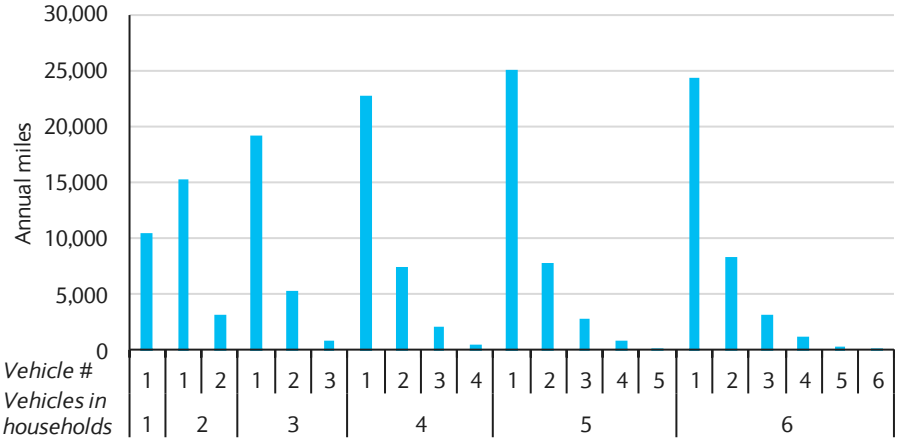
Source: EIA

In terms of car ownership and vehicle sales, the better question is what are the use cases that could reduce vehicle ownership faster. We believe the answer is that for multi-car households, anything beyond the first car could potentially be a candidate to be substituted by ride-sharing, given lower mileage and therefore fixed costs spread over a lower denominator.

In a two-car household, for example, the second car is on average only driven 6,380 miles/year, vs. 19,500 miles/year for the primary car (which is likely used for daily commuting and vacations, while the second car is more 'around town').

FIGURE 44

Annual miles per vehicles by vehicles in household – car ownership most at risk for low-mileage >2nd car fleets



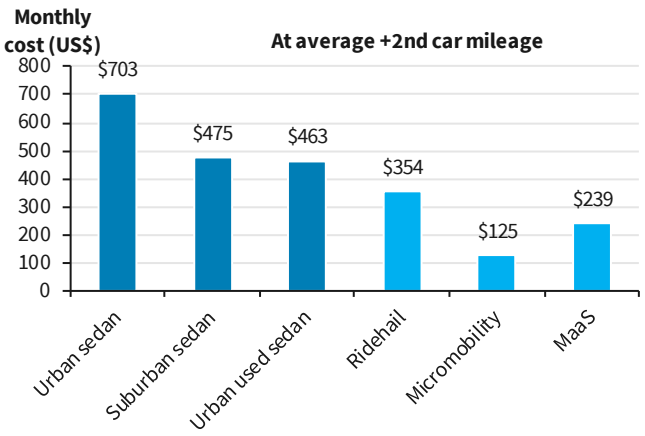
Source: 2017 National Household Travel Survey website: nhts.ornl.gov.

This equates to an average ~500 miles/month for the second car in a household or for anyone owning more than two cars, the monthly average mileage is just 100miles/month. When these levels of monthly mileage are pitted against MaaS costs, it becomes clear that multi-car ownership in urban areas works out as the costlier option.

The tipping point to ride-hail at current costs is ~200 miles/month (2,400/annum) for an urban driver. Therefore, the majority of US households with more than 2 cars, should in theory switch to MaaS when it is widely available in their area, albeit the average second car in a household (driving 500 miles/month or 6k/annum) should only be replaced by micromobility at current costs:

FIGURE 45

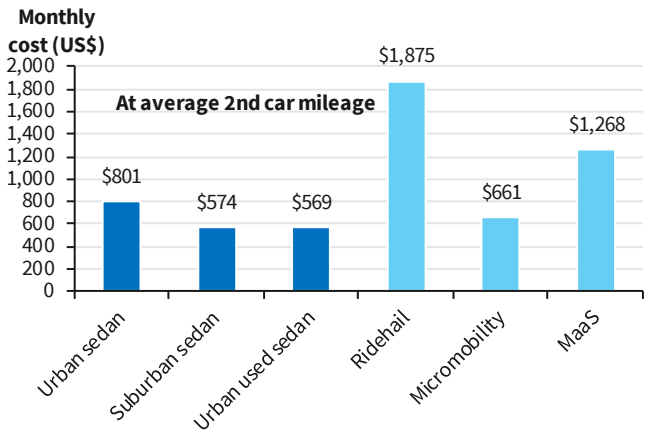
All MaaS options are cheaper for any third or above car in a household (or any car driving <200 miles/month)…



Source: Barclays Research *note MaaS assumes 50% of miles are ride-hail and 50% micromobility

FIGURE 46

…but the average second car in a household is cheaper to own than MaaS (unless all miles were substituted by micromobility)



Source: Barclays Research

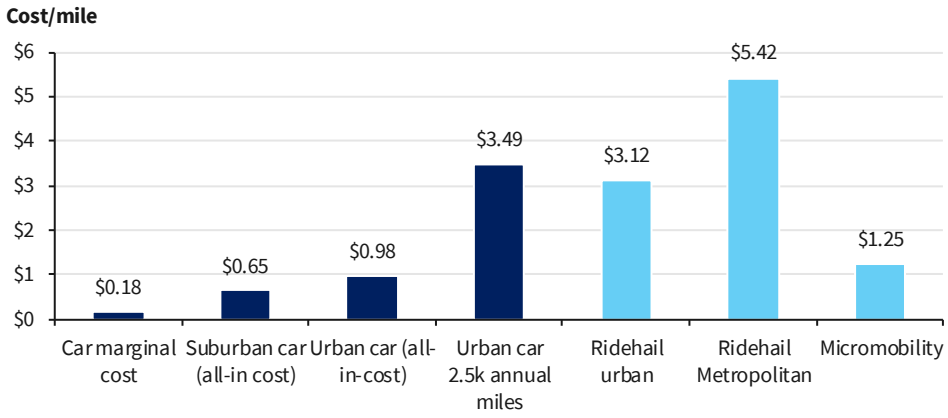
We calculate ~17-19% of the urban and suburban vehicle parc at risk from MaaS short-term even without any robotaxis

Based on our analysis of the 2017 National Household Travel Survey (NHTS) data, we have built a model to calculate total vehicles at risk as MaaS offerings expand in many urban areas. The model clusters the US vehicles in operation into 248 segments based on annual miles driven and population density. We have used this data to calculate:

1. Vehicles in the US car parc by population density (to differentiate between rural, suburban and urban areas)
2. Monthly VMT (vehicle miles travelled) by vehicle and population density
3. Monthly vehicle cost of car ownership based on the above VMT (factoring in higher parking costs in denser urban areas and higher depreciation costs for vehicles driven longer distances)
4. Compared monthly ownership cost to monthly cost for ride-hail and micromobility for the same trips and where the latter is cheaper (ie for the shorter trips in urban areas), assumed these miles to be at risk of switching to MaaS, assuming a mild uptake of micromobility.

FIGURE 47

Average US cost/mile (assuming average US annual mileage) of different mobility modes shows a personally owned car is cheapest until mileage falls below ~2.5k/annum



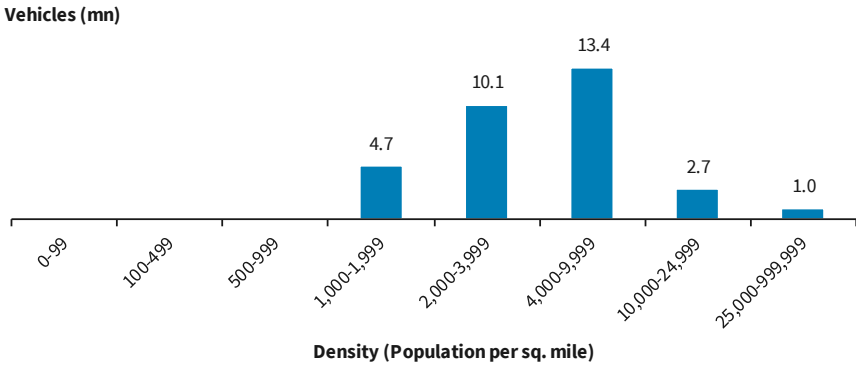
Source: Barclays Research

5. Compared the total miles and vehicles at risk to the overall US vehicle parc

Based on the above analysis, we found 25mn vehicles at risk, or 10% of total parc (as we assume rural areas are not accessible to rideshare). Specifically, ~ 17% of the suburban and up to~25% of the vehicles in operation in the densest urban areas – notably more vehicles are at risk in the less dense urban areas where car ownership is highest. In terms of VMT, we found 23bn of the 2.8tn VMT (for personal owned cars) could switch over to ride-hail based on current ride-hail costs.

FIGURE 48

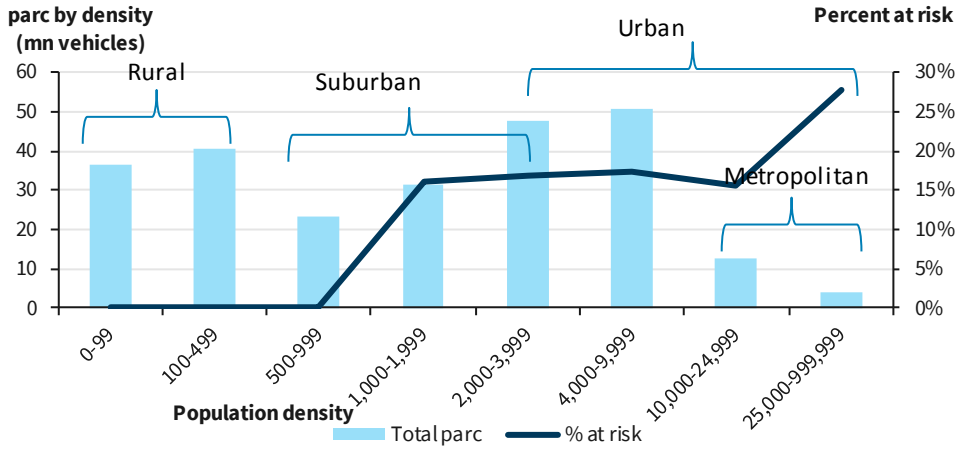
Potential vehicles "at risk" of switching to MaaS by region (bucketed by population density), show the greatest switching potential in less dense urban regions



Source: NHTS, AAA, Barclays Research

FIGURE 49

The highest volume of vehicles at risk are located in less dense urban/denser suburban regions



Source: Barclays Research

In the next section of this report we will look at how car ownership trends might shift further as micromobility adoption accelerates and Level 4 autonomy enables robotaxis to operate in certain conditions in certain geographies.

HOW DOES THE DYNAMIC SHIFT WITH LEVEL 4 AUTONOMY (ROBOTAXIS)?

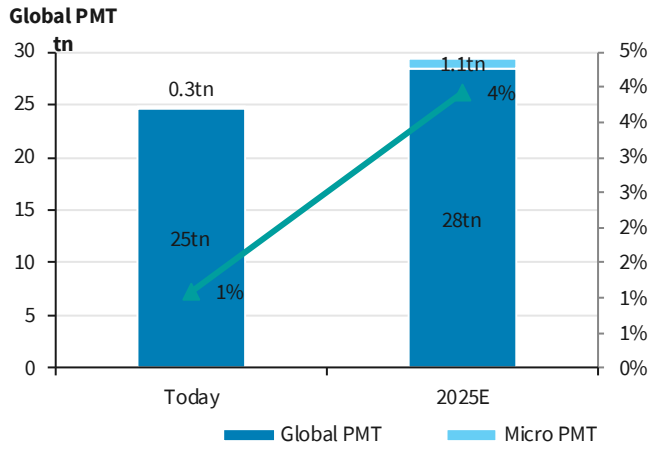
In the first section of this report we explored the uptake of ride-hail and micromobility assuming a static state of the mobility market versus today. However, we expect two strong dynamics to take over in the mid-2020s and disrupt urban mobility more drastically. These are:

1. The advent of robotaxis or level 4 autonomous vehicles, firstly in selected, geofenced areas but over time more widely available
2. Greater availability of shared micro vehicles in urban areas, driving accelerated consumer uptake of micromobility

We explored the latter of these trends in our longer report on micromobility (see *Sustainable & Thematic Investing: Micromobility: Fast, Cheap and Good Solution for 'Smart Cities'* (20th March 2019) and detailed our estimated uptake model for micromobility in terms of global vehicle volumes and global urban addressable market. We believe that by the mid-2020s, assuming city regulators embrace micromobility, global passenger miles travelled (PMT) could rise from 0.3tn today to 1.1tn (or 4% of total PMT and 9% of total global trips):

FIGURE 50

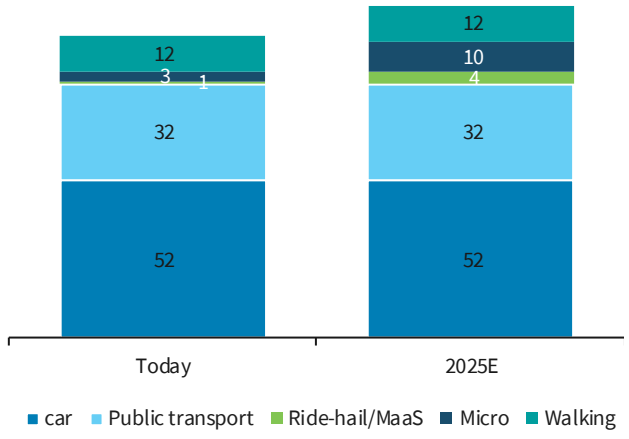
By 2025, we expect 4% of global PMT (1.1tn miles) to switch to micromobility…



Source: Barclays Research

FIGURE 51

…or indexed to 100 today, we expect growth in global trips by 2025E to drive an uptake of micro from 3% today to 9% (10/110)



Source: Barclays Research

While this trend of increased micromobility uptake could clearly be disruptive to car demand, we believe it will accelerate as the early stages of autonomous level 4 vehicles are gaining traction (for a discussion on the time horizons laid out by different companies, see the following section of the report).

We envisage the uptake of autonomy to happen in three stages:

1. Mid-2020s we see Level 4 robotaxis arriving in selected, geofenced areas. Starting first in the US and Singapore, with Chinese regions following fast behind, and European cities lagging. We expect companies to focus initially on less dense suburban/urban areas, before trying to tackle dense, metropolitan locations.

2. Late-2020s we see more widespread adoption of Level 4 robotaxis in many urban and suburban areas (we envisage up to 40% availability in some urban areas)

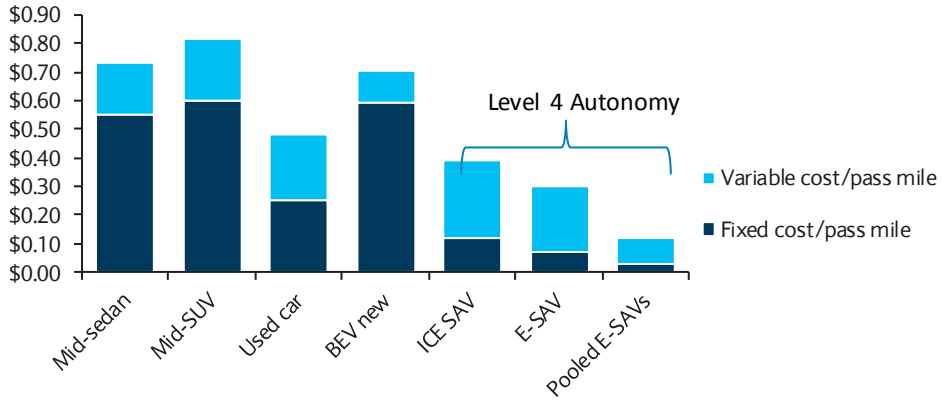
3. In the 2030s we envisage a world of full autonomy, i.e. Level 5 shared autonomous vehicles (SAVs) and family autonomous vehicles (FAVs) available everywhere

Compelling economics for shared autonomous mobility vs. personal car ownership

We think that basic economics will slowly drive the non-rural mass market from individual vehicle ownership to consuming autonomous mobility as a service – though we do see vehicle ownership at the luxury end of the market suffering less disruption, until full Level 5 autonomy is achieved.

Just as we showed in the earlier section of the report, the average urban mid-size sedan costs all-in 73c/mile ($0.98 including parking costs) to operate. Or for the typical US household urban mileage/year of 10,841, $660/month ($887 incl parking). Yet this could come down significantly. We calculate shared autonomous mobility costs could be as low as 30c/mile for an electric powered shared (but private) autonomous vehicle, or ~$0.5 for a combustion engine SAV (shared autonomous vehicle), falling to $0.3 by the time level 5 is more widely adopted. And for pooled vehicles, where the costs are spread among several riders, the cost could come down to 15c/mile. Or put differently, consumers potentially could bring their monthly mobility budget down to $450/month in the early stages of autonomy, to $270/month with full Level 5 or even $135/month for pool users, from $660/month currently.

FIGURE 52
Cost per mile could come down significantly in a world of autonomous driving (US)



Source: AAA, Barclays Research estimates
Note – SAV = shared autonomous vehicle; ICE = internal combustion engine; E-SAV = electric SAV

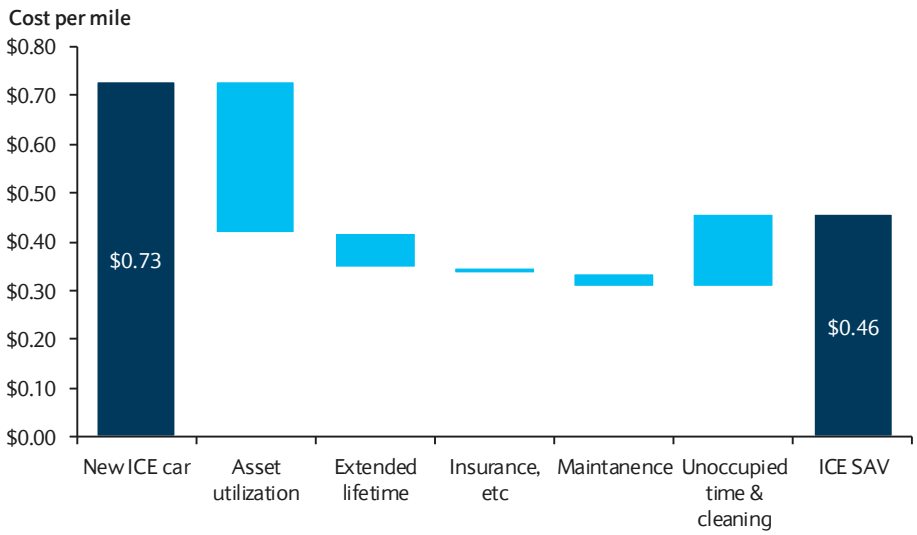
Vehicle economics - better asset utilization drives SAV savings

Shared autonomous vehicles (SAVs), think robotaxis, by the late 2020s could have operating costs of ~30c/mile vs. 98c for today's mid-size sedans, if you assume urban parking charges for an owned vehicle. Better asset utilization is the primary driver, followed by the benefits of being able to drive more miles before the vehicle is scrapped (about 300k for an ICE SAV or 500k for an E-SAV vs. 160k for traditional cars, due to better maintenance and less time for the vehicle to corrode or degrade). The ~$2,500 cost of autonomous hardware and software (which will be higher in the early 2020s, perhaps about $15,000

(which even requires reduction in LiDAR costs)), should eventually largely be offset by the economics of fleet buying, avoiding the dealer mark-up, and getting an OEM discount.

FIGURE 53

Waterfall of cost per mile shift from status quo to shared autonomous; better asset utilization is the primary driver in reducing cost per mile (US)



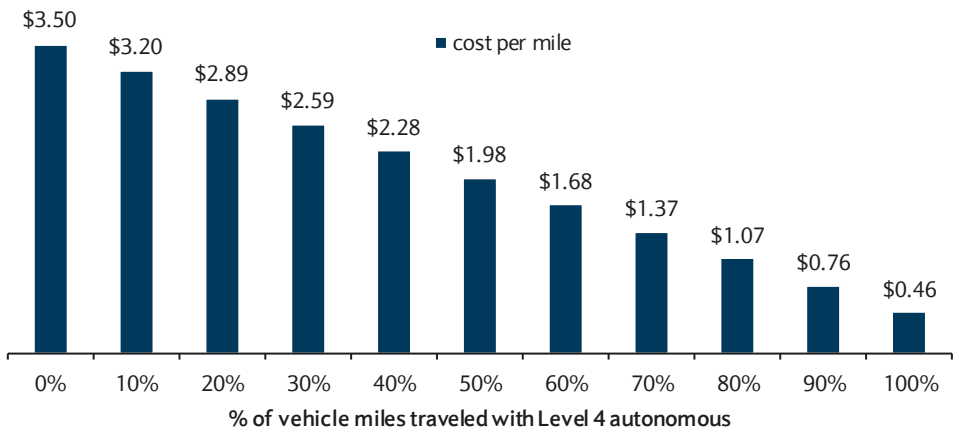
Source: AAA, Barclays Research estimates
Note - SAV = shared autonomous vehicle; ICE = internal combustion engine

Blended costs vary, depending on how much level 4 can handle of a consumer needs

The math is straightforward for the cost per mile in a "multi–modal" environment that blends Level 4 autonomous vehicles on some routes with traditional "Uber with a dude" ride sharing on other routes. With ~50c/mile for autonomous rideshare, and ~$3.50/mile for human-driven rideshare, the blended cost per mile would be, for example, ~$2.59/mile for a consumer who could use SAVs for 30% of her needs, falling to $1.07/mile (roughly in-line with the cost of individual urban vehicle ownership) once autonomous mobility can handle 80% of the travel.

FIGURE 54

Cost per mile of rideshare under different levels of Level 4 autonomous; as autonomous accounts for a greater portion of rideshare miles, cost per mile comes down (US)



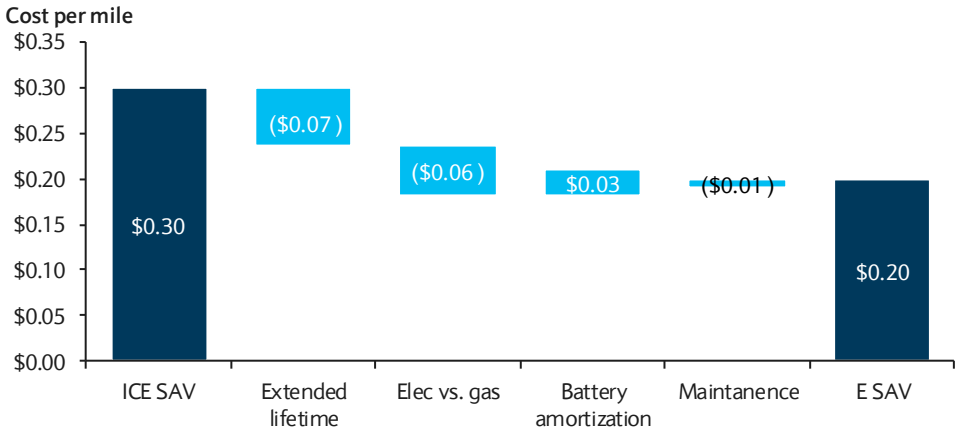
Source: AAA, Barclays Research estimates
Note – 0% indicates all rideshare miles are human driven

As economics improve and technology progresses more towards level 5, we expect the ~$0.5/mile cost for SAVs to come closer to $0.30/mile and the tip-over point for autonomy to rise.

While it is not 'mandatory' that autonomous vehicles need to have a purely electric powertrain (indeed, some fraction of the fleet that operates 24 hours/day may need to be hybrids), the economics longer-term will improve with EVs (electric vehicles). EVs offer a likely longer lifespan (even considering the need to replace a battery at ~150k miles), and lower per mile 'fuel' costs (electricity is inherently cheaper than even low-cost gas due to better thermal efficiency). Moving to EVs for shared autonomous vehicles could bring the cost down yet further to 20c/mile.

FIGURE 55

Waterfall of cost per mile shift from ICE shared, Level 5 autonomous vehicle to electric shared autonomous; electric vehicles could reduce cost per mile by 1/3 (US)



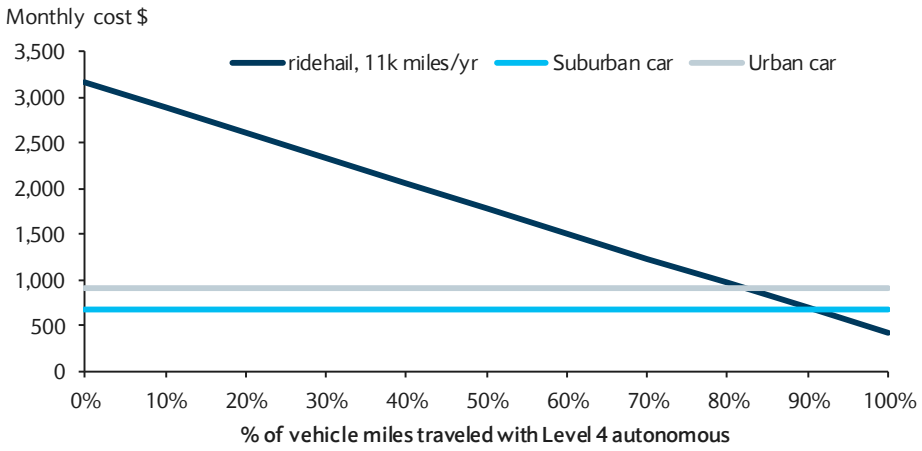
Source: AAA, Barclays Research estimates
Note - SAV = shared autonomous vehicle; ICE = internal combustion engine; E-SAV = electric SAV

Economics tilt toward 'transportation as a service' when it can handle ~80% of the average cars used in urban areas

One 'so what' right away is that we won't need Level 5 – full go anywhere, anytime autonomy – to begin to drive a shift away from personal car ownership. The ~80% effectiveness level – which we still likely won't see in most areas until the late 2020s, and depends on a slew of state and local regulatory authorizations, would be enough to bring the costs in urban areas below personal car ownership. And as we discussed earlier, many consumers will choose to switch to MaaS (or never choose to buy a car in the first place), even before the economics are more attractive, due to other considerations such as ease and monthly subscription preferences:

FIGURE 56

Monthly US personal transport cost under different scenarios of Level 4 autonomous miles traveled vs. suburban and urban vehicle ownership costs. At ~80% urban vehicle ownership and ridesharing are at parity



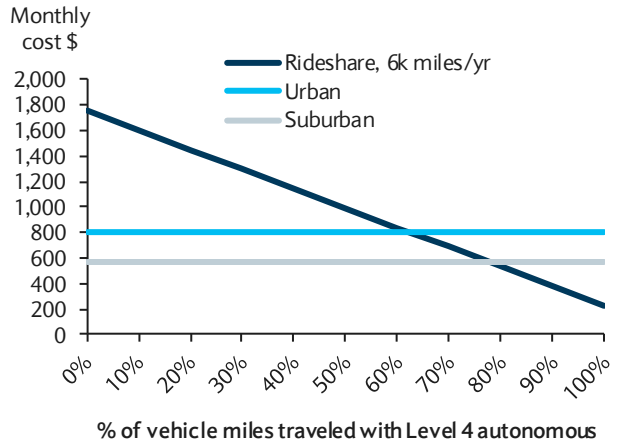
Source: AAA, Barclays Research estimates
Note – 0% indicates all rideshare miles are human driven

And multi-car households could shed excess cars sooner

Moreover, the above calculations assume the average US urban mileage of ~11k miles driven per year for the average car – but, as we discussed earlier, there is a wide distribution of miles driven per vehicle. At the average annual mileage of a two-car household (6k miles/year), rideshare breakeven on autonomy is 60% in urban areas. However, for anyone using their car more frequently (eg 15k miles/annum), it will only really be with the advent of full Level 5 autonomy, that MaaS will break even with ownership:

FIGURE 57

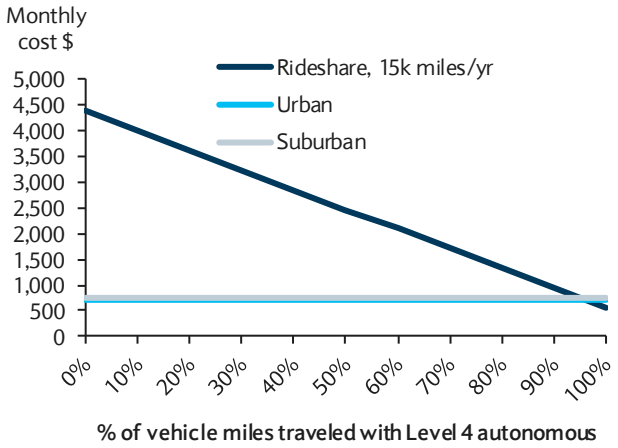
Lower miles driven per vehicle annually makes it easier for ridesharing to be at breakeven w/ vehicle ownership (US)…



Source: AAA, Barclays Research estimates
Note – 0% indicates all rideshare miles are human driven; assumes 7,800 miles traveled annually in vehicle ownership

FIGURE 58

…conversely, higher miles driven per vehicle annually makes it tougher for ridesharing to be at breakeven w/ ownership



Source: AAA, Barclays Research estimates
Note – 0% indicates all rideshare miles are human driven; assumes 15,900 miles traveled annually in vehicle ownership

What does this mean for "vehicles at risk"?

Taking into account these robotaxi costs, combined with a more aggressive uptake of micromobility miles in urban locations, what does this mean for our earlier "vehicles at risk" calculation? We have taken three stages to our robotaxi uptake:

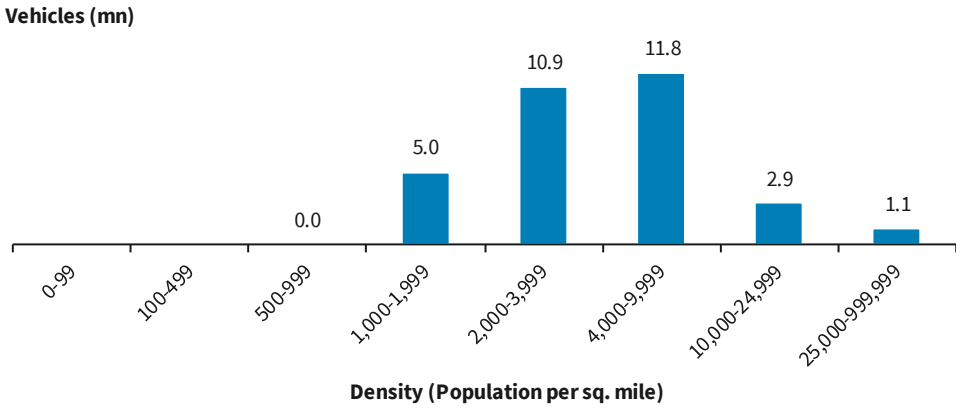
- **Limited robotaxi:** Selected geofenced uptake in a few geographies (mid 2020s)
- **Moderate robotaxi:** More widespread Level 4 uptake of up to 40% in urban areas (late-2020's)
- **Full robotaxi:** Full level 5 autonomy everywhere (2030s)

Limited robotaxi (mid-2020s): selected US regions, geo-fenced robotaxis

Assuming mild (15% on average) coverage of robotaxis in urban regions, and 4% micromobility uptake, we found 32mn vehicles at risk or 13% of the total vehicle parc in the US by 2025E. In terms of VMT, we found 43bn miles potentially switchable to MaaS in the US market:

FIGURE 59

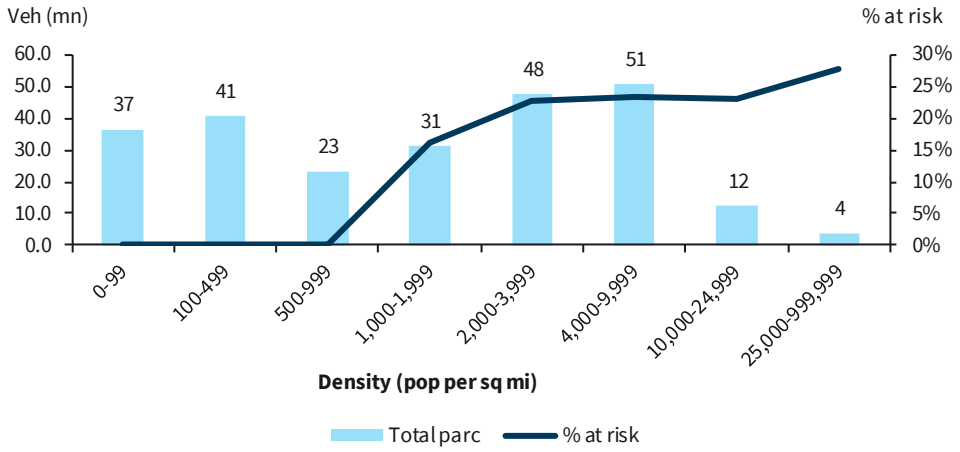
Potential vehicles "at risk" of switching to MaaS by region by mid-2020s (US)



Source: Barclays Research

FIGURE 60

23-25% of the urban vehicle parc could be at risk of switching by mid-2020s (US)

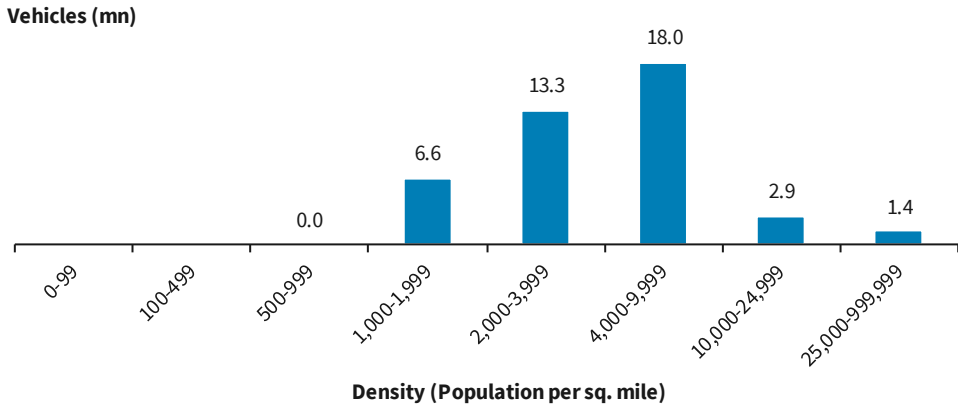


Moderate robotaxi (late-2020s): Level 4 robotaxis more widespread in US

Assuming strong (40% on average) uptake of robotaxis in urban regions, and ongoing micromobility uptake, we found 42mn vehicles at risk or 35% of the total urban vehicle parc in the US. In terms of VMT, we found 64bn miles potentially switchable to MaaS in the US market:

FIGURE 61

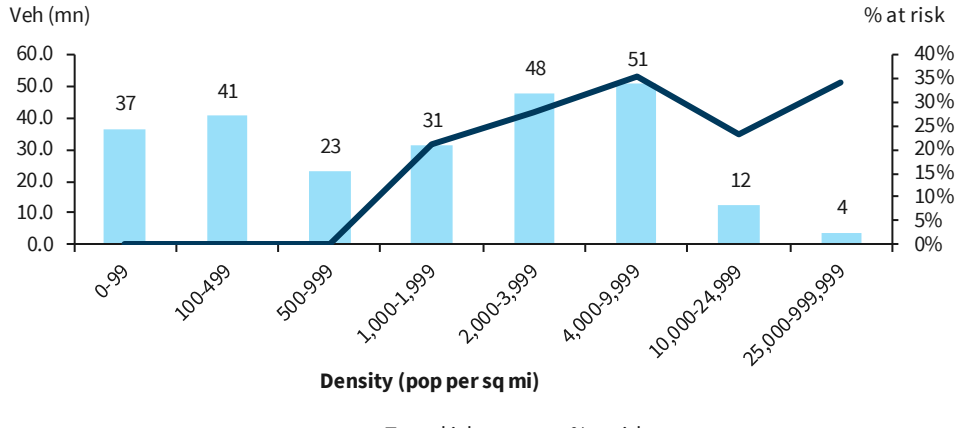
Potential US vehicles "at risk" of switching to MaaS by region by late 2020s



Source: Barclays Research

FIGURE 62

~35% of the urban and suburban vehicle parc could be at risk of switching by the late 2020's (US)



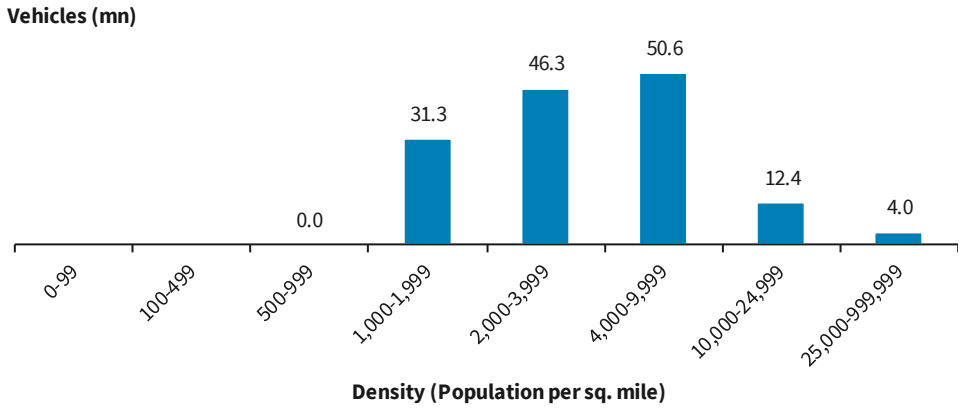
Source: Barclays Research

Full robotaxi (2030s): Level 5 robotaxis widespread in US

Assuming technology and regulations have progressed enough by the 2030s to enable Level 5 autonomy everywhere, and ongoing micromobility uptake, we found 145mn urban and suburban vehicles at risk in the US. In terms of VMT, this could equate to 1.7tn miles potentially able to be driven under Level 5 MaaS in the US market:

FIGURE 63

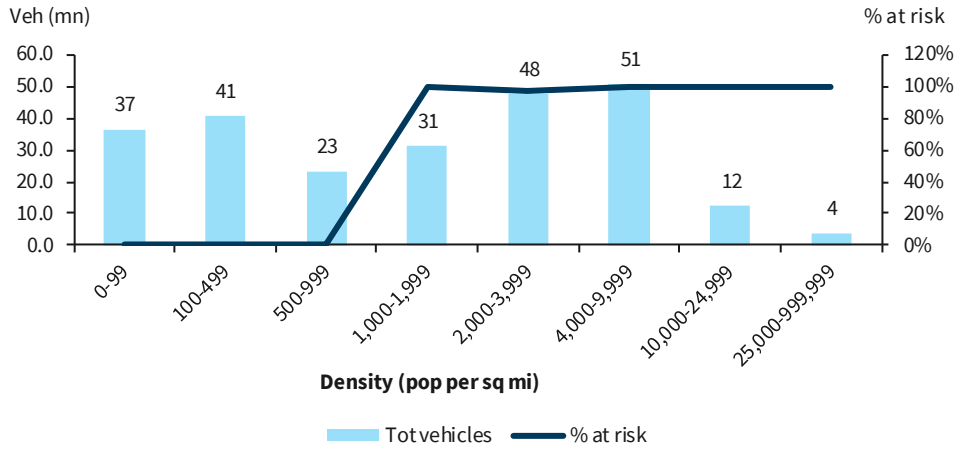
Potential US vehicles "at risk" of switching to full Level 5 robotaxis (US)



Source: Barclays Research

FIGURE 64

100% of the US urban vehicle parc could be at risk of a switch to Level 5 MaaS as the economics fall significantly in a fully autonomous world



Source: Barclays Research

HOW WILL VMT DIFFER BY GEOGRAPHY AS MAAS OPTIONS BUILD IN THE 2020'S AND 2030'S?

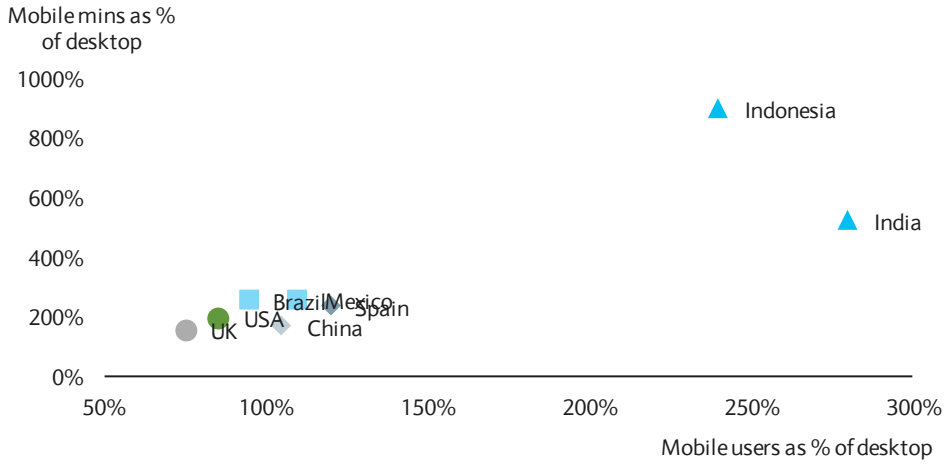
Global mobility divergence

We have focused on the US market in the earlier sections of the report, largely due to this being where we have the most granular data, via the NHTS. For the US we have full detail on trips length, trip mode, trip purpose, population density, along with many other detailed data points from the NHTS data. However, given the car-centric nature of the US market, it is important to understand the differences in mobility trends globally when thinking about scaling any model built for the US.

In media, while the US is a story of 'cord cutting,' globally – and esp. in emerging markets consumers are leapfrogging legacy pay TV, desktop PCs and landlines for mobile consumption

FIGURE 65

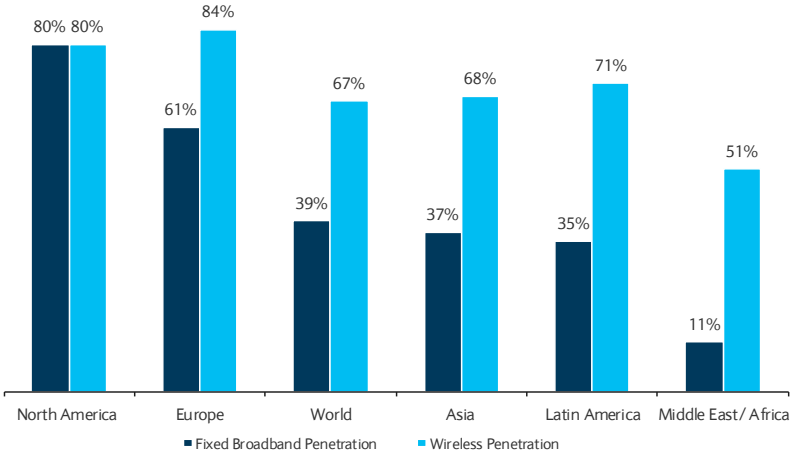
Emerging market mobile consumption both in terms of minutes and users outnumbers desktop viewing



Source: Comscore (Mobile's Hierarchy of Needs) Report, Company Info, Barclays Research

FIGURE 66

Fixed broadband penetration in most parts of the world is lagging wireless penetration resulting in a transition to wireless first consumption...

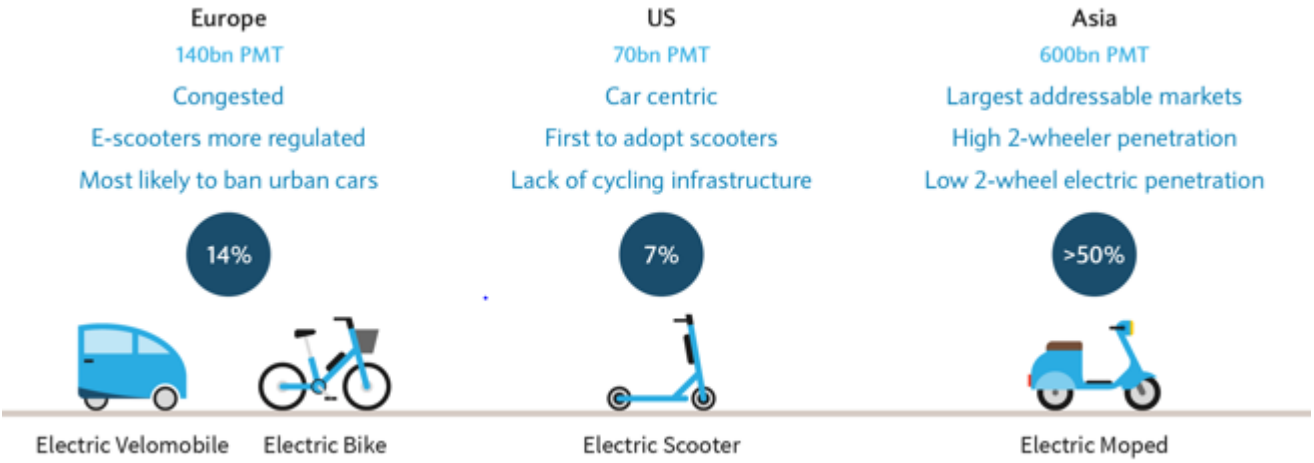


Source: SNL Kagan, GlobalWebIndex, World Bank
Note: Global Fixed Broadband penetration has been computed using total occupied households as the denominator

While future mobility is a global topic, we do expect differences to emerge globally based on demographic trends, economic development, climate, infrastructure, consumer preferences and regulations. In our deep dive on micromobility we highlighted that we expect to see distinct variations in mobility by region, as well as by demographic and population density within regions:

FIGURE 67

We expect divergence by geography as global mobility trends develop



Source: Barclays Research

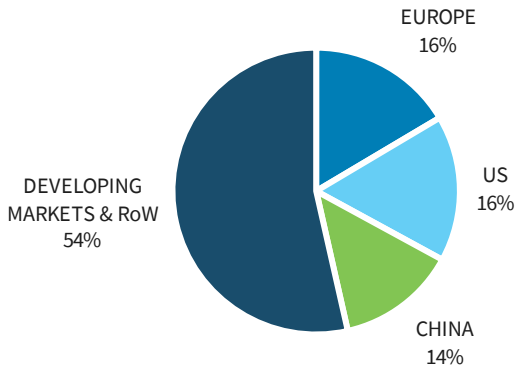
When we think about wider mobility trends, we see four distinct regions emerging with differing mobility requirements:

4. North America
5. Europe
6. China

7. Developing markets

FIGURE 68

Global land Passenger Miles Travelled (PMT) by geography (including light vehicles, 2-wheelers, bus & rail)

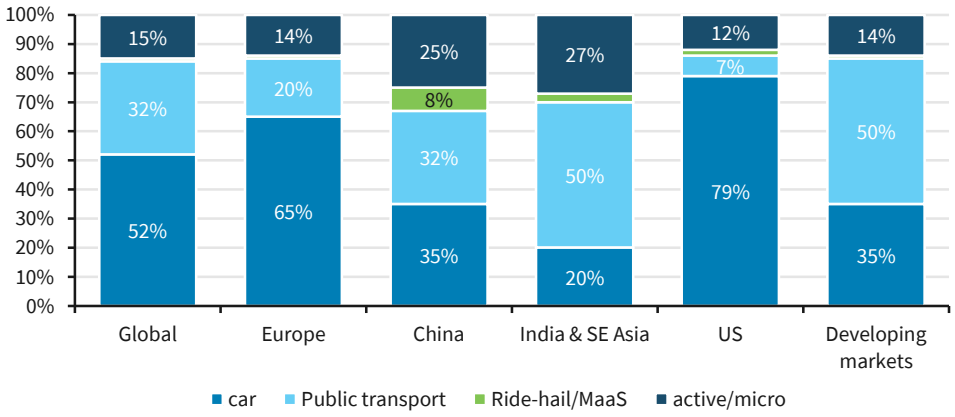


Source: Barclays Research, EIA forecasts for 2012 scaled by UN population growth forecasts

Travel mode differs greatly by region, and while the car continues to be the dominate mode in all developed markets, and in particular the US where 79% of all trips are taken by car, in developing markets, public transport and two-wheelers are much more dominant.

FIGURE 69

Mode of transport globally differs by region with the car the dominant mode of transport globally, but less so in developing markets (% of trips)



Source: Barclays Research, NHTS, national statistics * currently the majority of active/micro is 'walking', e.g. in the US 11% of trips are on foot versus 1% using bicycles or mopeds as per 2017 NHTS data

North America – ~20% of global PMT

The US makes up 16% of current PMT (passenger miles travelled), and 26% of light vehicle PMT globally, with the car still the dominant mode of transport. Despite the success of both ride-hail and the early stages of micromobility in the US, car ownership levels as yet have only seen minimal impact. But, as we have discussed earlier, we think MaaS will start disrupting car ownership in North America more aggressively in the 2020s, when level 4 robotaxis start to operate in narrow, geofenced areas. At current ride-hail and micromobility prices, the potential disruption to car ownership is largely only to multi-car households with low mileage on the additional cars and it is taking time for the US consumer to change their

mind-set away from being entirely car-centric and car ownership focused. But as discussed in the prior section, we see a greater number of vehicles potentially at risk as costs of ride-hail and other mobility services such as micromobility fall with the advent of increased autonomy in the 2020s and 2030s.

Europe – 16% of global PMT

With a much denser urban population in Europe and slightly lower annual car mileage than the US, car ownerships levels are already lower, with many more 1-car or even no-car households already. Many national and local governments across European cities are also increasingly discouraging car ownership, with driving restrictions, congestion charging and some cities starting to think of more innovative solutions, such as removing parking spaces to make driving less convenient.

FIGURE 70

Many European cities are currently considering banning cars entirely (or, in the case of Oslo city center, have done so already)

Cities starting to ban cars	Brief summary
Oslo	Plans to permanently ban all cars from its city centre by 2019 and replace 35 miles of roads previously dominated by cars with bike lanes
Madrid	Initiated low emission zone. Plans to ban cars from 500 acres of its city centre by 2020 with an aim to reduce daily car usage from 29% to 23%.
Hamburg	Plans to build a green network of connected spaces covering 40% of Hamburg by 2035. Also plans to make walking and biking its dominant mode of transport.
Copenhagen	Plans to become completely carbon-neutral by 2025. Currently has more than 200 miles of bike lanes with over half of the population biking to work every day.
Paris	Plans to double bike lanes and limit select streets to electric cars by 2020. Instated car-free Sundays in 2016. Restricts older polluting cars entering the city on weekdays. No diesel cars by 2024 and by 2030 no gasoline cars allowed. People given priority over cars at many intersections.
London	From April 2019 the ultra low emission zone (ULEZ) replaces congestion charge and will stop old "dirty" vehicles in the centre. The zone will be expanded in 2021
Brussels	Most streets that surround Brussel's city square, stock exchange and Rue Neuve (a shopping centre) are pedestrian-only. The roads make up second largest car-free zone in Europe behind Copenhagen and looking for more ways.
Berlin	Plans to build a dozen bike super-highways which will each stretch at least 13 feet wide and be blocked off from cars. The city began construction in 2017.
Helsinki	Plans to make cars obsolete by 2025, not by imposing bans but by developing and deploying mobility systems so effective that personal ownership would be seen as redundant.
Amsterdam	Have banned cars from city centers. Over 400 kilometers of cycle paths trails through the city with an estimated half of all city journeys taking place on two wheels.

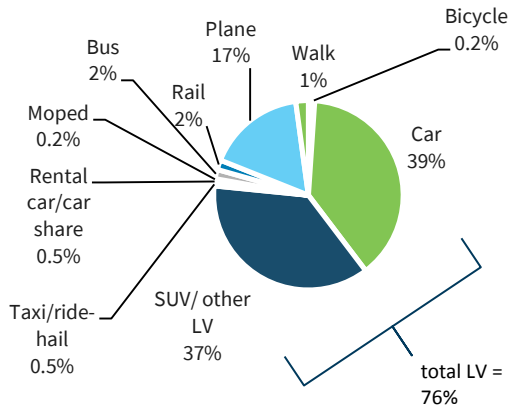
Source: National statistics

Additionally, the European market is highly fragmented in terms of mobility, with many regulations at a local as well as national level. This has made it harder for many TNCs (transport network companies) to take a proper foothold in the region. Many cities across Europe have much more prescriptive regulations on taxi usage that have restricted the expansion of ride-hail and there are equally many different regulations on the usage of micromobility vehicles. In the UK, electric scooters are still banned from both pavements and roads, although the law is currently in review. In Germany, electric scooters have been legalized only in the last few weeks and such differing regulations and restrictions have led to more local mobility champions than international ones in Europe.

But from the point of view of car ownership, we have seen trends away from the car, particularly in countries with the most focus on the environment. It is unsurprisingly that in the Netherlands, where cycling is a very popular form of mobility, there is one of the lowest car densities across Europe and equally Scandinavian countries, despite the harsh winters, have been fast to adopt MaaS and multi-modal transport options and move away from the car – in some instances pushed by local regulations, such as the car ban in Oslo.

FIGURE 71

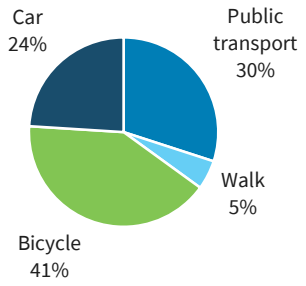
In 2017, 76% of all US passenger miles travelled were by personally owned Light Vehicle…



Source: NHTS 2017

FIGURE 72

…but in Europe, many cities such as Copenhagen are more cycling and public transit-focused

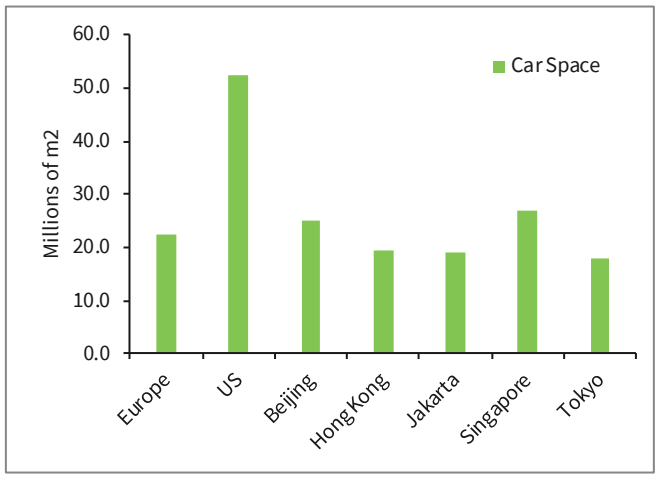


Source: *www.cycling-embassy.dk*

As yet it is hard to tell when the European consumer might decide to totally cut the cord with car ownership, given most households have fewer cars to shed than North American households. We expect 2-car households to be more likely to downsize to 1-car, than for a 1-car household to entirely cut the cord. That one car may be viewed as a necessity for certain journeys, particularly longer distances and vacation trips. That said, were more sharing options made available even this one car might over time be viewed as expendable. Public transportation is already popular for daily commutes across Europe and cycling infrastructure is superior, in many cities, to most regions of the US, making it a key market, in our view, for increased uptake of micromobility.

FIGURE 73

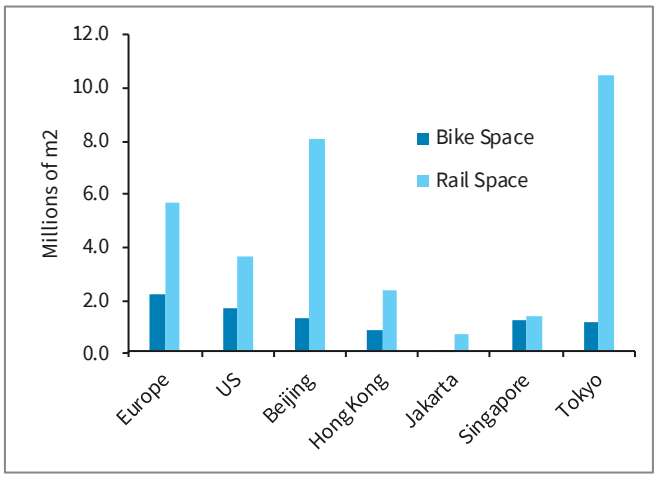
European cities devote less space to the car than US cities…



Source: Moovel Lab's 'What the street!?', McKinsey

FIGURE 74

…and more space to bicycles and public transport (although less than in some Asian cities)



Source: Moovel Lab's 'What the street!?', McKinsey

Many European city regulators continue to pursue anti-car policies because of high congestion levels are high, urban land being at a premium given the density of many urban areas and climate change being strongly on the agenda. But with ride-hail inroads currently more fragmented, we expect the European market to be a tough battleground for many mobility operators and for multi-modal mobility solutions, which integrate public

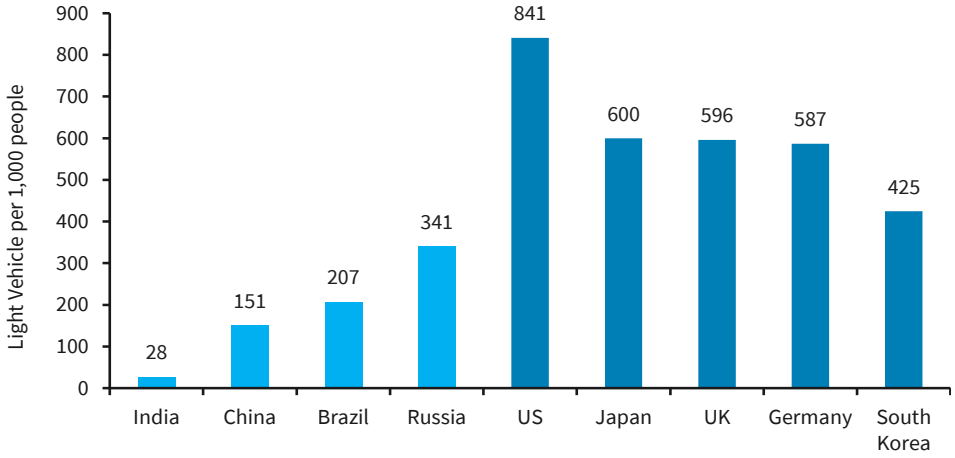
transportation and more active mobility options, to be the most successful and gain the most regulatory support.

China – 14% of global PMT

While China is a fertile region for mobility, given it compromises 14% of total global PMT, car ownership levels are still lower than other more developed regions, despite strong car parc growth in recent years.

FIGURE 75

Car density (ownership/1000 inhabitants) in developing markets is significantly lower than in mature markets

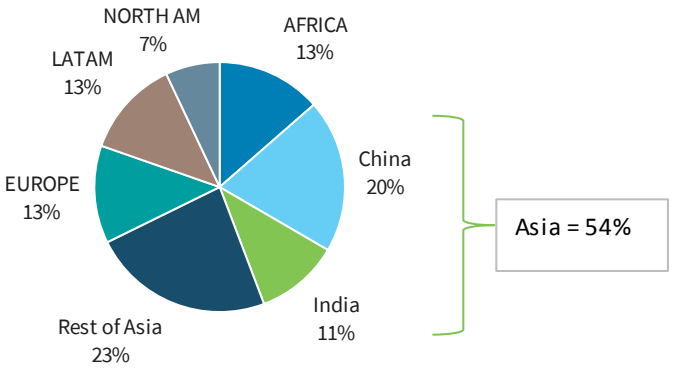


Source: IHS, Barclays Research

We wrote at length on the development of dockless bikeshare in China in our recent deep dive on micromobility and we continue to see China as a region ripe for micromobility uptake (we forecast 20% of all micromobility miles travelled will be in the region by 2025):

FIGURE 76

Barclays' forecast 1.1tn miles will be travelled by micromobility by 2025, of which 20% will be in China



Source: Barclays Research

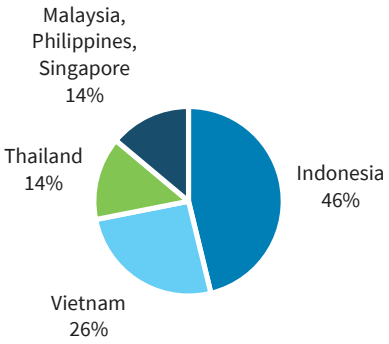
Ride-hail has already enjoyed strong uptake in China with c8% of all trips currently travelled by the mode (versus <2% globally). However, with one dominant domestic player in the region and neither Uber nor Lyft operating in the region, the mobility market is likely to remain closed to most western operators for the foreseeable future.

Rest of World & Emerging Markets – 54% of global PMT

Given urban population trends and economic developments, we believe emerging markets could provide a fertile growth market for mobility operators. Currently miles travelled per capita are significantly lower in developing markets than the US and Europe but with the growth of the middle class in many developing regions globally, these mileage statistics could grow significantly. But will emerging market prove fertile for new car sales, as many OEMs have hoped, or will we see these markets leap-frog the technology and instead of experiencing the 'cord cutting' of developed markets, instead never switch to car ownership in the first place. With both car ownership and car infrastructure much lower than in western markets, consumers might switch directly to non-car modes of mobility.

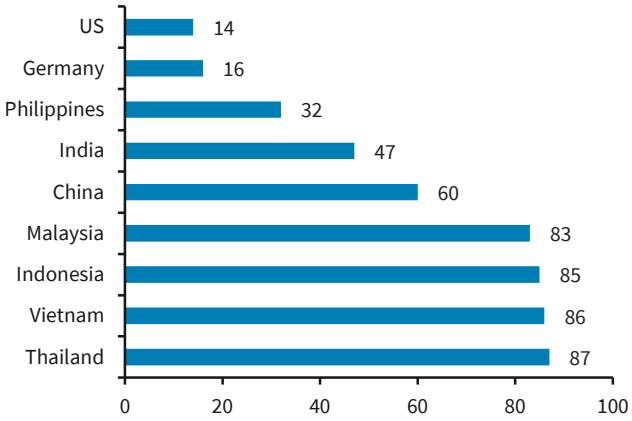
In our deep dive on micromobility we discussed the opportunities for two and three-wheeler vehicles and why we believe markets like SE Asia, India and over time Africa look ripe for disruption by micro-vehicles. Currently two-wheelers make up 80% of the traffic on India's roads, with bicycles, rickshaws, public transport and ride-hail making up the majority of all other travel and car ownership levels just 28/1000 people.

FIGURE 77
SE Asian 2-wheeler sales by country, 2017



Source: Roland Berger

FIGURE 78
Percentage of households owning 2-wheelers (%)



Source: Roland Berger (based on 2014 data)

The electric vehicle market in India is still nascent but electric-two-wheeler sales are growing fast (from a low base). In 2017, the government announced plan for all vehicles to be electric by 2030. While, they have since stepped this target back to 30%, the government has also backed the target up with investment. In February, the Indian government announced $1.4bn in subsidies for lithium-ion EV purchases, with the subsidies weighted towards buses and two-wheelers, as well as three-wheelers for hire. There is currently very little charging infrastructure, but government focus on electrifying the fleet could encourage greater uptake. But recent declines in battery costs and the fact that micro-vehicles require smaller batteries than cars should also drive the micromobility opportunities.

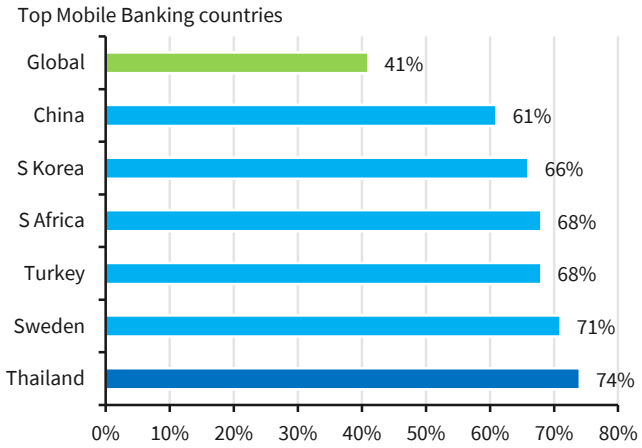
E-commerce penetration in SE Asia is very supportive of micromobility

Two-wheel ownership is also high in SE Asia and we expect the region to offer high micromobility uptake due equally to the high level of mobile e-commerce. Indonesia has the world's highest mobile e-commerce penetration rate (76% versus rest of world at 55%),

Thailand has the highest mobile banking penetration and Singapore leads the way for ride-hailing. Go-JEK can be partially credited with sparking the region's penchant for online shopping. A major part of the app's popularity is its Go-Food delivery service, which allows users to order meals from popular restaurants and *warung* – small, family-owned shops. The company says[4] the service processes $2 billion of annualized gross transaction value. Could these deliveries in time be made by electric micro-vehicles?

FIGURE 79

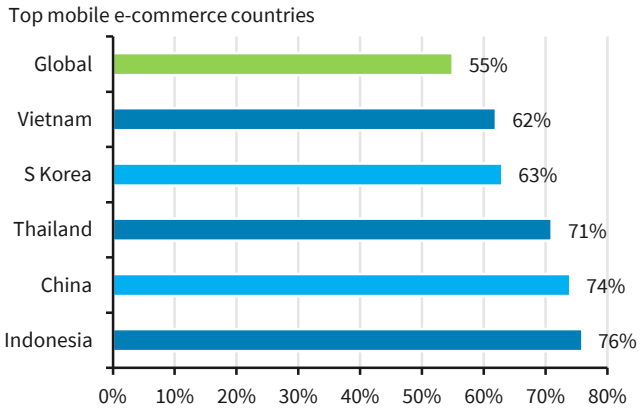
Thailand leads the way for mobile banking (classified as % of internet users who access banking services via mobile)



Source: We Are Social, Hootsuite

FIGURE 80

For mobile e-commerce, Indonesia beats China (% of internet users who make regular purchases via mobile)



Source: We Are Social, Hootsuite

Ride-hailing is popular in SE Asia

Similarly, e-commerce popularity in Singapore has helped its home-grown ride-hail business, **Grab**, grow since inception in 2013 to become SE Asia's largest ride-hail player. Similarly to Go-JEK's success in Indonesia and beyond, digital payments have helped Grab gain market share. In 2018 Grab acquired Uber's SE Asian operation.

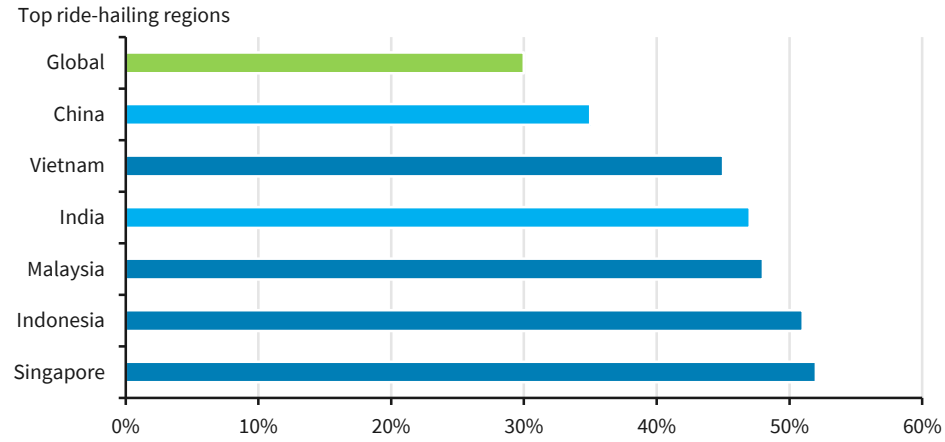
But bikeshare expansion in SE Asia has not been without its failures. **oBike**, a Singapore-based bikeshare operator (which entered into a strategic partnership with ride-hailing company Grab in January 2018 to integrate GrabPay into its app), went into liquidation in June 2018 citing vandalism, strict regulations in many countries and fines, after expansion into Europe.

But we believe TNCs should not overlook emerging markets, given the growing percentage of global miles travelled. However, it will be important for operators to have a flexible approach that takes in the cultural differences and understands the need to offer non-car forms of ride-hail via three-wheel and two-wheel vehicles.

[4] 'Southeast Asia eclipses China as the world's mobile economy hot spot', Nikkei, 12 February 2019

FIGURE 81

Grab has helped Singapore lead the way globally in ride-hailing (% of internet users who use taxi/ride-hail apps at least once a month)



Source: We Are Social, Hootsuite

Similarly to the trends in mobile consumption and wireless penetration, which can be seen below, we wonder whether many emerging economies will leapfrog car ownership and move directly to MaaS, with TNCs needing to understand their local markets to gauge the level of appetite for travel mode. We expect to see strong uptake for micromobility in these regions (although as yet the majority of vehicles are non-electric). Go-JEK has embraced this trend with its e-commerce services dominates by motorcycle deliveries and ride-hail services by moped as well as car:

WHERE ARE WE ON THE ROAD TO LEVEL 5 AUTONOMY?

OEMs, rideshare firms, suppliers, and new tech entrants all see the mobility landscape shifting given the obvious benefits of a world of full autonomy, but the industry is starting to grasp just how complicated the last 10% (or even 1%) of the problem really is. Some companies have communicated timeline for driverless AV deployment as soon as this year while others are taking a more conservative stance. That said, while many questions about autonomous technology, adoption, and applications remain unanswered, everyone is trying to extract a piece of the potentially multi-trillion-dollar market. While many companies are still forecasting launches in the 2020-21 time-period, we note that those could very well be extremely tightly geofenced, time of day and weather limited routes – making us more comfortable with the mid-2020s of a moderate deployment of robotaxis and the late 2020s for broader deployment (albeit still goefenced) and the 2030s for full robotaxi "Level 5" capabilities.

Automakers- preparing for a world without personally owned, manually driven vehicles

The traditional OEMs are well aware of the impending disruptions to their business model and view it critical to develop autonomous capabilities for both active safety features (becoming more popular amongst car buyers) and the eventual adoption of full-self driving, when human driven cars (and those who supply them) will be largely obsolete. Nearly every major OEM is involved to some degree in autonomous development, either through acquisitions (GM, Ford) consortiums (Daimler, BMW) partnerships (Honda, FCA) or some combination of the three along with internal R&D (Hyundai, Nissan/Renault, PSA, Toyota).

US-Based OEMs

General Motors

GM acquired San Francisco based Cruise Automation in 2016 for $581mn and has since grown it to over ~1,000 engineers in the last three years, to be a leader in autonomous. GM has since received 3 rounds of outside funding (Softbank, Honda, and most recently a $19bn valuation led by T. Rowe Price). In some ways, GM kick-started the Autonomous Vehicle hype when CEO Marry Barra famously said autonomous testing will be here in "quarters, not years". Cruise is currently testing its autonomous Chevy Bolts in San Francisco, and aims to deploy small scale driverless rideshare by the end of the year.

Ford

Ford has been testing AVs through its $1bn majority stake investment in Argo AI in 2017. Based in Pittsburgh, Argo AI's founders bring with them expertise from bot Uber and Google's self-driving car project. Testing Ford Fusions in Miami, Pittsburgh and Detroit, (recently received a permit to test in California), Argo AI aims for an initial commercial deployment in 2021. Ford has partnered with Dominos, staking out a unique position in autonomous delivery, vs the somewhat crowded area of robotaxis.

Tesla- bull bear debate continues in autonomy

Caught somewhere between an OEM and tech disrupter, Tesla is relatively new in their autonomous developments, but have made significant progress in the last several years. As shared with us at the recent autonomy investor day, Tesla is taking a 'going at it alone' approach, developing its FSD computer and software capabilities in-house. Tesla takes a vision-based approach choosing only to use cameras, ultrasonic sensors and radars vs the more commonly used LiDAR. Also, without the use of HD mapping, Tesla views its solution entirely unconstrained by geographies or city limits, going against the consensus view that

AV deployments should be confined to geofenced locations. Tesla says that all of its vehicles are capable of full self-driving, with continual SW updates allowing Tesla to commercially deploy robotaxis in 2020. Hyberbulls will assert that Tesla's +1bn miles traveled in "shadow mode" (100x that of any other competitor, i.e. Waymo) gives them an insurmountable advantage, while skeptics will note that the company is still lagging in terms of AV functionality, and that developing a pure neural net/vision based AV will be a far greater challenge than the company anticipates.

European OEMs

For a more in-depth view of what the German OEMs are focusing on in the regions of MaaS, please see our EU Autos report: European Autos & Auto Parts: Dinosaurs vs. Disruptors (14th May 2019).

BMW

BMW established itself within the field of autonomous driving in 2016 via the creation of a partnership with Intel and Mobileye; this collaboration aims to develop a Level 3-5 platform ready for series production by 2021, with the iNEXT model representing the foundation of the carmaker's autonomous driving strategy. Following the creation of the tripartite partnership in 2016, numerous other Auto players have also joined: Aptiv, Continental, FCA and Magna. Moreover, in February 2019 year BMW signed a MoU with Daimler that aims to advance the development of technologies for driver assistance systems, automated driving on highways and parking features (up to Level 4). The two OEMs aim to have these technologies ready for market by the mid-2020s. BMW has also tried to assert its position within the Chinese market, having signed an MoU with Baidu last year under which it will join the Chinese tech company's autonomous driverless platform (Apollo), as well as boasting the accolade of being the first international OEM to obtain an autonomous driving road test license in China. In addition, BMW's VC portfolio (i Ventures) has invested in a couple of start-ups focused on autonomous vehicles: May Mobility and Nauto.

Daimler

Daimler entered into a development agreement with Bosch in April 2017, aiming to bring automated and driverless vehicles (Level 4-5) to market by the beginning of the 2020s. This partnership is set to pilot a Level 4-5 autonomous on demand ride-hailing service in San José in H2 2019. Additionally, as highlighted above, Daimler has established a MoU with BMW to advance various autonomous technologies. Daimler has also been striving to advance itself within the field of autonomous trucks. In September 2018 the company unveiled its new Actros, the world's first truck with a partially automated assistance system. Moreover, the carmaker announced at the start of this year that it intends to invest €500m over the next few years in self-driving trucking technology, creating more than 200 jobs in doing so, as it plans to bring highly automated trucks (Level 4) to the market within the next decade. As part of this longer term goal, Daimler acquired a majority stake in Torc Robotics in March 2019. Daimler's VC portfolio (Tech Invest) has also invested in several start-ups focused on autonomous vehicles: Momenta, Starship Technologies and Volocopter.

Renault

By the end of its *'Drive The Future'* 2017-2022 strategic plan, Renault plans to have 15 vehicle models integrated with autonomous driving capabilities of varying degrees; this fits into The Alliance's wider plan of having 40 models integrated by 2022. In February 2019, the Nikkei reported that The Alliance would partner with Waymo to develop autonomous vehicles and taxis, although this has yet to be confirmed by either party. The VC fund of The Alliance (Alliance Ventures) has also invested in WeRide, a leading Chinese autonomous driving start-up focused on creating Level 4 self-driving technology for the Chinese market.

PSA

PSA currently has several vehicle models that are equipped with Level 2 autonomous driving: the DS 7 CROSSBACK, DS 3 CROSSBACK and Peugeot 508 & 508 SW vehicles. The French OEM acquired a licence to start autonomous driving tests on open roads in China (Chongqing) in January 2019, and also started testing Level 3 autonomous driving capabilities on open roads in France in April 2019.

Tech entrants- a market ripe for disruption

Non-traditional tech entrants view the mobility landscape as an addressable market too large to ignore, and while mobility has been dominated by human operators since its origin, the economic use cases for autonomous vehicles has caused tech players to allocate significant capital and energy into the development of AV technology. The most notable self-driving venture was the Google Self-Driving Car project, started in 2009 later forming into Waymo, but other tech giants including Apple and Amazon have discussed autonomous efforts, while many others tech companies have invested in components of the solution, (AD chips, vision software, LiDAR). Additionally, over 15 startups (e.g. Aurora, Zoox, Drive Ai) are currently testing AVs in California.

Waymo- the leader in pure autonomous miles

Testing its AVs in the Bay area since 2009, Waymo has now moved to Phoenix where it recently received approval to test vehicles without a safety driver. At over 10mn miles, Waymo has logged the most fully autonomous miles to date, twice that of any other company in the California AV disengagement reports. Further, Waymo's recent Chrysler minivans order bolsters its fleet to over 60k vehicles. Currently operating a small-scale ride-hailing service in Phoenix, Waymo is planning to deploy 10 vehicles on the Lyft network this year. Regarded by many to be at the forefront of autonomous, investors/analysts have independently valued Waymo up to $250bn.

Numerous start-ups also attacking the challenge

Attracted by the long-term opportunity in robotaxi, and the nearer term prospect of an exit (e.g., Cruise, Argo), numerous start-ups are pursuing a full-stack approach. Unlike the larger firms who share their test drive progress with investors, details on many of these firms are limited. Key Silicon Valley players include:

- Zoox. Highly secretive, Silicon Valley based Zoox nevertheless garnered $790mn of funding by mid-2018. Zoox has designed an AV dedicated vehicle without a steering wheel, and as of July 2018 believed it could be in operation by 2020[5]
- Drive.ai, last valued at $200mn in 2017 has raised over $77mn in equity investments to date. Drive.ai is piloting its driverless Nissan NV200 shuttles in Texas, ferrying passengers to select destinations in Arlington. Drive.ai is planning to remove its safety drivers from the car in 2021.
- Aurora was most recently in the news for its $530mn funding round with Amazon as a participant (valuing Aurora at ~$2.5bn). The company plans to grow to over 200 people between Pittsburgh and the Bay area, and has partnerships with Byton and Hyundai and other OEM(s) to develop and test AV systems.
- Voyage launched a robotaxi service in two Florida and California retirement home communities in February 2019 after one year of testing. Voyage vehicles are only in select neighborhoods with a top speed of 25mph. Unlike other companies launching in San Francisco, Voyage prefers to roll out its technology on quieter, easy-to-navigate streets at this stage of development.

[5] https://www.bloomberg.com/hyperdrive

- Pronto, founded by an Uber alumnus, primarily focuses on advanced driver assist applications for commercial trucks. Pronto's Copilot technology is a level 2 solution, but the company intends to build on its capabilities and take a more gradual path towards full autonomy.

Ride share- the first logical autonomous use case

With the rise of the gig economy, rideshare is viewed as the first plausible initial AV application given the economics associated with removing the driver from the vehicle (~70-75% of the fee per ride goes to the driver). Uber and Lyft are each pursuing AV development, as is DiDi Chuxing in China.

Uber- gradual robotaxi rollout, elongated 'hybrid driver' era

The company started its Advanced Technologies Group in 2015 to develop autonomous vehicle solutions, and now has over 100 Volvo XC90s on the road testing in Pittsburgh in autonomous mode, with plans to test in San Francisco and Toronto. In an interview with CNBC, CEO Dara Khosrowshahi stated that the arrival of driverless robotaxis will be "quite a few years" beyond 2020, and that a "hybrid" solution, i.e. a network of both humans and robotaxis, can continue for "a much longer period than you think". Denso, Toyota and Softbank invested $1bn in Uber ATG at a $7.25bn valuation earlier this year.

Lyft- taking a multiple partnership approach

Lyft is currently co-developing AV software with Magna but also partners with Tier 1 tech provider Aptiv to deploy driverless vehicles on its network in Las Vegas, as well as Waymo who plans to deploy its vehicles in Phoenix. Ford also plans for a commercial AV launch with Lyft in 2021.

Tier ones- Active safety / automotive-grade knowhow lends itself to compete in autonomous

Stemming from a history in safety sensors, controllers and software, many suppliers have made the decision to invest into higher levels of active safety (L2+ / 3) as well as L4/5 software. OEMs have largely decided to delay investments in L4/5 personally owned vehicles leaving the market for AV system suppliers somewhat bifurcated between advanced "collaborative driving" L2-2+ solutions (e.g. GM Supercruise) and robotaxi applications. While the advanced active safety market is concentrated amongst four players (Aptiv, Bosch, Conti, Veoneer) certain suppliers have made strategic investments to develop full software stacks. Notable tier 1 investments include Magna's minority stake in Lyft, Veoneer's Zenuity JV, Aptiv's acquisitions nuTonomy/ottomatika, and the Bosch/Daimler AV joint development partnership.

Aptiv, leader in autonomous amongst suppliers

In our view, the overwhelming leader in autonomous amongst Tier 1s, Aptiv completed its first coast to coast autonomous drive (99% autonomous mode) from San Francisco to NYC in 2015 and has since tested AVs in over 10 cities across the globe. Aptiv utilizes a dual stack approach combining software capabilities from both ottomatika and nuTonomy to achieve full redundancy. Earlier last year, Aptiv began to commercially deploy autonomous vehicles on the Lyft network in Las Vegas early 2018, executing over 50k rides since launch. Aptiv expects to be able to remove its safety driver from the vehicle in 2022 for limited geofenced robotaxi applications.

FIGURE 82

Autonomous profile by company

	Hardware	Origin of capabilities	Valuation benchmark	AV testing	Deployment plans	Size- engineers/ cars
Tech firms						
Waymo	Lidar (6x) Radar (4x) Camera (8x) IMU (1x)	Google self-driving project (2009)	$75-250bn (sell-side estimates)	+10mn miles driven on public roads	Small scale commercial operation in Phoenix	Order for 62,000 Chrysler Pacificas, ~600 engineers
Intel/Mobileye	Camera centric approach plus low end Lidar	Mobileye acquisition in 2017	$15.3bn (acquisition price)	Testing 100 vehicles in Jerusalem	Testing MAAS pilot in Jerusalem	450 engineers at acquisition
OEMs						
Ford	Lidar Radar Cameras	Argo AI acquisition in 2017	~$4bn (estimated valuation of recent $1.7bn investment)	AV testing in Miami, Pittsburg and Detroit, received permit for CA	Commercial deployment in 2021	~350 employees
GM	Lidar (5x) Radar (8x) Camera (14x) IMU (1x)	Cruise Automation acquisition in 2016	~$19bn (latest funding round)	Testing in San Francisco	Commercial deployment by end of 2019	~1,200 engineers
Tesla	Ultrasonic sensors (12x) Camera (8x) Radar (1x)	Internally developed	N/A	+1bn miles driven in autopilot	1mn robotaxis by 2020	+500k vehicles
BMW	N/A	2016 partnership with Intel/Mobileye	N/A	N/A	Market ready L4 capable vehicles by mid-2020s	N/A
Daimler	N/A	2017 development agreement with Bosch	N/A	Approval for AV testing in the US, Germany and Beijing	L4-5 pilot in San Jose 2H 2019	N/A
Tier ones						
Aptiv	Lidar Radar Cameras DSRC sensors	nuTonomy / ottomatika acquisition	$450mn (nuTonomy purchase price)	AV testing in over 10 cities	50k+ rides in Las Vegas, no safety driver by late first half of 2020s	~700 AD engineers
Ride share						
Uber	Lidar (1x) Radar (4x) Camera (7x) IMU (1x)	Advanced Technologies Group	Toyota, Denso, Softbank investment - $7.25bn	AV testing in Pittsburgh, mapping in San Francisco, Toronto	Robotaxis on the road "quite a few years" beyond 2020	~100 AVs
Lyft	N/A	Co-developing AV software through partnership with Magna	N/A	N/A	Multiple AV deployments on Lyft network	N/A

Source: Company reports, Barclays research

ANALYST(S) CERTIFICATION(S):

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Overweight - The stock is expected to outperform the unweighted expected total return of the industry coverage universe over a 12-month investment horizon.

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