WIDER, TALLER, HEAVIER: EVOLUTION OF LIGHT DUTY VEHICLE SIZE OVER GENERATIONS

Working Paper 17

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Acknowledgements

This publication was prepared by François Cuenot. The manuscript was shared for review with the following representatives of the GFEI partner organizations: Peter Mock, John German, and Anup Bandivadekar of ICCT, and Sheila Watson of the FIA Foundation. The FIA Foundation provided funding for the development of this work.

Key points

- Vehicle size is a key parameter in car purchase decisions. Most potential buyers know the desired vehicle size before considering any other specifications, such as fuel type, engine power, or body style.
- Measuring vehicle dimensions to classify vehicle sizes can be confusing and does not bring robust information to the potential buyer. Interior space, though used by U.S. regulators to classify vehicle size, is not a good indicator of vehicle size. The industry has favored a more subjective segmentation based on relative comparisons of the model range available and the competition model portfolio.
- Weight and footprint (wheelbase multiplied by vehicle track) are the two most popular proxies used in fuel-economy policies. Footprint offers a more robust metric for corporate average fuel economy (CAFE) standards because it emphasizes weight reduction and allows for less possibility to game the system.
- While footprint is the best metric for representing vehicle size for policy purposes, to analyze market evolution, it is also appropriate to look at weight and vehicle segment, especially for evaluating the impact of SUVs.
- From 2010 to 2015, the average vehicle registered globally increased in weight by more than 5% and in footprint by more than 3%, based on more than 70 million new vehicles recorded annually in the database of the Global Fuel Economy Initiative (GFEI), covering more than 80% of global vehicle sales.
- The Chinese market, now the biggest globally, is quickly increasing the worldwide averages for vehicle weight and footprint, driven by local manufacturers now matching the size and weight of advanced foreign designs produced in China through joint ventures.
- The Indian market has by far the smallest and lowest-powered vehicles while the U.S. market has the largest, heaviest, and most over-powered. The average American vehicle in 2015 was 30% larger, 60% heavier, and 180% more powerful than the average Indian vehicle.
- Engine downsizing has been a reality mostly for large and very powerful engines. Low-cost brands still increase engine size along with vehicle size. Engine downsizing had no or very limited impact on vehicle size, with average engine power still increasing.
- There has been a dramatic increase in demand for SUV body styles in the recent years, shifting the market toward larger, taller, and heavier autos at a faster pace. Where previous model types took more than 20 years and at least three design generations to increase weight by 30%, SUVs are doing that in just one generation (see Figure ES1).
- SUV footprints are usually similar to those of their sedan variants. The major difference in the vehicles is increased weight and height. Footprint-based fuel-economy standards are therefore better suited for managing expansion of the SUV market and encouraging better SUV fuel economy, as weight-based standards artificially reward manufacturers for the additional weight of the SUV.
- SUVs have preferential treatment on certification test cycles, which use lower average speeds than real drivers do. So the higher aerodynamic load of SUVs, reflecting a bigger frontal area because of height, is not fully captured by such tests. This results in better fuel-economy readings than the SUVs deliver on the road compared with similar sedans.

Figure ES1: Example of size and weight evolution for the BMW 3-series, from 1st generation to last sedan and SUV variant

- Even though the proportion of advanced, lighter-weight materials used in autos is increasing, average vehicle weight is still rising. These materials offset the weight of upscale features or simply increases in vehicle size. The market shift toward heavier SUVs adds to the trend.
- A review of model evolution from generation to generation shows that vehicle footprint increases slowly even as weight has sometimes doubled from initial models in the 1960s or 1970s. Technical innovations to improve fuel economy have been used primarily to limit consumption growth that would otherwise have occurred because of substantial weight increases.
- Light-weighting is starting to be deployed on a large scale in some models through a wide variety of technical approaches depending on the manufacturer. Optimization of existing material and manufacturing processes has been used most often, with material substitution a rarer option for engine or body parts.
- Battery electric vehicles (BEVs) still have a significant weight penalty because of the battery pack. Most BEV makers prefer to use significant improvements in power density and specific power of the batteries to increase vehicle range rather than to reduce vehicle weight.

Policy recommendations

- Interior size should not be used as a vehicle size metric. Vehicles perceived as large sometimes have tight interior spaces that can lead to confusion.
- Harmonized worldwide definitions for vehicle segments would reduce confusion and improve policies and analyses. Definitions should be developed by an authoritative independent body at the global level. A UN framework would be an appropriate arena for defining and maintaining such a classification scheme.
- Footprint-based fuel-economy standards should be adopted as widely as possible to spur more-aggressive weight-reduction strategies and deployment of more fuel-efficient SUVs.
- Real-life fuel-economy measurements complementing laboratory tests should be implemented to better capture real-life driving conditions, such as higher average speeds and a higher share of urban driving, and lower ambient temperatures.
- Corporate average weight reduction targets should be considered to strongly encourage weight-reduction strategies. This would benefit not only fuel economy but also safety, road wear, and road occupation. It would also decrease the need for high engine power, further reducing vehicle weight.

Introduction: The importance of vehicle size for fuel economy

The Global Fuel Economy Initiative (GFEI) started in March 2009 to engage countries, policy makers, and all stakeholders to dramatically improve vehicle fuel economy by encouraging adoption of fuel economy technologies and policies around the world. Policies in place are sometimes lacking in ambition and consistency.

Auto makers, also known as original equipment manufacturers (OEMs), continuously apply new fuel-economy technologies in search of competitive advantage through more efficient powertrains and other features. But this doesn't always result in better vehicle fuel economy. Often, engineers apply these technologies to offset the negative effects on fuel economy of increased weight, size, or engine power, resulting in no net fuel-economy gains for the vehicle.

To better understand how the size and weight of vehicles have evolved and have affected fuel economy, this paper examines how cars have changed in size over time. We also study trends in auto characteristics and demand as well as changes in markets around the world relative to vehicle size.

Vehicle size: Qualitative definition and measurable metrics

Each car user has a different need for his or her vehicle. Size is one of the top criteria triggering a decision to purchase or replace a car. In India, for example, vehicle size is the second-most important reason given for a purchase by first-time and replacement buyers, behind availability of new technology (see Figure 1).

Figure 1: Top drivers for vehicle renewal in India (Deloitte, 2014)

Vehicle size and meaning are rather subjective. A family with three children is likely to have a different interpretation of how big is a car compared with a young driver purchasing for the first time.

How to define, measure and classify vehicle size

Vehicle size has important consequences for an auto's choice and use. Size affects price, the amount of interior space for passengers and luggage, and the ease of parking in tight spaces. Each user will prioritize each criteria differently, making vehicle size hard to standardize and quantify.

Nevertheless, there is a need to be able to compare vehicles by size as buyers choose from vehicles made by different OEMs. There are different approaches for quantifying vehicle sizes and classifying vehicles by size bins:

- A standard exists for measuring exterior and interior vehicle size: SAE's J1100 paper defines how to measure vehicle size in a standardized way.
- Specialized media often use sets of suitcases to quantify trunk size and humans to assess leg and head room, often in the rear seats.
- Most car manufacturers, suppliers, and some stakeholders use vehicle segmentation, where the market is split into about 10 categories, to group vehicles by size class (e.g. EU, 1999).
- Rental agencies have put in place a unique code for organizing vehicle classes, trim and refinement levels (ACRISS, 2017).

Standard for measuring vehicle size

In 1984 the U.S. SAE published a detailed paper on how to measure interior and exterior vehicle sizes. It details the procedures for measuring dimensions, surface areas, and volumes to determine light and heavy duty vehicle size categories. It is used in U.S. road safety legislation to define passenger carrying volume (U.S. GPO, 1998).

This guideline paper stipulates more than 160 interior dimensions for characterizing passenger and luggage compartments and almost 100 exterior dimensions for determining exterior vehicle size. For example, there are no fewer than 63 dimensions to characterize interior vehicle heights (see Figure 2).

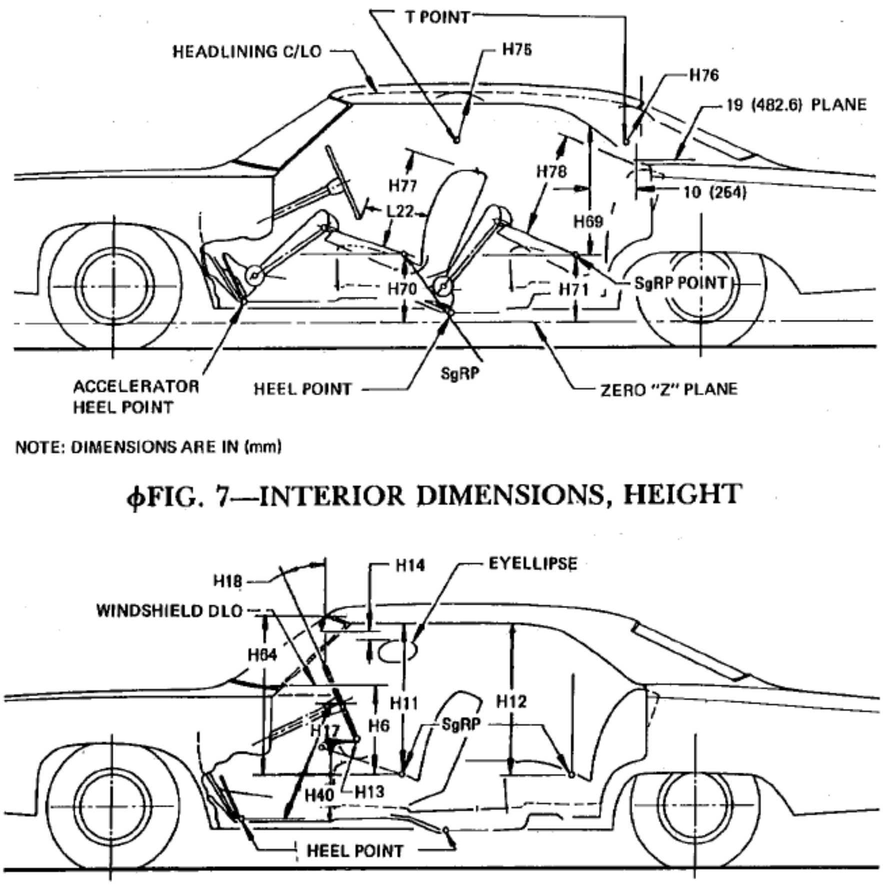


Figure 2: Sample of interior height dimensions according to SAE J1100

The SAE J1100 paper is quite exhaustive, and it is likely that not all measurements would be necessary to categorize vehicle size and class. This process seems cumbersome, and it is not clear more than 30 years after they were devised that the definitions would be appropriate for today's vehicle and non-U.S. body shapes.

To measure usable luggage capacity, the paper defines dimensions for a standard luggage set that has to be placed inside the luggage compartment. This luggage set consists of four women's suitcases, two men's suitcases and dimensions of a golf bag. Some motoring media have adopted a similar approach for comparing cargo capacity.

Specialized media approach for classifying vehicle sizes

To compare vehicle sizes, dimensions are often not enough, with inner and outer shapes being curvy and not continuous. The motoring press has a long history of vehicle testing for each new model placed on the market. Loading a standard set of luggage in test vehicles allows a visual comparison of cargo capacity (see Figure 3).

Figure 3: Online media using standard set of luggage to compare luggage capacity (Km77.com, 2017)

Journalists sometimes use a similar approach for passenger compartment, posing seated to show the interior space (see Figure 4). This does not provide a robust way to classify vehicle sizes. To be fully consistent, the same set of luggage and, more challenging, the same person would have to be used in all the vehicles tested. As soon as the reference changes, all the comparative effort would lose credibility and consistency.

Figure 4: Journalist using himself to highlight and compare rear passenger compartment size (L'argus, 2017)

The use of SAE J1100 in fuel-economy related legislation

The U.S. DOE uses some dimensions defined in the SAE J1100 paper to group vehicles by classes based on interior passenger and cargo volumes for cars (U.S. DOE, 2017). Gross vehicle weight is used as the metric defining vehicle size bin for pick-ups and vans.

Though the *fueleconomy.gov* website outlines vehicle classes with a clear definition and metric as used in the official EPA Fuel Economy Guide, the size classes are not consistent with such definitions when browsing the "find a car" section of the website (see Table 1). The Oak Ridge National Laboratory, which maintains the website, chose a different approach for the search engine to make it easier for the consumer to identify the vehicle desired (ORNL, 2017).

Official EPA classification using interior space can sometimes be misleading and not representative of what people would expect. For example, a Honda Civic hatchback is classified as a large car and a Bentley Continental GT, as a sub-compact.[1] The *fueleconomy.gov* search engine mimics the Consumer Reports approach of vehicle segmentation and adds a price tag to separate premium autos from mainstream sedans.

Official EPA Fuel Economy Guide size categories based on interior and cargo size	Market classes as used in fueleconomy.gov search engine
Two-Seaters	
Sedans	**Sedans**
	Small Cars
	Family Sedans
Minicompact	Upscale Sedans
Subcompact	Luxury Sedans
Compact	Large Sedans
Mid-Size	Hatchbacks
Large	Coupes
	Convertibles
	Sports/Sporty Cars
Station Wagons	Station Wagons
Small	
Mid-Size	
Large	
Pickup Trucks	Pickup Trucks
Small	
Standard	
Vans	Vans
Passenger	
Cargo	
Minivans	Minivans
SUVs	SUVs
Small	
Standard	

Table 1: Size class quantified definition versus market class in search engine of fueleconomy.gov

Industry approach for classifying vehicle sizes

The automotive industry, car manufacturers, suppliers, and most related stakeholders around the world use segmentation to group vehicle by size class. A car segment is a group of car models of similar size that the potential customer is likely to compare once he or she chose the type of vehicle he or she is willing to buy.

This approach does not rely on any specific measurement of a vehicle's size. The criteria for attributing a vehicle to a given segment are not clearly defined and mainly reflect the direct market competitors of a specific model. The number and naming of the segments vary and depend on the use of the segmentation (see Table 2), and on the market share of a specific segment. For example, the SUV segment can be split into four subcategories in the United States, but until recently it was just one category in Europe. Once a given segment gets too big, it is usually split into more refined categories. For example the Japanese Kei cars (microcars with engines smaller than 660 cc) represent about 25% of the Japanese market, while the category is virtually non-existent in other regions.

Harmonizing definitions across different markets can also be challenging. For example, the Toyota RAV4 is considered a compact SUV in the United States and a medium SUV in Europe. So market structure also influences segment definition.

Typical vehicle	IEA segment	Simplified segmentation
Smart fortwo Fiat 500	A	Small
Opel Corsa Renault Clio	B	
Toyota Corolla VW Golf	C	Medium
Honda Accord Mercedes C Class	D	Large
BMW 7 series Buick Lacrosse	E	
Porsche Carrera Bentley Arnage	F	
Wuling Zhiguang Maruti / Suzuki Wagon R	Micro truck	Big
Renault Kangoo Renault Modus	Compact truck	
Toyota RAV4 Suzuki Gran Vitara	Medium Truck	
Audi Q7 Chevrolet Silverado	Large Truck	

Table 2: Example of market segmentation used for GFEI analysis (IEA, 2011 and IEA, 2017)

Even though market segmentation as a proxy for vehicle size seems to be the most widely used method for classification, it is subjective and limited. This is especially true with the multiplication of segments and with some manufacturers marketing vehicles as cross-overs straddling two segments. The first generation Nissan Qashqai, for example, was designed to slot in between a sedan and an SUV. Classifying such models poses a challenge as there is no quantifiable way to separate one segment from the other. Some OEMs even switch segments for similar models. For example, the first generation of the Peugeot 2008 was marketed as a cross-over, and the only slightly modified second generation is now marketed as an SUV (AutoNews, 2016).

Rental agencies' classification system

The Association of Car Rental Industry Systems Standards (ACRISS) provides a standard coding system to provide harmonized information about the type of vehicle rented, regardless of the brand and model. The ACRISS code is a sequence of 4 digits that characterize a rental vehicle (see Table 3). The number of variants has recently been extended to better define vehicle type, class, transmission, and fuel.

CATEGORY		TYPE		TRANSMISSION/DRIVE		FUEL/AIR COND.	
M	Mini	B	2-3 Door	M	Manual Unspecified Drive	R	Unspecified Fuel/Power With Air
N	Mini Elite	C	2/4 Door	N	Manual 4WD	N	Unspecified Fuel/Power Without Air
E	Economy	D	4-5 Door	C	Manual AWD	D	Diesel Air
H	Economy Elite	W	Wagon/Estate	A	Auto Unspecified Drive	Q	Diesel No Air
C	Compact	V	Passenger Van	B	Auto 4WD	H	Hybrid Air
D	Compact Elite	L	Limousine	D	Auto AWD	I	Hybrid No Air
I	Intermediate	S	Sport			E	Electric Air
J	Intermediate Elite	T	Convertible			C	Electric No Air
S	Standard	F	SUV			L	LPG/Compressed Gas Air
R	Standard Elite	J	Open Air All Terrain			S	LPG/Compressed Gas No Air
F	Full size	X	Special			A	Hydrogen Air
G	Full-size Elite	P	Pick up Regular Car			B	Hydrogen No Air
P	Premium	Q	Pick up Extended Car			M	Multi Fuel/Power Air
U	Premium Elite	Z	Special Offer Car			F	Multi fuel/power No Air
L	Luxury	E	Coupe			V	Petrol Air
W	Luxury Elite	M	Monospace			Z	Petrol No Air
O	Oversize	R	Recreational Vehicle			U	Ethanol Air
X	Special	H	Motor Home			X	Ethanol No Air
		Y	2 Wheel Vehicle				
		N	Roadster				
		G	Crossover				
		K	Commercial Van/Truck				

Table 3: ACRISS car codes definitions

Note: For example, an ACRISS code CDMV would be a compact 4-5 door gasoline car with manual transmission and air-conditioning.

Strengths and weaknesses of approaches for classifying vehicle size

Characterizing quantitatively the size of vehicles is doable, with some standards and guidelines published for measuring vehicle size in every detail. Choosing the right metric for classifying vehicles by size is much more challenging, as focusing on interior or exterior size would lead to completely different outcomes, as shown by the approaches used in the United States by the EPA and fueleconomy.gov. The segmentation approach seems to be the most consistent, even though it uses a more qualitative approach with no quantified threshold between segments (see Table 4). The multiplication of vehicle models that are designed and marketed between segments can also lead to inconsistent classification.

Vehicle size measurement approach	**Description**	**Pros**	**Cons**
SAE J1100 guidelines	Measuring all vehicle dimensions	- Accurate - Robust - Extensive and comprehensive	- Many dimensions to be measured - Which ones to choose to characterize vehicle size? - Best metric varies by vehicle
Specialized media	Standard luggage and passenger	- Comparability - Good for photo/media support	- Choice of luggage and passenger might impact the size appreciation - Same set of luggage and passenger must always be available
Industry Segmentation	Based on model portfolio and competitors	- Easily understandable - Matches customer expectations	- Subjective approach with no common metric to split segments - Model multiplications making thresholds unclear
Rental agencies	4 digits to characterize vehicle types	- Common approach and definition for most rental companies - A single institution decides how to classify vehicles	- Parameters specific for the rental companies, not ideal to be used for other purposes - Updating codes triggers break in series

Table 4: Pros and cons of each vehicle size measurement and categorization approach

Interior versus exterior sizes: Some extreme examples

If all body shapes were similar, then the bigger the exterior size, the bigger the interior size would be. This is not the case as auto makers sometimes put vehicles on the market that defy such a principle.

In a sample of more than 250 U.S. models, a proxy for exterior volume (length*width*height) was charted against a proxy for interior size (front and rear seat room). For the vehicles analyzed, there was no robust trend correlating bigger exterior size with greater interior size (see Figure 5).

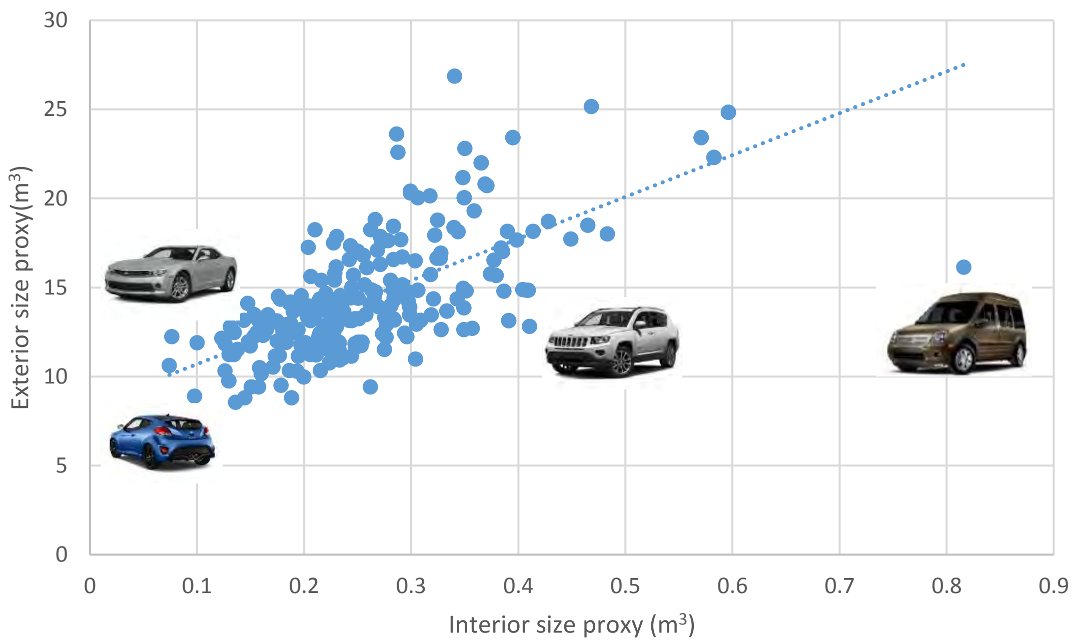


Figure 5: Exterior versus interior size comparisons for U.S. models (Consumer Reports, 2017)

The analysis turned up outliers that can be considered extreme cases. For big interior volumes with relatively modest exterior sizes, the Ford Transit Connect (derived from a light commercial vehicle) has by far the highest ratio, followed by the Jeep Renegade. On the other side of the scale, the Chevrolet Camaro and the Hyundai Veloster have the smallest interior size relative to exterior size.

Vehicle size and fuel economy policies

Fuel economy policies are classified in three main categories (IEA, 2012):

- Fiscal measures: To overcome higher upfront costs of more efficient technologies and to provide incentives to purchase higher performing vehicles.
- Information and labeling: To overcome the information gap and raise awareness about fuel economy.
- Standards: To overcome market failure where consumers do not value fuel economy.

Such policies are aimed at encouraging drivers to buy and drive more fuel-efficient vehicles to decrease reliance on fossil fuels and reduce greenhouse gas emissions.

Existing fiscal policies including fuel taxes, registration, and ownership taxes are not based on vehicle size. The main metrics for setting taxation are vehicle price, CO_2 emissions, engine capacity, or power. In Europe, only Malta uses vehicle length as a criteria for a vehicle purchase tax (ACEA, 2016).

Most fuel-economy labels use either absolute fuel economy or CO_2 emissions to classify vehicle energy efficiency (APEC/ICCT, 2016). Some countries, such as Switzerland and Germany, use weight to create vehicle categories. Spain uses footprint to make a relative vehicle comparison for the purpose of fuel-economy labeling (Ricardo, 2016).

All fuel-economy standards use a corporate average approach, combined with the use of a parameter to take different market strategies among car manufacturers into account. Indeed, some brands specialize in certain segments, for example selling only large, premium cars or specializing in small vehicles. Average vehicle size differences among manufacturers has been taken into account under fuel economy standards adopted globally.

Vehicle weight or footprint is used as a proxy to characterize vehicle size in fuel-economy standards adopted around the world (TransportPolicy.net, 2017).

Why are weight and footprint the main metrics used as a proxy for vehicle size?

When developing fuel-economy standards, lawmakers have considered several metrics to represent vehicle size. They include interior volume, weight, footprint, shadow (length*width of the vehicle), and volume (length*width*height of the vehicle). Qualitative assessments of potential parameters have already been carried out, highlighting the pros and cons of each option (see Table 5).

		Diversity competitively neutral, vertical spread	**Robustness** avoids perverse effects (gaming)	**Flexibility** no discrimination of technologies	**Representativeness** proxy for utility, socially equitable	**Comprehensiveness** avoid adverse effects, safety	**Practicability** data, continuous, definition, complexity
	Flat standard	-	++	++	--	o	++
WEIGHT	**Curb weight**	+	-	-	-	o	+
	Payload	+	--	-	-	o	+
	Gross weight	+	--	-	--	o	+
SIZE	**Pan area**	++	-	+	+	+	o
	Footprint	++	+	+	o	++	+
	Volume	++	-	o	o	-	+
PERFORMANCE	**Engine power**	+	--	-	-	o	+
	Displacement	+	--	-	-	o	-
	Top speed	+	--	-	-	o	-
CAPACITY	**Seats**	++	-	+	++	o	-
	Boot volume	++	-	+	++	o	-
	Price	++	-	++	--	o	-

Index parameter: Meets criterion substantially (++) / meets criterion (+) / does not affect criterion (o) / does not meet criterion in most cases (-) / does not meet criterion at all (--)

Table 5: Overview of potential index parameters including qualitative assessment (ICCT, 2011)

Two-thirds of the nine markets that have adopted fuel-economy standards use weight as a proxy for vehicle size. The three that don't – the NAFTA group of the United States, Canada, and Mexico – use footprint instead. Although weight doesn't rank as the most robust parameter, one reason it is widely used might be that data is usually easily available and practical to collect and manipulate.

Are vehicle size, vehicle footprint, and weight a close match?

Interior and exterior sizes, though complicated to calculate accurately, are available for a large sample of U.S. models (Consumer Reports, 2017). To assess whether weight and footprint are representative of vehicle size, interior and exterior sizes have been plotted against weight and footprint. Interior size, calculated as the sum of front and rear seat room, cannot easily be linked to either weight, footprint, or segmentation (see Figure 6). For a similar interior size, many different vehicles are available covering a broad spectrum of weight, footprint, and segment. So interior size has no strong link with other proxies for vehicle size.

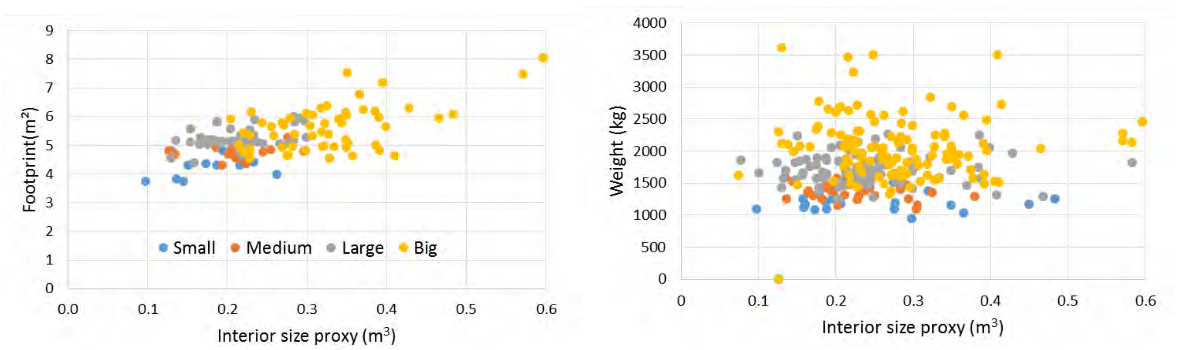


Figure 6: interior size versus footprint and weight, by segment

Exterior size, calculated as the product of a vehicle's length, width, and height, is much more closely correlated with weight and footprint, and the higher average height of big vehicles (SUVs, pick-ups and vans) show clearly (Figure 7).

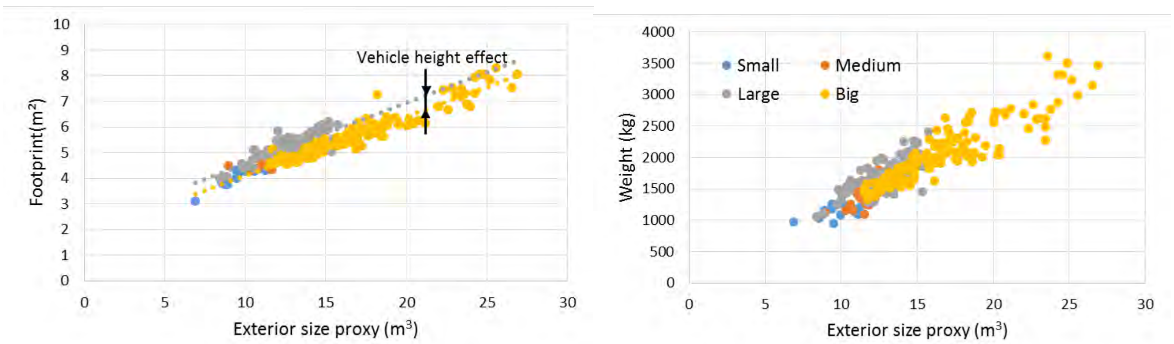


Figure 7: Exterior size versus footprint and weight, by segment

Note: Big vehicles include SUVs, MPVs and pick-ups

No evidence has been found in the public domain on whether consumers put more value in purchasing decisions on interior or exterior size. But the data show that interior space is not a good proxy for vehicle size as it does not correlate with other proxies such as exterior size, weight, or footprint.

For policy purposes, weight and footprint do show some linearity (see Figure 8), as the larger the footprint, the heavier the vehicle. This has been true over a period of years for models sold globally, based on data from the GFEI database. Global average weight and footprint increased significantly from 2010 to 2015, with smaller and lighter cars in emerging markets partially offsetting vehicle size growth in mature markets.

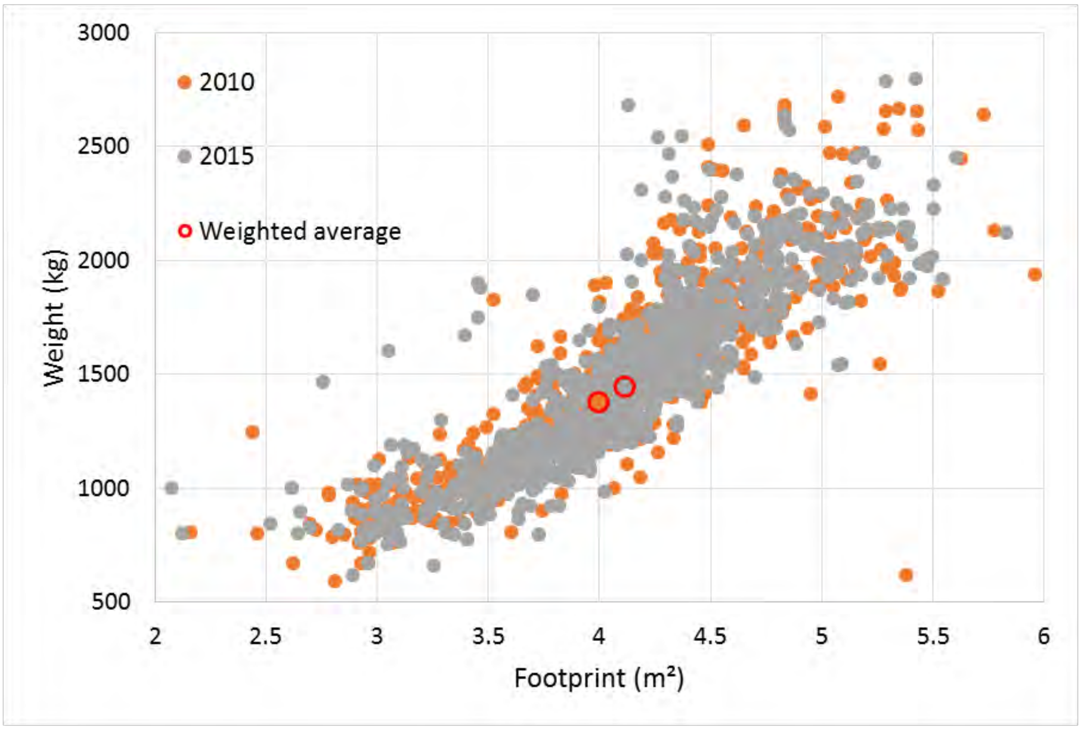


Figure 8: Footprint versus weight for all models sold globally in the last decade

Note: Only models selling more than 1,000 units a year have been included.

Even though the linearity is acceptable (R^2 = 0.75), there is ample deviation around the average values, showing the large discrepancy of weight for a given footprint, or of footprint for a given weight. The evolution of each parameter in a top-down, holistic approach is worth looking at to analyze how each has evolved over time.

Macro Analysis: Macroscopic trends in weight and footprint

Methodological approaches

The GFEI database uniquely compiles sales, type-approval fuel economy, and most vehicle attributes model by model on more than 80% of light-duty vehicles sold worldwide (GFEI, 2017). It is based on the authoritative IHS Markit sales and registration database (IHS Markit, 2016), upgraded by GFEI members to include weight, footprint, and fuel economy in countries where the information is missing. It covers new vehicle registrations and sales for 2005, 2008, and 2010 to 2015. For 2005 and 2008, there is only partial data for weight and footprint. Most of the analysis is based on the 2010 to 2015 period.

To analyze weight and footprint evolution globally, several additional features have been added to the GFEI database, including:

- OEM origin: OEMs have been classified by region of origin. For example, all Toyota vehicles are classified as originating in Japan, VW from Europe, and GM from the United States. For Chinese joint ventures, the country of origin of the foreign partner has been assumed. PSA-Dongfeng, for example, is classified as originating in Europe, as most models sold by the venture are usually derived from European models. Purely Chinese OEMs, such as Great Wall or BYD, are counted as Chinese.

- OEM type: OEMs have also been classified into three categories: low-cost, mainstream, and premium. This differentiation is based on the average vehicle price for each OEM taken from the latest price analysis (GFEI, 2017). The threshold between low-cost and mainstream manufacturers was set at U.S. $17,000, ensuring that certain OEMs such as Dacia in Europe are included in the low-cost category. The dividing line between mainstream and premium OEMs was set at $50,000, placing producers such as Volvo in the premium range. With those thresholds, mainstream OEMs represent 80% of annual global registrations. Most Chinese OEMs are in the low-cost category. Annex I shows average vehicle prices by OEM.

All the analysis below is sales-weighted, representing a macroscopic market approach. A more microscopic analysis, making comparisons at the vehicle level, appears in the following section. The macro analysis includes all light-duty vehicles, both for passenger and commercial applications, especially because of the high share of LCVs in the United States and the high use of LCVs, such as pick-ups, for passenger transport.

Weight and footprint evolution

By region

Average light-duty vehicle weight across different regions globally has not changed significantly over the past decade. Even though partial data is available in this time frame, this is due to a decrease in size and weight from 2005 to 2010. From 2010 to 2015, when the weight and footprint data were collected in a more systematic and robust way, weight increased by 5%. The trend was similar for average global footprint, with a 3% increase over the five years. In regions where heavier vehicles were sold, in North America, autos are slowly becoming lighter and smaller, and in regions where lighter vehicles were sold, such as India and Latin America, autos are getting heavier and bigger. So it over time vehicle weight and footprint are converging and slowly expanding (see Figure 9).

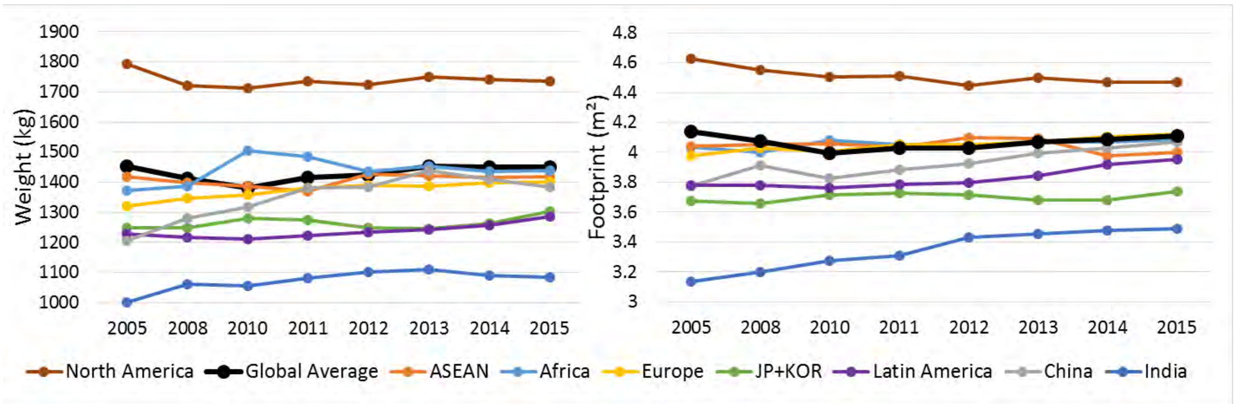


Figure 9: Weight and footprint evolution by region of registration, 2005 to 2015

China recorded a sharp increase in average weight and footprint over the decade and by 2015 matched Europe on those metrics. This reflects a rising share of sales of vehicles from joint venture manufacturers mostly from Europe or the United States, which have higher average weights and footprints (see Figure 14).

By Origin of auto manufacturers

Chinese manufacturers increased the average weight of their vehicles by almost 300 kg (+30% over the 10-year period) and footprint by 20% over the 10 years (see Figure 10). Vehicles from Indian

OEMs remain the lightest and smallest. Despite the local market for small vehicles in Japan, Japanese OEMs are selling cars around the globe that have a weight similar to that of the average vehicle from European OEMs. Only Korean OEMs continuously decreased the average weight of their vehicles by about 150 kg, with a stable footprint.

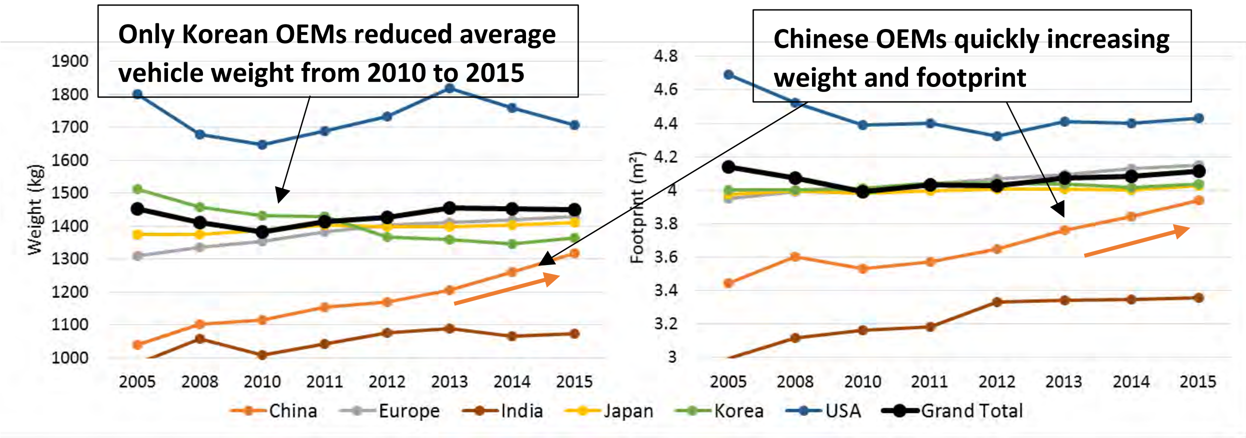


Figure 10: Average vehicle weight and footprint by OEM region of origin

By auto manufacturer type

Low-cost vehicles expanded significantly in weight and footprint over the decade, gaining more than 200 kg, driven by the Chinese OEMs (see Figure 11). There is a significant weight and footprint gap between the average premium car and the average low-cost vehicle, amounting to more than 500 kg and almost 1m^2. The weight difference between mainstream and premium vehicles is much larger than the footprint difference. Small luxury cars marketed by premium brands such as the Audi A1 and the Aston Martin Cygnet did not yet represent a significant part of premium OEMs' market share.

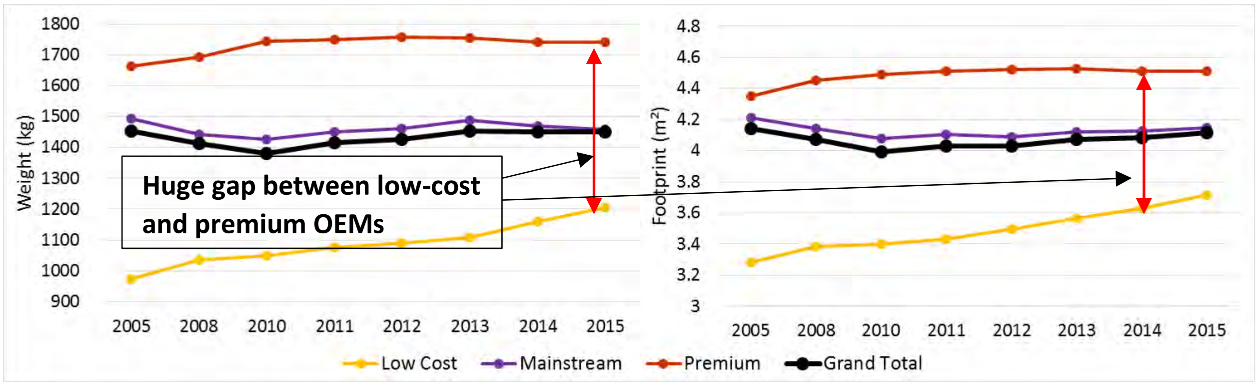


Figure 11: Weight and footprint evolution by OEM type

By fuel type

Analyzing vehicle attributes and specifications, the average diesel vehicle was around 200 kg heavier than its gasoline equivalent in 2015 (see Figure 12). Electric vehicles, including battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) quickly gained weight as footprints appeared to stabilize.

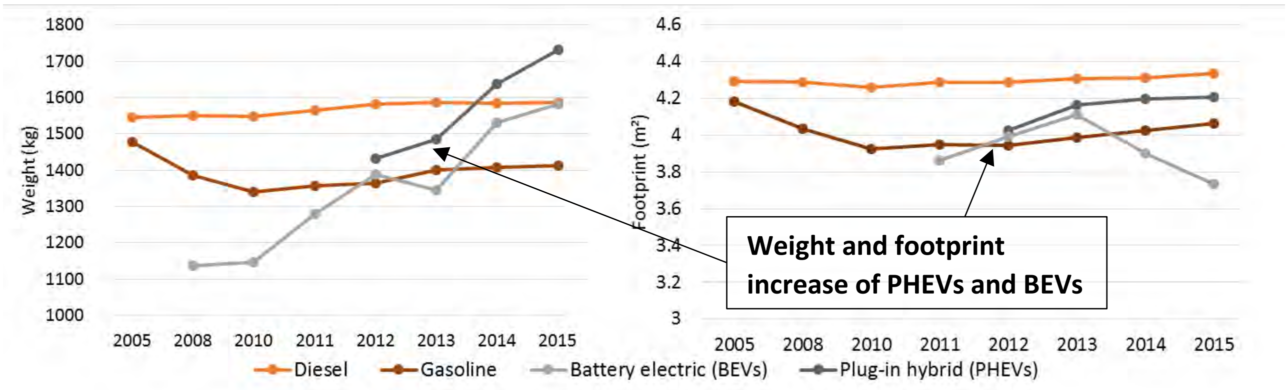


Figure 12: Weight and footprint evolution by fuel type

By power

Classifying vehicles by power bins shows that the average weight of identically powered vehicles has been slowly decreasing, compensated by a gradual average power increase so that the global average weight slowly increases (see Figure 13). Footprint by power bins was remarkably stable except in the top power category, where the average footprint decreased.

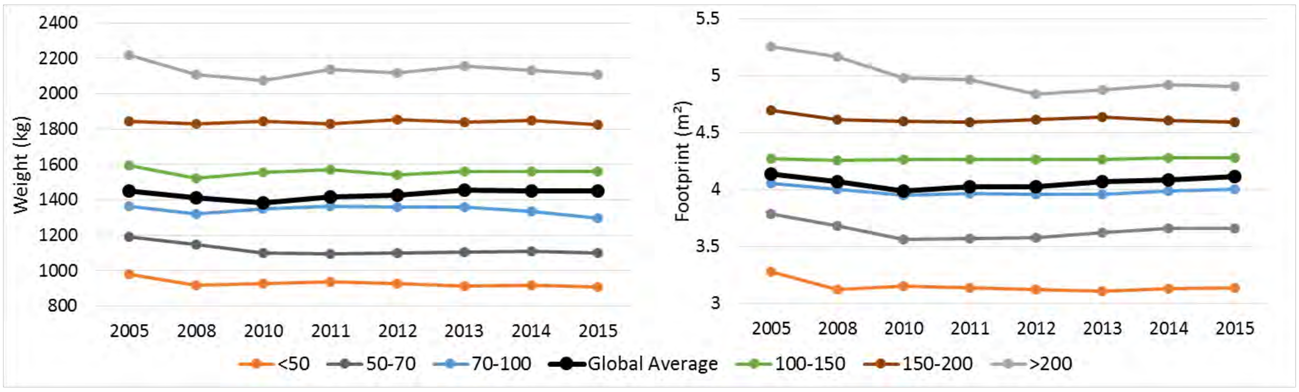
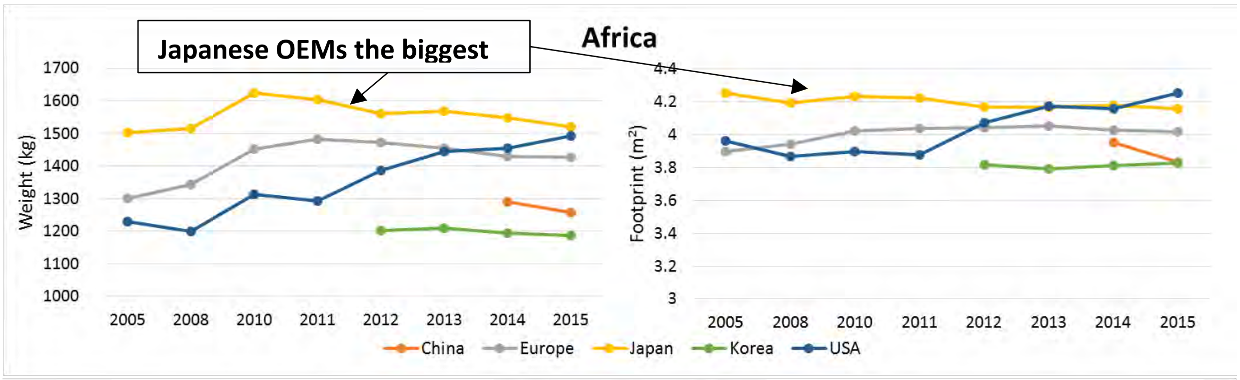


Figure 13: Average weight and footprint by power bin (kW)

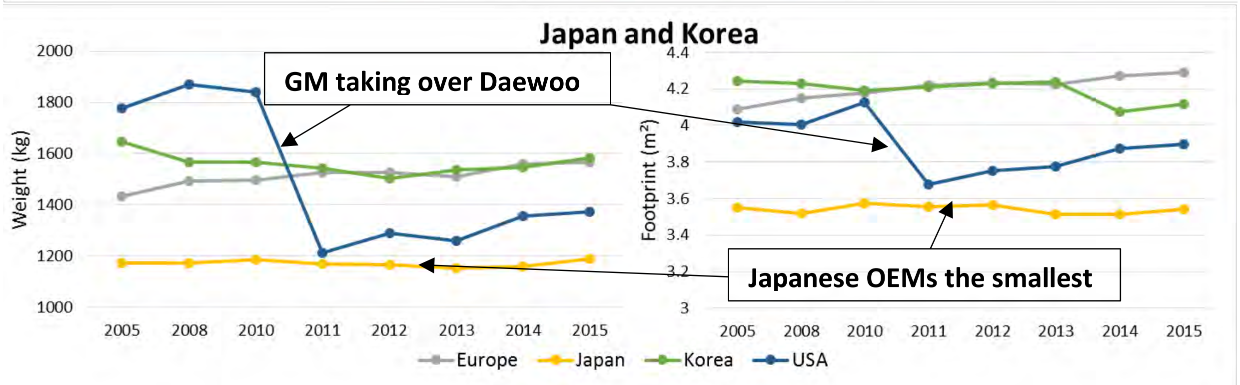
How OEMs alter fleets depending on region

The enhanced database shows how OEMs adapt their model ranges by region of sale. The major exporting OEMs are based in Japan, Korea, Europe, and the United States. India and China manufacturers are mainly local-market players and did not export a significant share of production during the study period.

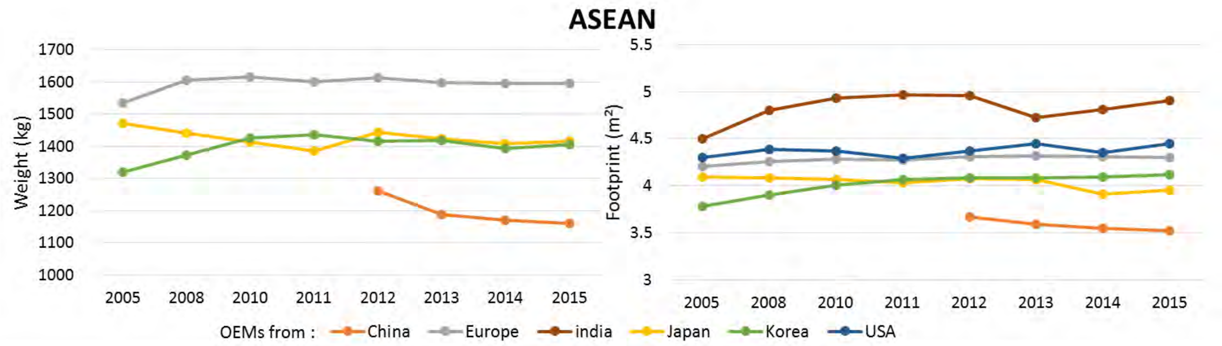
OEMs have different strategies for adapting their vehicles by market. Japanese OEMs have the smallest, lightest vehicles in their home market but sell the largest, heaviest autos in Africa and Latin America. U.S. OEMs are always among the top two groups for largest, heaviest vehicles, regardless of the market – and especially so in North America (see Figure 14).



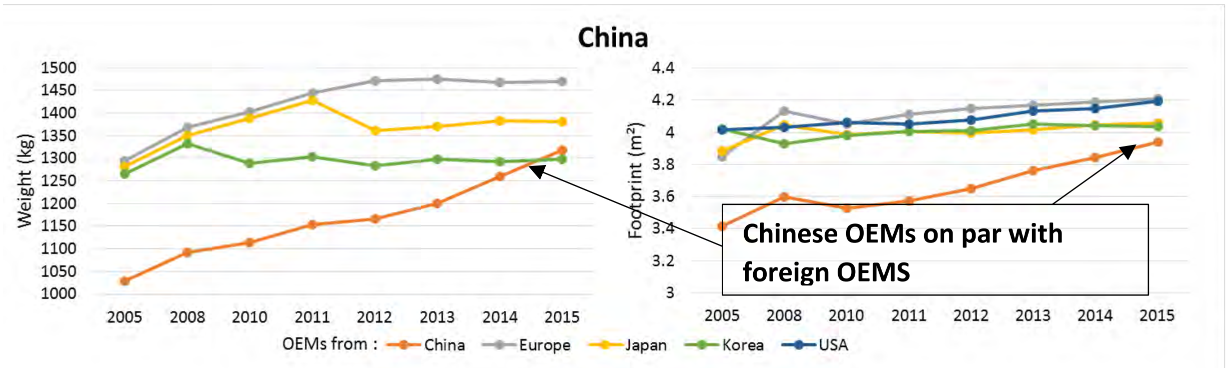
Africa
Japanese OEMs the biggest
Weight (kg)
1700
1600
1500
1400
1300
1200
1100
1000
2005 2008 2010 2011 2012 2013 2014 2015
Footprint (m²)
4.4
4.2
4
3.8
3.6
3.4
3.2
3
2005 2008 2010 2011 2012 2013 2014 2015
China Europe Japan Korea USA



Japan and Korea
GM taking over Daewoo
Japanese OEMs the smallest
Weight (kg)
2000
1800
1600
1400
1200
1000
2005 2008 2010 2011 2012 2013 2014 2015
Footprint (m²)
4.4
4.2
4
3.8
3.6
3.4
3.2
3
2005 2008 2010 2011 2012 2013 2014 2015
Europe Japan Korea USA



ASEAN
Weight (kg)
1700
1600
1500
1400
1300
1200
1100
1000
2005 2008 2010 2011 2012 2013 2014 2015
Footprint (m²)
5.5
5
4.5
4
3.5
3
2005 2008 2010 2011 2012 2013 2014 2015
OEMs from : China Europe india Japan Korea USA



China
Chinese OEMs on par with foreign OEMS
Weight (kg)
1500
1450
1400
1350
1300
1250
1200
1150
1100
1050
1000
2005 2008 2010 2011 2012 2013 2014 2015
Footprint (m²)
4.4
4.2
4
3.8
3.6
3.4
3.2
3
2005 2008 2010 2011 2012 2013 2014 2015
OEMs from : China Europe Japan Korea USA

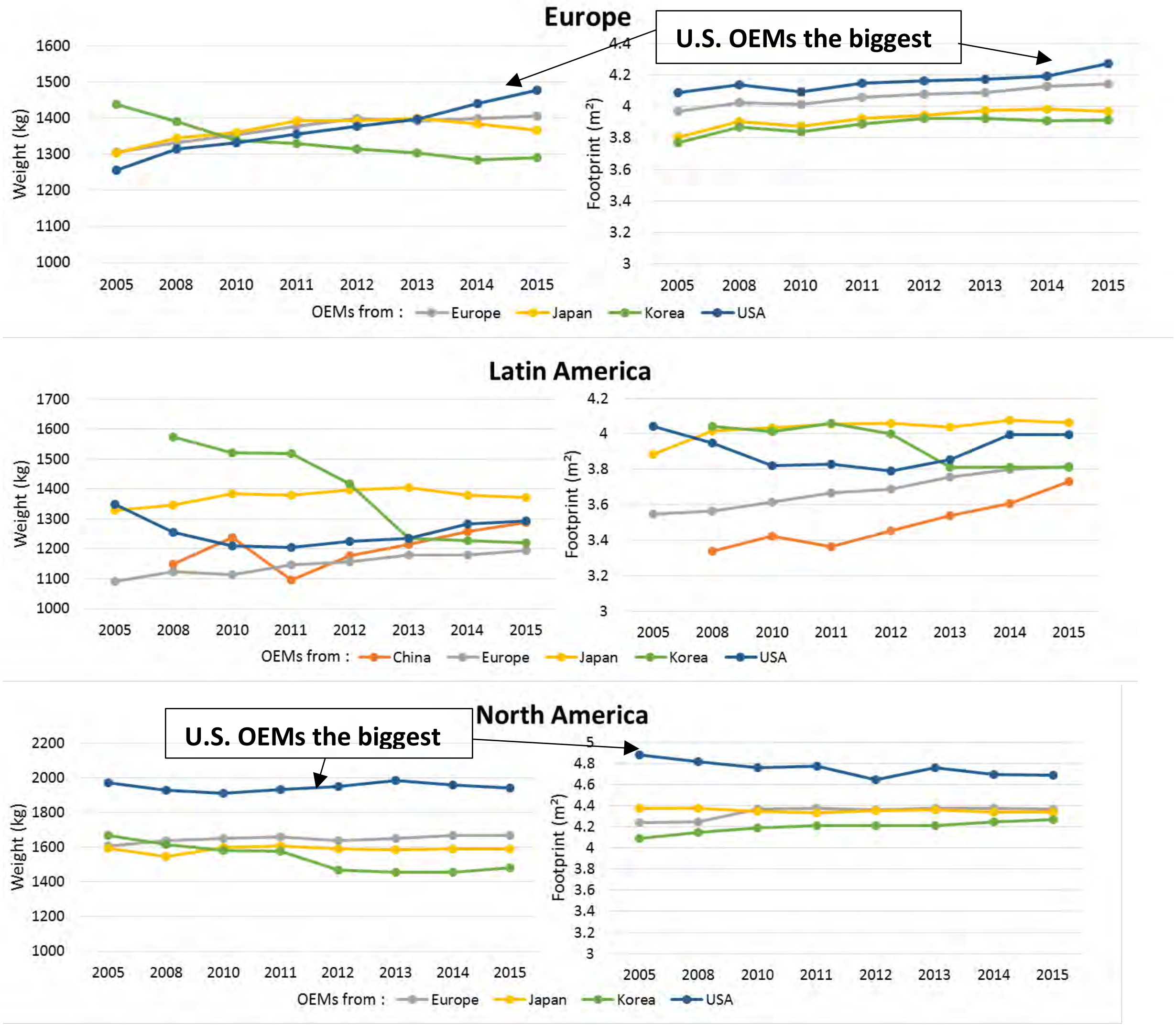


Figure 14: Weight and footprint evolution by region and OEM country of origin

To analyze the evolution of vehicle footprint and weight as compared with powertrain specifications, we developed these indicators:

- kW/t: The ratio of rated engine power to weight. A high power-to-weight ratio enables fast acceleration, usually for sporty vehicles. A low power-to-weight ratio indicates under-powered autos that are not capable of fast acceleration.
- kW/m²: The ratio of rated engine power to footprint. It shows the power impact of high SUV share, as such vehicle have a similar footprint than their traditional equivalent, but much heavier.

Indian OEMs emerged as building vehicles with a much lower power-to-weight ratio than those of any other region (see Figure 15). This coincides with India's exhaust emission certification test having a lower maximum speed than that of any other region (Sharma, 2013). U.S. OEMs sold the highest-powered vehicles, especially with respect to footprint. This reflects the high proportion of U.S. SUVs, which are heavier (thus higher power requirements) than other types of vehicles with similar footprints (see Figure 7).

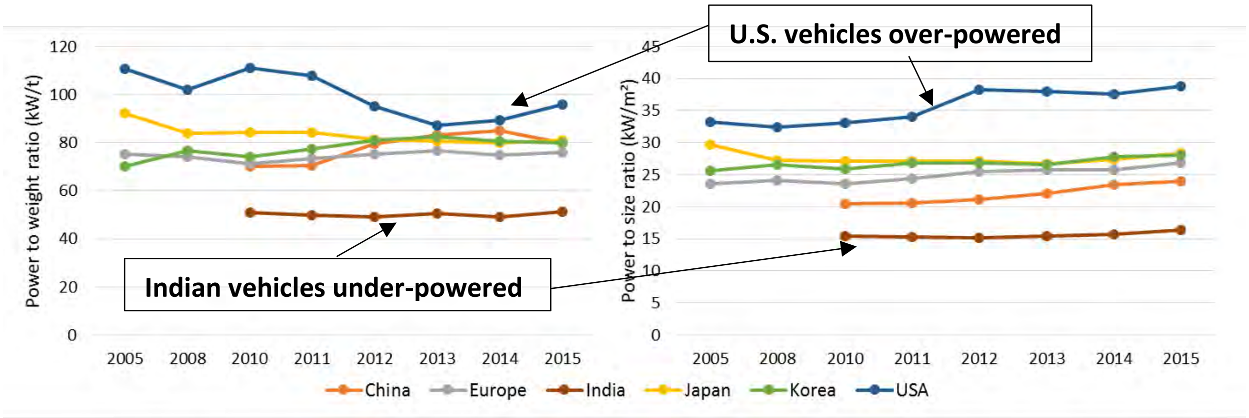


Figure 15: Power-to-weight and power-to-footprint by OEM origin

Engine downsizing: Benefits for vehicle size?
There has been a strong trend toward reducing engine size in recent years with the implementation of fuel-efficiency technologies such as turbochargers and high-pressure fuel injection systems. Even though most OEMs in Europe (Frost, 2010), Japan, and the United States have downsized engine line-ups, sales-weighted average engine size has stagnated globally since 2010, especially for the OEMs that represent more than 80% of global sales (see Figure 16).
This is because:

- Average vehicle size has increased, requiring bigger and more powerful engines.
- Engine downsizing is coupled with increased power density, making engines more powerful.

Engine downsizing has really been effective for premium cars and large engines, with average engine size of premium cars dropping by almost 500cc from 2005 to 2015 (see Figure 16). On the other hand, low-cost cars have increased in average engine size, along with the growth of vehicles, as technologies allowing for engine downsizing have usually not been implemented for such vehicles.

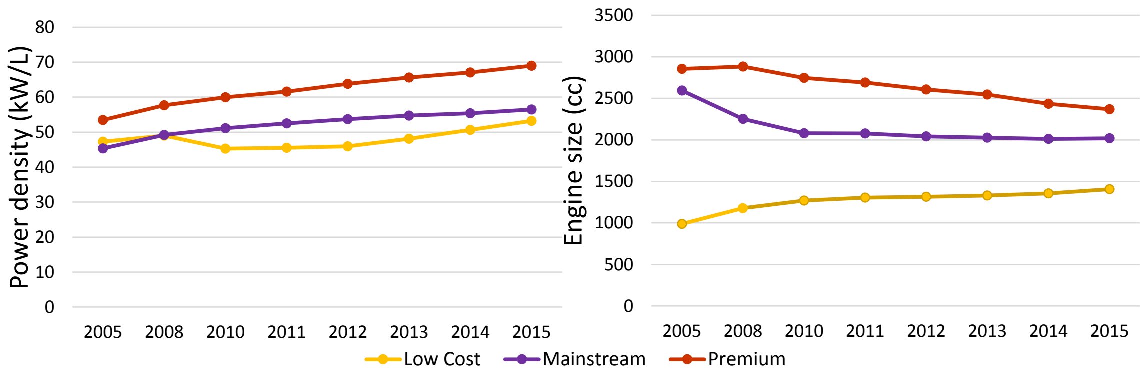


Figure 16: Average power density and engine size, by OEM type

So globally, engine downsizing had very little or no impact on vehicle size, and recent news suggests that the industry is likely to stop engine downsizing in favor or a more resilient “right-sizing” concept (Honeywell, 2015) for turbocharged engines.

Tracking sales-weighted averages over time shows how the composition of the global vehicle market changes slowly, reflecting strong market inertia. Even the fastest-growing emerging markets don't help move the needle because these markets usually rely on old or existing vehicle platforms from mature markets. One notable, quickly unfolding evolution is the global spread of SUVs, which were limited initially to the U.S. market. The market share of SUVs more than doubled over the 2005-2015 period from 12% to more than 25%. Hatchbacks and van/multi-purpose vehicles (MPVs) lost market share (see Figure 17).

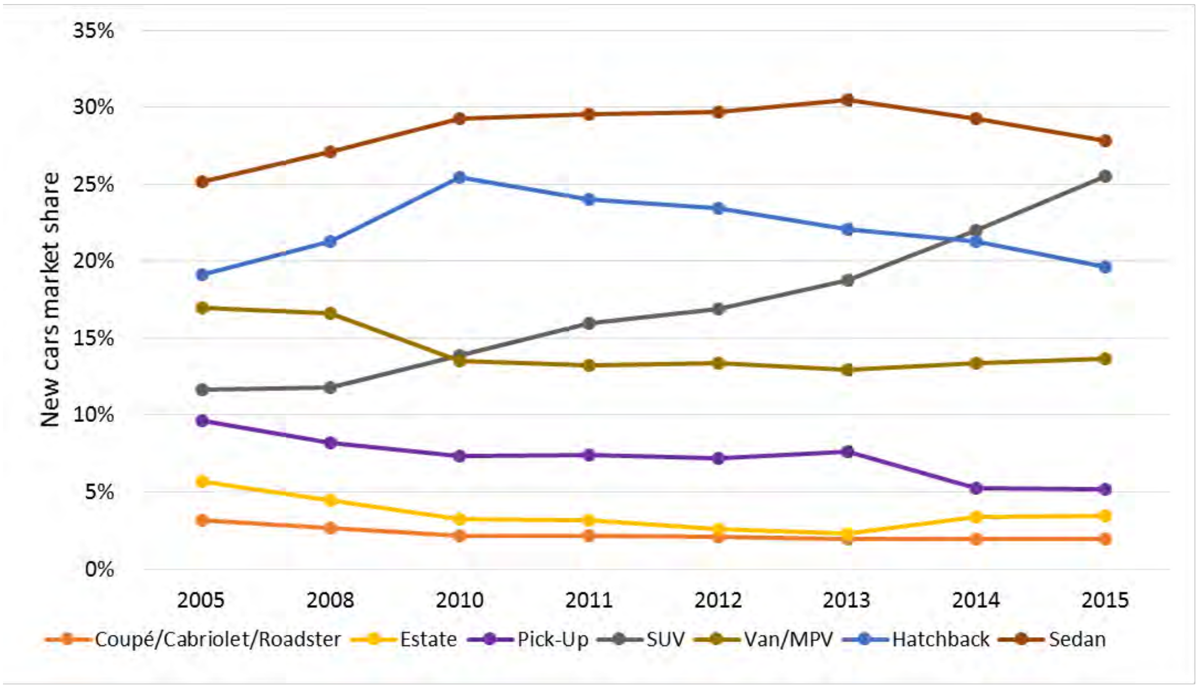


Figure 17: Global market share by body style, 2005 to 2015

Micro analysis: Top sellers' weight and footprint evolution

Some manufacturers retain the same model names over multiple generations, making evolution of weight and footprint easy to track and compare. For this analysis, we selected vehicles based on availability in several regions and on cumulative global sales over generations. In the GFEI database, the Ford Focus topped global sales from 2005 to 2015 (see Table 6). The analysis follows not only vehicle footprint and weight over time but also body variation, showing the impact of body design on vehicle footprint and weight. For example, BMW in the early 2000s added the X-line SUV design based on the same platform as a sedan.

Vehicle selection and market representation

Some OEMs produce similar vehicles that could in theory be compared over time but change the name for each new vehicle generation. For example, Peugeot uses a number that increases for each vehicle generation, such as the Peugeot 205, 206, 207, and the current 208. In some cases, we have selected vehicles that have changed names over their lifetime, but tried to choose models that have long-lasting names.

Other OEMs use the same names for completely different vehicles. Toyota, for example, has long applied the Corolla brand to separate designs marketed in the United States, European, and Japan.

Even though designs might differ, we have considered the vehicles to be of equivalent size/segment and all models with identical name were added together.

	2005 – 2015 Average annual registrations
Ford Focus	590 000
Toyota Corolla	565 000
Ford Fiesta	536 000
Honda Civic	530 000
Toyota Camry	512 000
Ford F-150	502 000
VW Golf	502 000
Wuling Zhiguang	500 000
Honda CR-V	414 000
VW Polo	375 000

Table 6: Top 10 model registrations in the GFEI database

We selected the models in Table 7 for analysis as a representative sampling covering different OEMs, OEM origins, brand types, and segments. The comparison covers several decades, starting as early as 1958, and includes as many as 11 generations.

Brand	OEM origin	Model name	Model main markets	Model segment	First introduction (year)	Number of vehicle generations
Ford	U.S.	Escort / Focus	Europe/Latin America/U.S.	Medium	1968	9
Volkswagen	Europe	Golf	Europe	Medium	1974	7
Toyota	Japan	Corolla	Japan/ ASEAN/Europe	Medium	1966	11
BMW	Europe	3 Series	Europe/ U.S./China	Medium	1975	6
Chevrolet	U.S.	Impala/Caprice	U.S.	Large	1958	11
Honda	Japan	Civic	Global	Small	1972	10
Renault	Europe	5/Clio	Europe/Latin America	Small	1990	4
Opel	Europe	Corsa	Europe/Latin America	Small	1983	5
Chrysler	U.S.	Voyager / Town and Country	U.S./Europe	Big	1984	6
Toyota	Japan	Prius	U.S./Europe/ Japan	Medium	1997	4

Table 7: Vehicles selected for size and weight comparison over generations

Comparing pick-ups over generations (such as the popular Ford F-150 or Toyota HiLux) would have been interesting given their high sales volumes and growing market shares. But doing so would be complex because these vehicle are usually available is many configurations of wheelbase, transmission type, and other attributives that have a significant impact on footprint and weight. Such vehicles therefore have not been included in the analysis. SUVs are included, when possible, as a variant of the conventional sedan model to highlight the footprint and weight increases for vehicles that are usually aimed at the same customers.

All weight and size evolution charts for each vehicle selected are available in Annex I.

50 years of emblematic models' size and weight evolution

Over 50 years, the analysis by model shows that weight has been the parameter that increased the fastest generation after generation. Only the large Chevrolet Impala/Caprice decreased in weight from the 1960s, especially after the oil crises of the 1970s and the early 2000s. Even though the vehicle sample is not representative of the trends highlighted in the macro analysis, the larger the vehicle, the lower the rate of weight increase over 40 to 50 years on the market (see Figure 18). The Honda Civic is the vehicle that increased the most in weight since its market introduction in 1972, up by more than 90% for the last generation launched in 2017. The Impala held at almost the same weight from first to last generation, with some ups and downs in between.

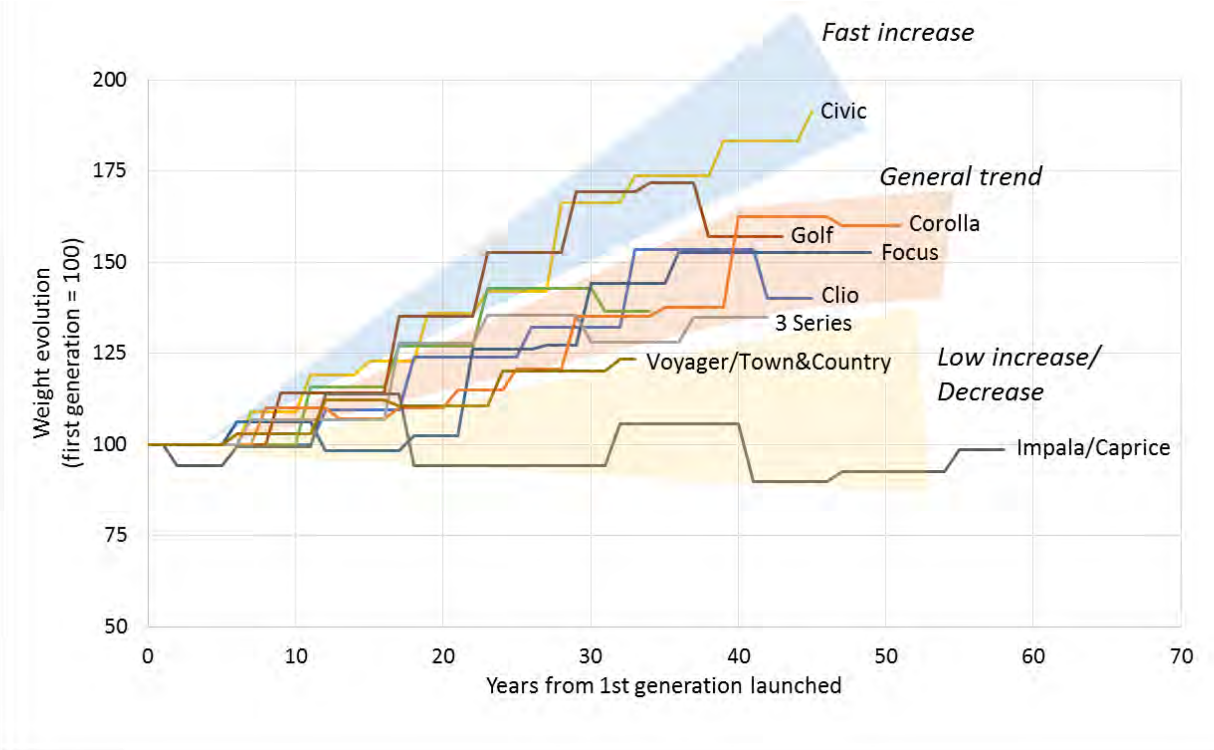


Figure 18: Weight evolution from market introduction of typical long-lasting model names

Most of the models in the analysis increased in weight by more than 50% over about 40 years. For the medium-sized vehicles, the most-represented category, weight seemed to stabilize in the past two decades. Premium vehicles initiated this stabilization earlier than mainstream competitors. Designers of some models, such as the VW Golf, deployed weight-reduction strategies for the last generation that partly compensated for the more significant weight increases of previous generations. Indeed, all mainstream models in the analysis – the Golf, Corolla, and Escort/Focus – have gained weight in similar proportion from first to last vehicle generation (see Figure 19).

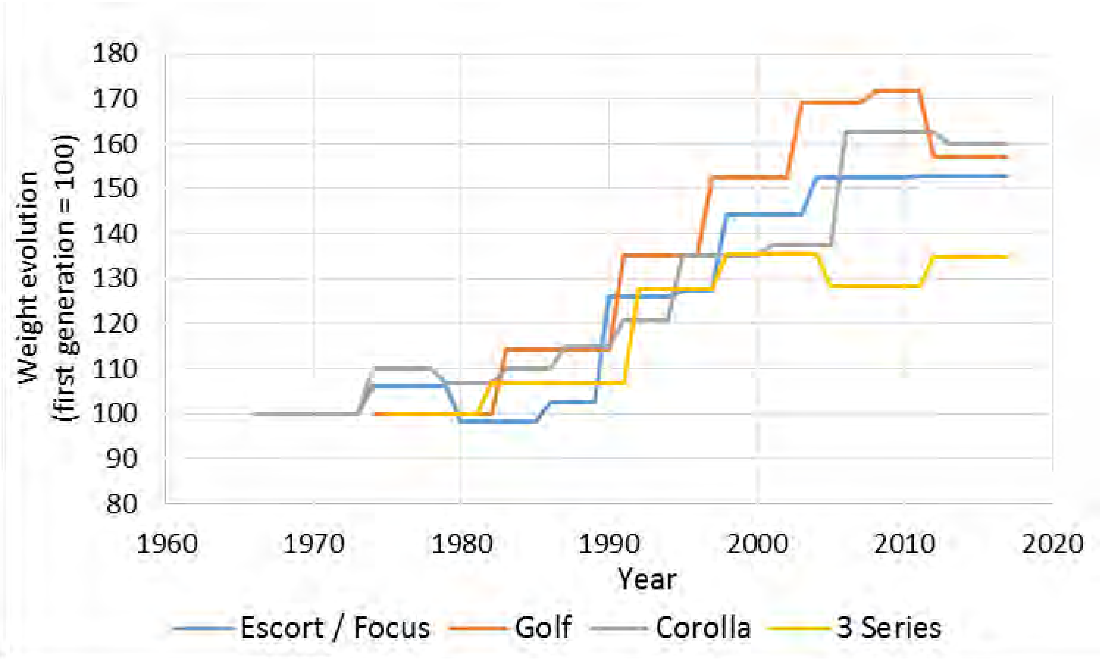


Figure 19: Medium-sized vehicles weigh evolution over generations

Impact of vehicle size increase on parking accidents and crashes

A recent study in the U.K. for insurance companies showed that crashes have dramatically increased in parking lots (Accident Exchange, 2017). The study attributes this to the rising number of SUVs with footprints sometimes larger than the parking spaces they occupy. Most local authorities still follow old parking space guidelines. But rapid market evolution and the growing popularity of large mean autos are outgrowing these spaces (see Figure 20).

Figure 20: Example of Large SUV versus average parking space size in the U.K. (Accident Exchange, 2017)

Such size increases trigger many crashes in parking lots, costing car insurance companies £1.4 billion in the U.K. in 2015. Accidents in parking lots now account for 30% of all collisions, following a 35% jump from 2014.

One of the first popular MPVs, the Chrysler Voyager/Town and Country, had a slightly lower-than-average increase in footprint and weight over its more than 30 years on the market (see Annex I). That ended with a significant footprint increase for the latest Pacifica, which replaced the outdated Voyager (see Figure 21). MPVs have lost market share since the early 2000s and have virtually disappeared in most markets, being replaced by bigger, heavier, though not roomier SUVs. With the revived Renault Espace and new Chrysler Pacifica, some OEMs are trying to make MPVs attractive again.

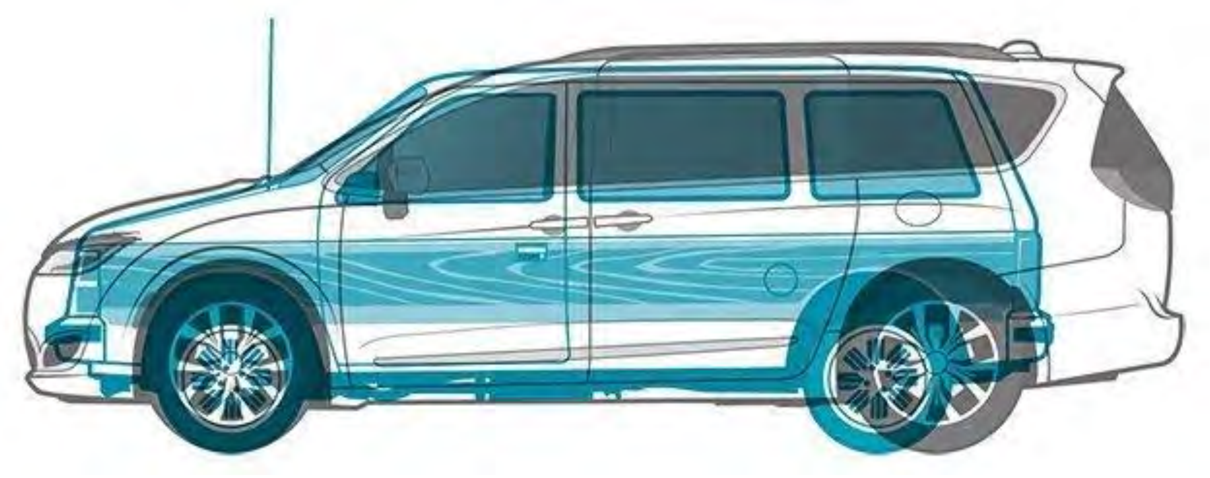


Figure 21: Longer and taller: side view of 1984 Voyager versus 2017 Pacifica (Car and Driver, 2017)

Environmentally friendly vehicles that are sold and marketed as such are no exception to the trend of increased weight and footprint over generations. The most popular of this category, the Toyota Prius, increased in weight by 20% and in footprint by 10% over the first three generations. The fourth and latest generation reversed that trend with a 10% weight reduction and a smaller footprint increase (see Figure 22).

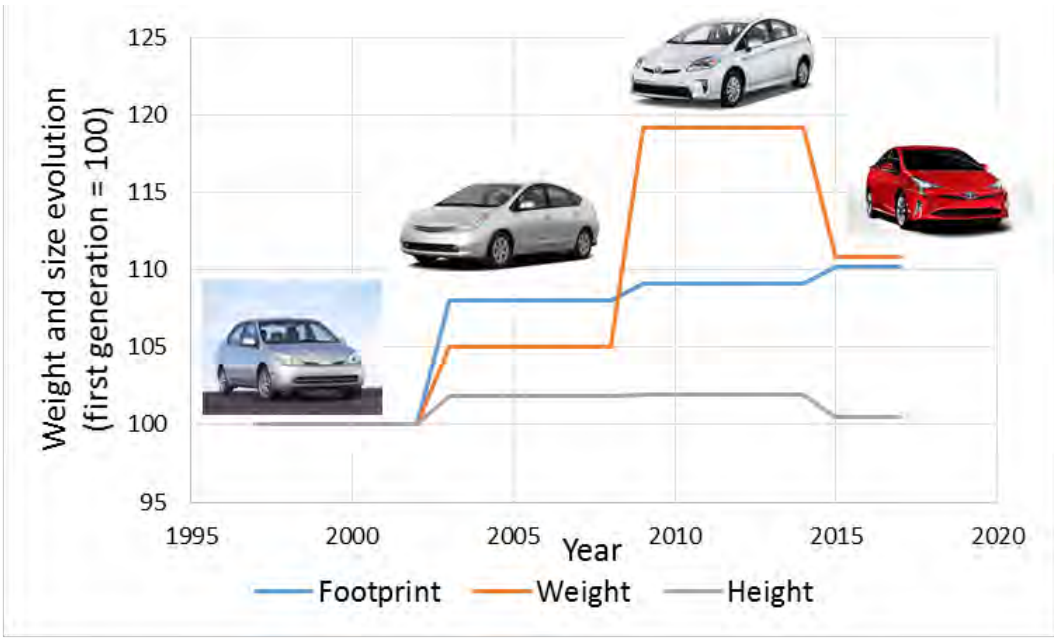


Figure 22: Weight and size evolution of the most popular hybrid vehicle, the Toyota Prius, over four generations

SUVs: Game changers to size and weight evolution

The strong and still-growing demand for SUVs reflects higher seating position and better visibility together with better handling and driving dynamics that are now close to those of sedans (AutomotiveNews.com, 2015). The vast majority of OEMs now offer SUV variants to their traditional sedan/hatchback line-ups. To minimize cost, most OEMs use similar vehicle platforms and diversify body types to cover a wider portfolio of body options. So for one platform, potential buyers who had only a sedan or a hatchback as a choice in the past can now choose among sedan/hatchback, MPV, and SUV options.

Even though the size of the sedan versions has stabilized in the past decade or so, and sometimes light-weighting strategies have been deployed, the MPV and SUV alternatives are much taller, and as a consequence heavier. Footprint is usually similar for all body styles within vehicle families as the vehicle platform is the same. Thus, based only on footprint, the shift to MPVs and SUVs seems almost invisible.

This is a reason why footprint-based emissions policies may be more effective than weight-based policies. Under a weight-based policy, the CAFE limit for CO_2 goes up with the increase in weight from sedan to SUV. Under a footprint-based scheme, the CAFÉ target wouldn't rise, and the heavier SUV would be held to the same emissions standard as the lighter sedan.

One consequence of MPV and SUV variants is that such vehicles undermine efforts to limit or decrease the weight of vehicles in the interest of reducing total emissions. Switching from sedan to MPV and SUV is equivalent to 20 years and three generations of weight evolution (see Figure 23). All weight reduction efforts recently deployed by some OEMs are offset by the increase in SUV market shares and the weight they add.

Fuel economy policies should discourage increased market share for SUVs. Today's weight-based standards do not accomplish that.

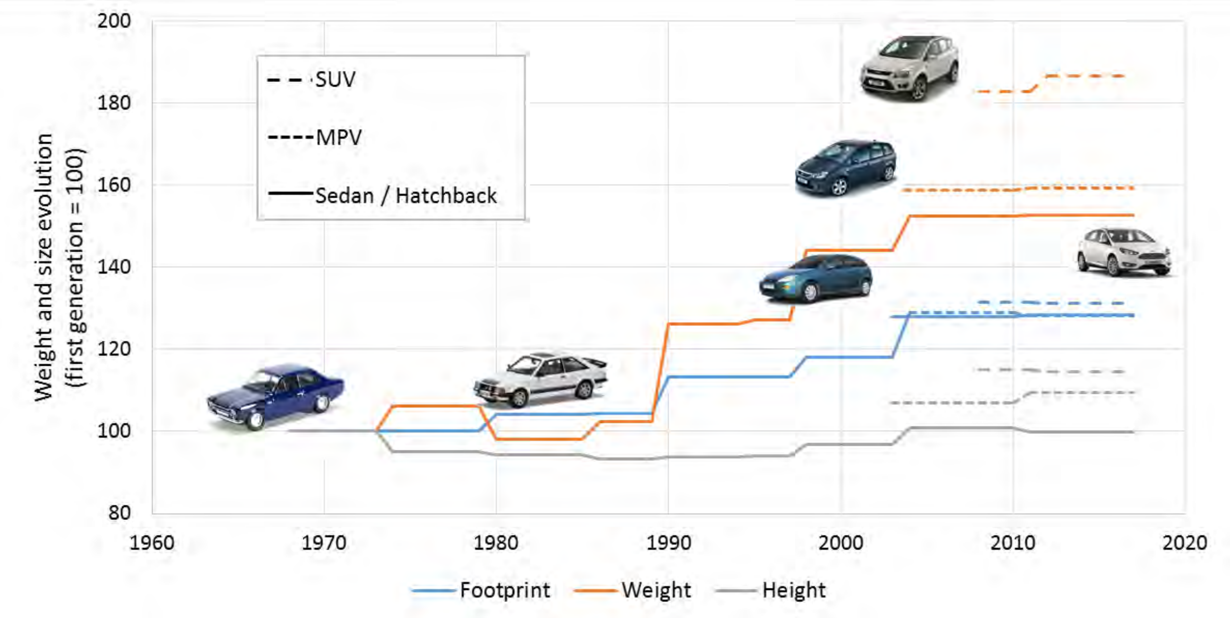


Figure 23: Ford midsize vehicle weight and size evolution, together with MPV and SUV variants

Fuel economy tests favor SUVs

Fuel-economy measurements show that there is a wider gap for MPVs and SUVs between certification test findings and real-life results than for traditional sedans and hatchbacks. That is because average road speeds are significantly higher than those in certification tests (ICCT, 2016, T&E, PSA, 2017).

Because of their larger frontal areas (see Figure 24), the aerodynamics of MPVs and SUVs are usually worse than for sedans with comparable footprints. Certification tests do not fully account for this aerodynamic handicap, which is proportional to velocity squared, because of the lower certification speeds than on-road averages.

Having real-life tests as part of fuel economy certification tests would make displayed fuel economy for SUVs more realistic.

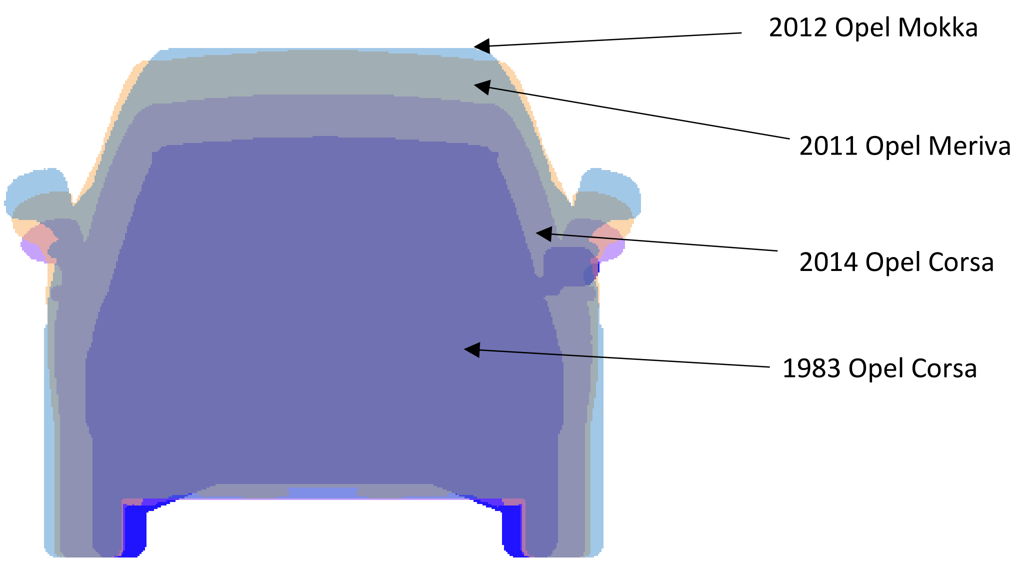


Figure 24: Frontal areas of Opel Corsa and its body variants

Why do models continuously increase in size?

For nearly all models studied, the footprint, height, and weight have all increased from generation to generation (see Annex I). The one exception was the U.S. Chevy Impala, whose footprint in 2014 was 15% smaller than that of the 1959 model. Oil crises in the 1970s and early 2000s forced American OEMs to reduce vehicle size in response to demand for more fuel-efficient vehicles. Nonetheless, the United States still produces and sells the largest vehicles by far (see Figure 10 and Figure 14).

All other models in the analysis expanded dramatically in footprint and weight, so much so that some models have changed segment from generation to generation. For example, the original VW Golf from the mid-1970s is smaller than today's Polo, though the Polo is marketed in the next-smaller segment than the current Golf (see Figure 25).

Figure 25: Size comparison of 1st Generation Golf versus last generation Polo

One reason for the continuous growth of most models relates to marketing. To retain customer loyalty for a given model, OEMs try to create new designs that follow the expanding aspirations and expectations of consumers as they become older and probably wealthier, and seek more comfort and space. Once a vehicle becomes too large for younger buyers, manufacturers create new vehicles to fill in the gaps. For example, VW slotted the Polo in behind the larger Golf, and the Honda developed the Fit/Jazz as the Civic outgrew its marketing space.

Is light-weighting a reality?

After decades of substantial weight increase for the models analyzed, some OEMs are now deploying weight reduction strategies to improve fuel economy and help meet CAFE targets. They are employing several strategies:

- Computing/manufacturing: Use of computer simulation enables engineers to remove unnecessary material, reducing weight. Designers can also use alternative manufacturing processes, for example gluing body assemblies rather than welding or using rivets.
- Upgraded material: Substituting higher-strength materials, such as high-strength steel, allows for the use of less material for the same strength behavior.
- Material substitution: Switching from steel to aluminium or composites can significantly reduce weight (Ricardo AEA, 2015).

Different OEMs use different strategies to limit weight growth or reduce weight. Material substitution such as replacing metal with carbon fiber for body panels or chassis parts (MaterialsToday, 2011), is usually the costliest option. As a result, that strategy is often most suitable for premium large or sporty vehicles.

Steel still accounts for more than 50% of total vehicle weight as mainstream, mass-produced vehicles use various forms of steel for chassis and body parts, based on U.S. market data (see Figure 26). While the share of advanced materials such as high-strength steel, aluminium, and plastic composites has expanded, the weight savings in the past have been used to offset the increased weight of upscale features, safety enhancements, and increased vehicle size (ICCT, 2017). Consequently, the deployment of lightweight materials has had a limited impact on total vehicle weight.

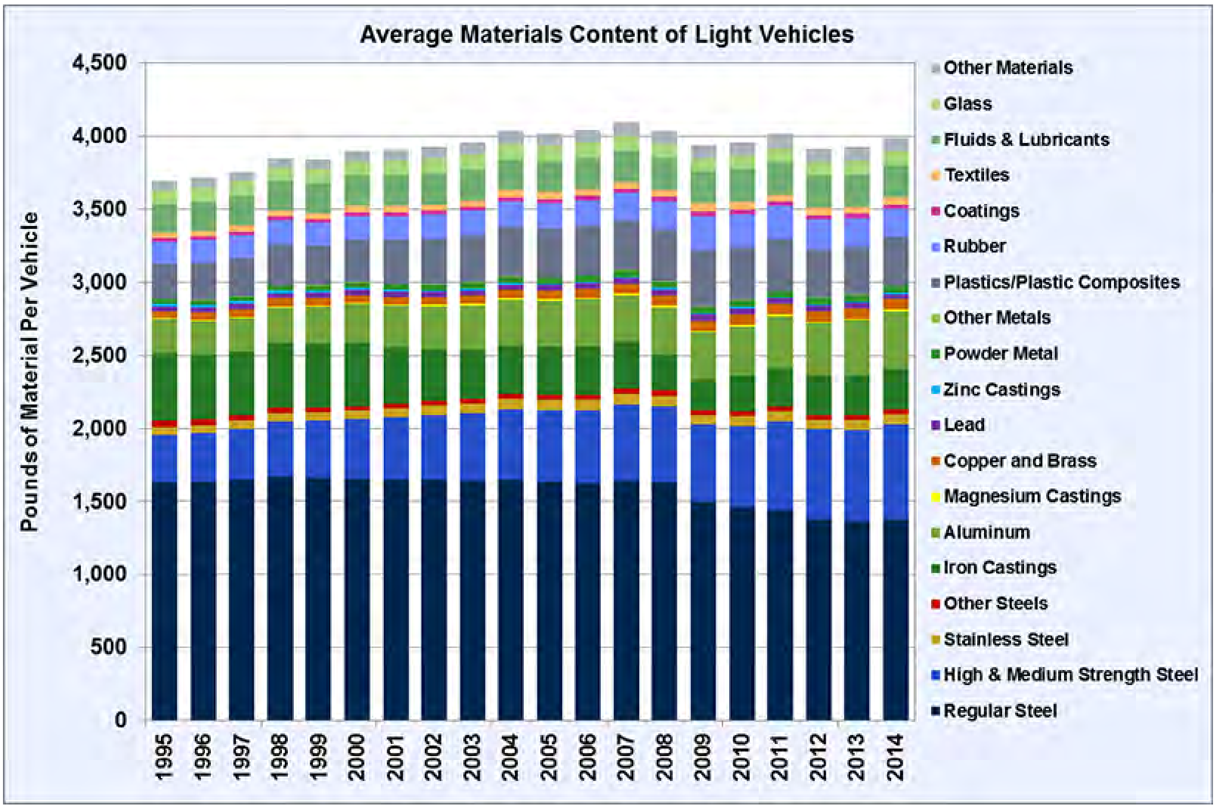


Figure 26: Average material content of light duty vehicles in the United States (DoE, 2017)

In the United States, the leading OEMs Ford and GM have adopted opposite strategies for reducing weight. Ford has emphasized material substitution for body and panels, replacing steel with aluminium in the current generation and with composites for future generation. GM is sticking with steel and is making significant progress on manufacturing processes and material optimization to reduce weight (AutomotiveNews, 2014 and Pickuptrucks, 2016).

In Europe, three vehicles in this analysis claimed reduced weight when the most recent generation was launched. For example, the Golf and Clio lost up to 100 kg. In that case, the OEMs used different strategies:

- For the seventh-generation Golf, weight savings in the powertrain account for about half of the reduction. The rest came from the vehicle body. VW optimized materials and increased the use of high-strength steel. Switching to an aluminium block was the main feature of engine weight reduction (VWVortex, 2012).
- Renault similarly split weight reductions equally between the powertrain and the body in its fourth-generation Clio. It did so differently from VW. The company substituted turbocharged 3-cylinder gasoline engines for 4-cylinder engines, saving around 50 kg (Le Point, 2012). Renault also used thermoplastics for the rear closure (CompositesWorld, 2012), making the body lighter.

A more global model, the hybrid Toyota Prius, lost 100 kg between the third and fourth generations. Vehicle platform, battery, and powertrain were the main sources of weight reduction.

Based on sales-weighted average weights, these light-weighting strategies struggle to have an effect in the marketplace (see Figure 27). The new Prius did not appear in time to move the needle in the data. The Renault Clio's average weight declined around 50 kg between 2011 and 2013.

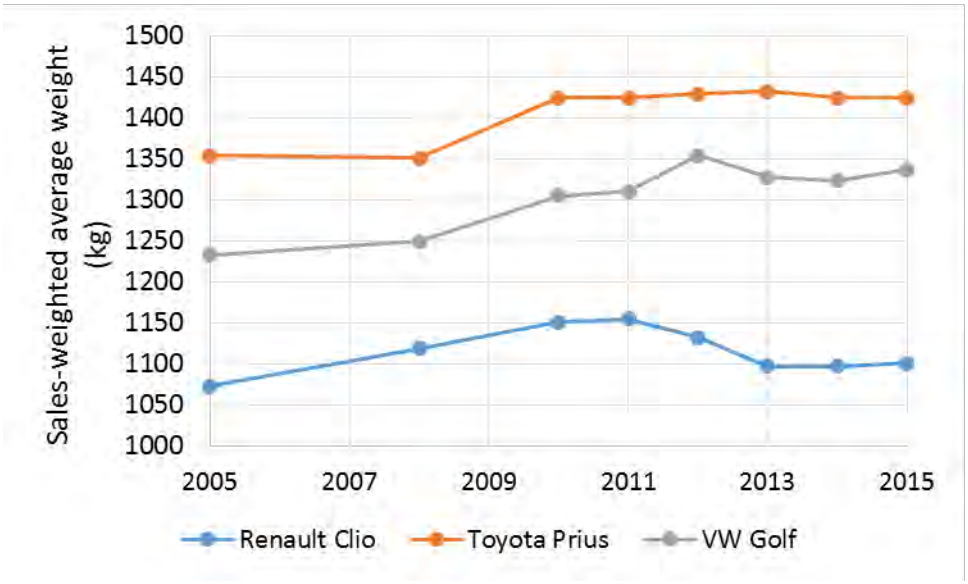


Figure 27: Sales-weighted average weight of key models that have deployed weight reduction strategies

The VW Golf offers a more complex case. VW offers the Golf with multiple powertrain options that have an impact of average vehicle weight. Causing the average weight to tilt upward most recently is the increasing popularity of plug-in hybrid and battery electric versions, which are more than 200 kg heavier than models with conventional powertrains (see Figure 28).

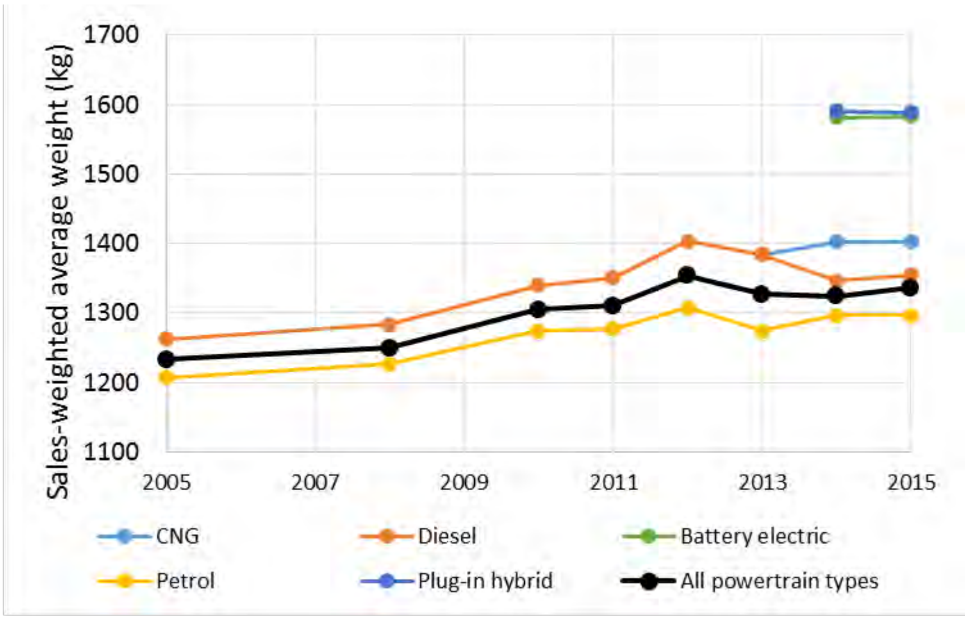


Figure 28: Sales-weighted average weight of VW Golf by powertrain type

Though bringing significant fuel economy benefits, plug-in hybrids and battery electric variants are having a significant impact on the vehicle's weight.

Battery weight still a barrier to widespread electric vehicle deployment

Electrifying powertrains using a hybrid strategy is likely to increase weight with the need for both internal combustion engines and electric motors. For pure battery electric vehicles (BEVs), the battery is still a big barrier to reducing weight. Nevertheless, BEV makers have a strong incentive to reduce weight because doing so will translate into longer vehicle range, a critical factor for BEV market growth. Battery technology improvements over time might be enough to solve the issue, but further incentives, such as weight reduction targets for OEMs, shall be put in place to encourage compensating the increased weight due to the battery pack elsewhere in the vehicle.

Recent advances in battery technology have increased the battery storage capacity and thus vehicle range, rather than decreasing battery pack size and weight to keep range constant. For example, the latest generation of Nissan Leaf expanded the battery pack's storage capacity by 25%, from 24 kWh to 30 kWh. But it also increased weight by 14%, from 151 kg to 172 kg (PushEVs, 2015). Nissan claimed a range gain of 27%, from 135 km to 172 km for EPA ratings.

Among the most popular BEVs that have other powertrain options available on the same body, the extra weight is around 200 kg (see Table 8). The limited weight difference for the Kangoo LCV comes from the size difference of the EV version compared with the internal combustion engine (ICE) version. The Kangoo is available in three different lengths, with shorter versions projected to represent a bigger share of electric Kangoos. The fact that Kangoos are also almost exclusively available with heavier diesel engines would also contribute to a smaller gap between the ICE and BEV versions.

	Sales weighted average weight (kg)		
	EV	ICE	weight difference
Ford Focus	1526	1320	206
Kia Soul	1462	1272	190
Mercedes B-Class	1592	1426	166
Renault Fluence	1550	1290	260
Renault Kangoo	1461	1390	71
Smart Fortwo	911	791	120
Toyota RAV4	1830	1606	224
VW Golf	1580	1324	256
VW Up!	1210	930	280

Table 8: BEV powertrain extra weight on popular models

Designing dedicated vehicle platforms for BEVs may be a more efficient approach to fully optimize the chassis specifications for BEVs. Several OEMs have put BEV-dedicated vehicles on the market, usually in the premium segment with high-end materials, equipment, and prices.

Weight-based fuel-economy policies and especially fuel-economy standards give EVs a significant incentive, as heavier vehicles have a higher target while providing 0g CO_2/km for each vehicle sold. On top of that, some places, such as the EU, are giving super-credits in which each PHEV and BEV sold counts for more than one vehicle (ICCT, 2014).

Looking ahead: Regulating vehicle size?

This paper has documented how vehicle size can be and is measured by regulators and other parties involved in the automotive business. Vehicle size is subjective, and various metrics have been developed over the years to classify vehicles by size. Attempts to use a quantifiable approach to vehicle size, such as the U.S. EPA Fuel Economy Guide using interior size to classify vehicles, have not been conclusive and have led to confusion. Vehicle market segmentation, the most popular metric used by auto industry players, relies on relative vehicle comparison to classify vehicles. Even though OEMs can game segmentation, it is an interesting way to perform market analysis.

Weight and footprint, the most popular vehicle size proxies used in fuel economy policies, both have strengths and weaknesses. Nevertheless, the best metric for fuel economy policy remains footprint as it provides stronger incentives for weight reduction and offers fewer opportunities for gaming the system. The EU will have an opportunity to switch away from a weight-based fuel-economy standard when it defines the 2025 CO_2 targets for cars and LCVs.

Globally, average new vehicle weight increased by 5% and footprint by 3% between 2010 and 2015, based on registration data in the GFEI database. Chinese vehicles' footprint and weight especially grew quickly as registered vehicles gained almost 200 kg, +18% from 2010 to 2015. Only Korea reduced average vehicle weight significantly during the time period in the analysis.

OEMs around the world adopt different strategies by market. For example, Japanese OEMs produce the smallest vehicles in their local markets but offer larger products in Africa and Latin America. On the other hand, U.S. OEMs usually sell the largest vehicles regardless of region, especially in North America.

An analysis of longer time periods at the vehicle level provides a different perspective on the evolution of weight and footprint for popular models that have been on the market for decades. Vehicle footprint and weight increase continuously from generation to generation. The introduction of MPVs and SUVs in most line-ups has accelerated the weight and height increase. The addition of MPV/SUV variants usually increases vehicle weight immediately as much as would otherwise take three or four design generations, or more than 20 years. Switching to MPVs/SUVs accelerates the weight increase of the fleet and undermines most efforts to limit or reduce vehicle weight in the interest of less fuel consumption and fewer emissions. Other collateral damage of this rapid shift to SUVs includes higher rates of parking accidents because of space limitations in parking lots that have not kept pace with increases in vehicle size.

MPVs and SUVs benefit compared with traditional body styles under fuel-economy certification tests. These tests tend to understate the real-world fuel consumption and emissions of MPVs and SUVs more than they do for conventional body styles. MPVs/SUVs have an aerodynamic disadvantage on the road because of their larger frontal surfaces. Certification tests conducted at significantly lower average speeds than in real life fail to capture this aerodynamic handicap. The certification tests produce misleading data on fuel consumption and emissions for policy makers and consumers. Completing the certification tests with on-road CO2 measurements with representative conditions would provide more realistic fuel economy values for all vehicle types.

No policies forbid or discourage the purchase of vehicles purely based on size. Weight has a significant impact on real-life fuel economy, CO_2 emissions, and fuel-economy policies should discourage vehicle weight increases. Footprint-based fuel-economy standards provide a stronger basis for discouraging the evolution of much larger fleets. Fuel-economy policies would benefit from going beyond the existing stance to mandate weight reduction targets as part of the corporate average targets.

Electric vehicles still need substantial technical innovation to lose weight and get on a par with internal combustion engine variants. BEV-specific platforms might result in better integration of the electric powertrains and in greater weight reductions, enabling better energy efficiency, better capacity and/or longer vehicle range.

Finally, though outside the scope of this paper, strong incentives should be put in place to encourage higher demand for smaller and lighter cars. Customers tend to buy larger cars than what they need, for the occasional trip done at full occupancy. Better and flexible car sharing schemes would offer the possibility to choose the right car size for any journey, reducing unnecessary large cars used in all circumstances.

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Annex I: Average vehicle price by OEM

Derived from analysis performed using the GFEI database (GFEI, 2017).

OEM	2015 average vehicle price (USD)	OEM type	OEM	2015 average vehicle price (USD)	OEM type
Hafei	$6,400	Low Cost	Kia	$24,700	Mainstream
Datsun	$6,700	Low Cost	Subaru	$25,600	Mainstream
Maruti	$7,900	Low Cost	Holden	$26,300	Mainstream
Wuling	$7,900	Low Cost	Ford	$26,700	Mainstream
Tata	$8,200	Low Cost	Skoda	$26,700	Mainstream
Geely	$8,600	Low Cost	Mitsubishi	$26,800	Mainstream
FAW	$9,100	Low Cost	VW	$27,200	Mainstream
Daewoo	$9,200	Low Cost	Ssangyong	$27,900	Mainstream
UAZ	$10,700	Low Cost	Dodge	$28,100	Mainstream
Dongfeng	$11,700	Low Cost	Chrysler	$28,300	Mainstream
Daihatsu	$11,900	Low Cost	Alfa Romeo	$29,400	Mainstream
Lada	$12,200	Low Cost	Mini	$29,700	Mainstream
Baojun	$12,300	Low Cost	Jeep	$29,800	Mainstream
Chery	$12,600	Low Cost	Buick	$34,000	Mainstream
Brilliance	$12,700	Low Cost	Saab	$35,400	Mainstream
Suzuki	$13,900	Low Cost	GMC	$41,500	Mainstream
Venucia	$14,300	Low Cost	Volvo	$46,300	Premium
Dacia	$15,000	Low Cost	Infiniti	$48,800	Premium
Proton	$15,000	Low Cost	Lexus	$49,200	Premium
BYD	$15,900	Low Cost	Audi	$51,000	Premium
Fiat	$16,800	Mainstream	Cadillac	$56,800	Premium
Smart	$18,000	Mainstream	BMW	$58,200	Premium
Hyundai	$19,500	Mainstream	Mercedes	$60,100	Premium
MG	$20,200	Mainstream	Jaguar	$79,100	Premium
Renault	$21,600	Mainstream	Land Rover	$91,900	Premium
Honda	$22,100	Mainstream	Corvette	$106,800	Premium
Mazda	$22,300	Mainstream	Porsche	$107,600	Premium
Nissan	$22,700	Mainstream	Maserati	$135,100	Premium
Citroen	$23,600	Mainstream	Hummer	$201,700	Premium
Seat	$24,100	Mainstream	Aston Martin	$238,600	Premium
Toyota	$24,300	Mainstream	Bentley	$310,300	Premium
Opel	$24,600	Mainstream	Ferrari	$320,300	Premium
Peugeot	$24,600	Mainstream			

Annex II: Weight and Footprint evolution of emblematic models

Vehicles are shown as ordered in Table 7.

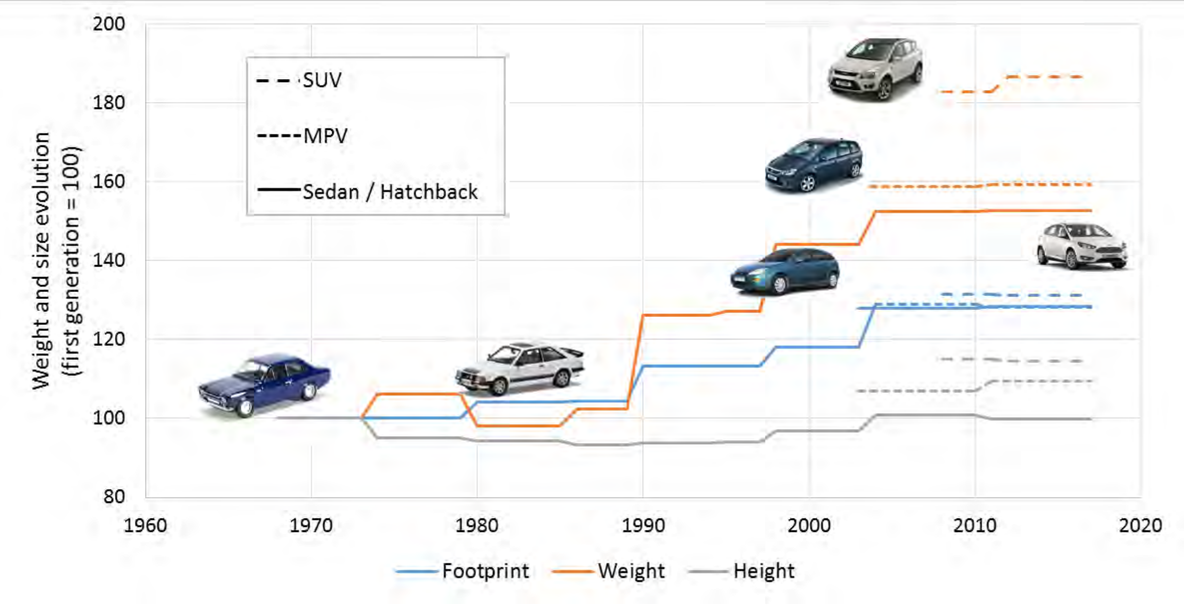

Figure 29: Ford Escort /Focus, C-Max, Kuga weight and size evolution

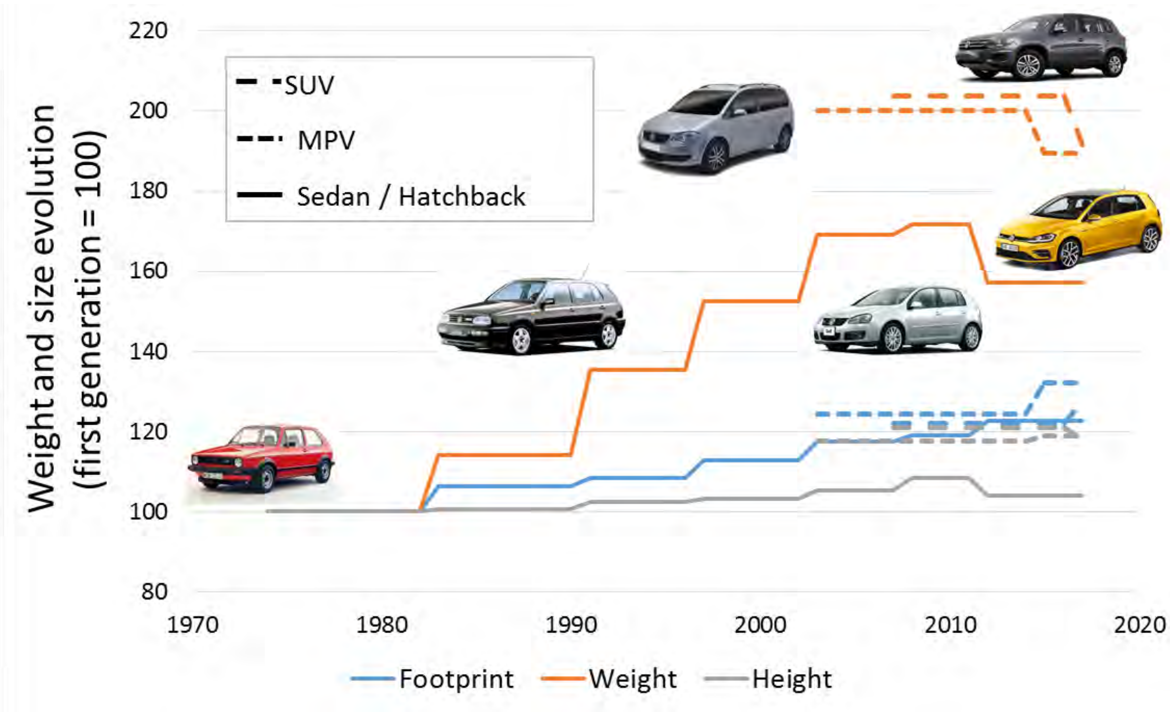

Figure 30: Volkswagen Golf, Touran, Tiguan weight and size evolution

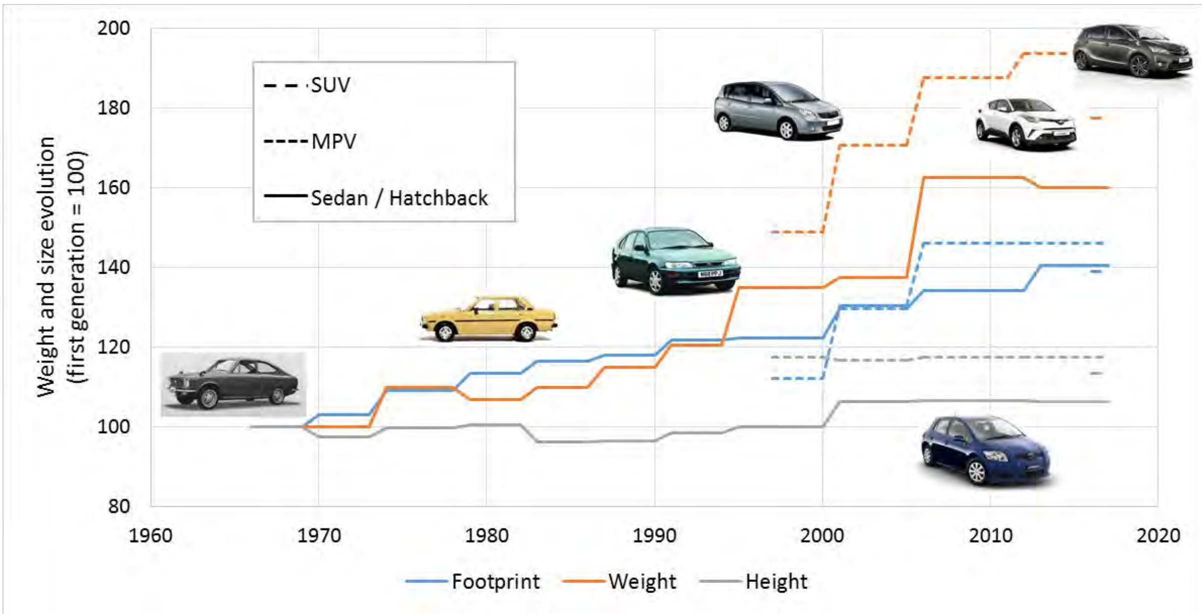

Figure 31: Toyota Corolla, C-HR weight and size evolution

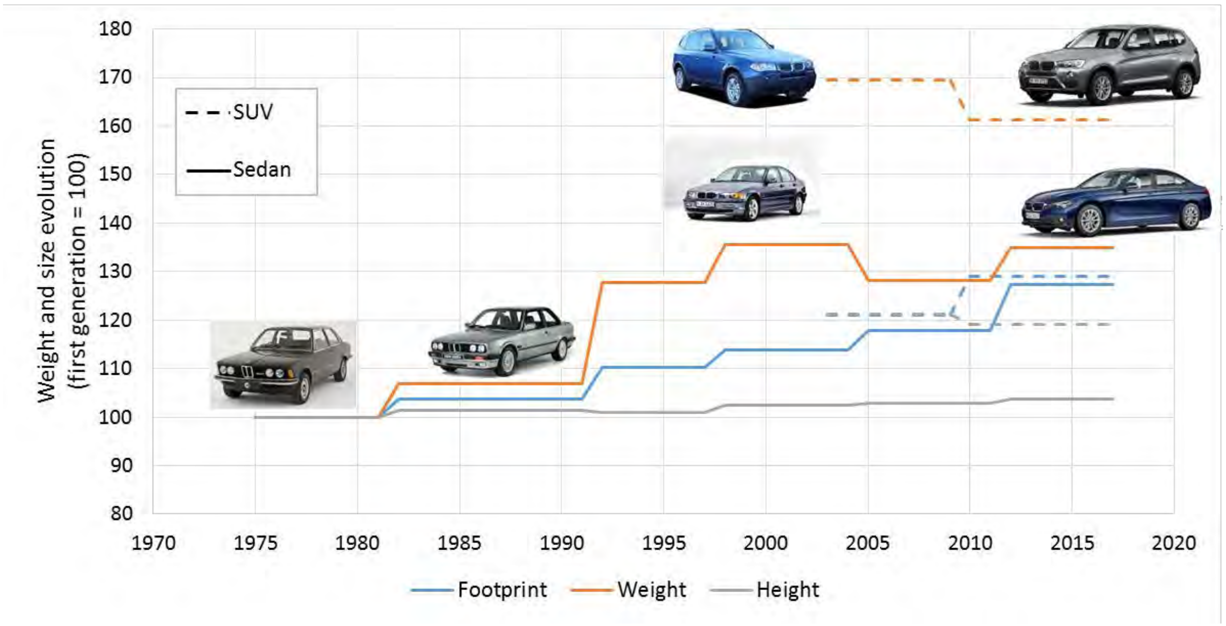

Figure 32: BMW 3-series and X3 weight and size evolution

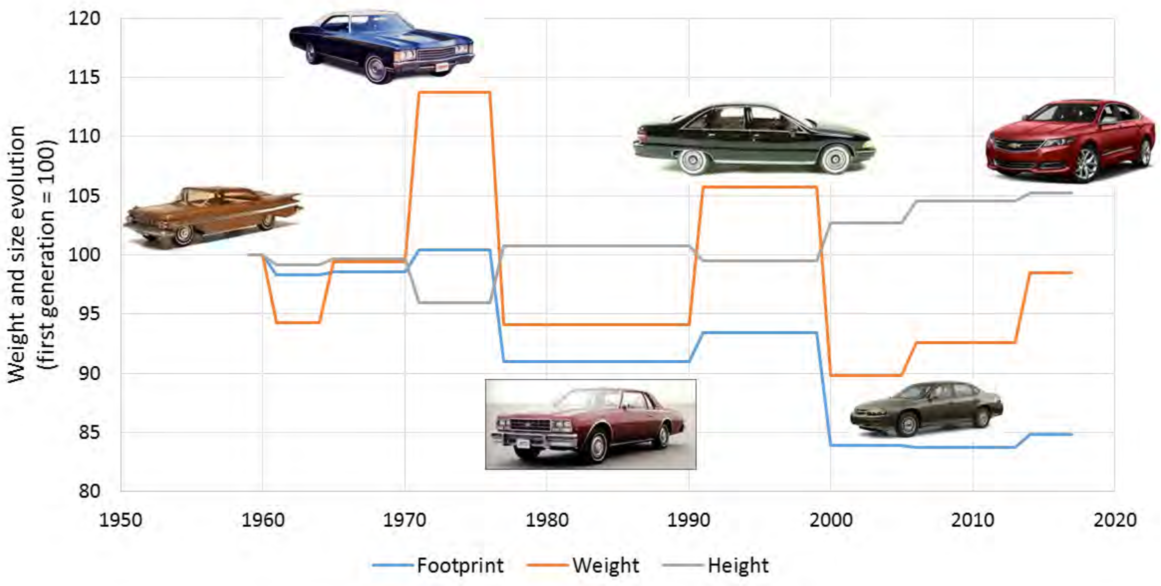

Figure 33: Chevrolet Impala weight and size evolution

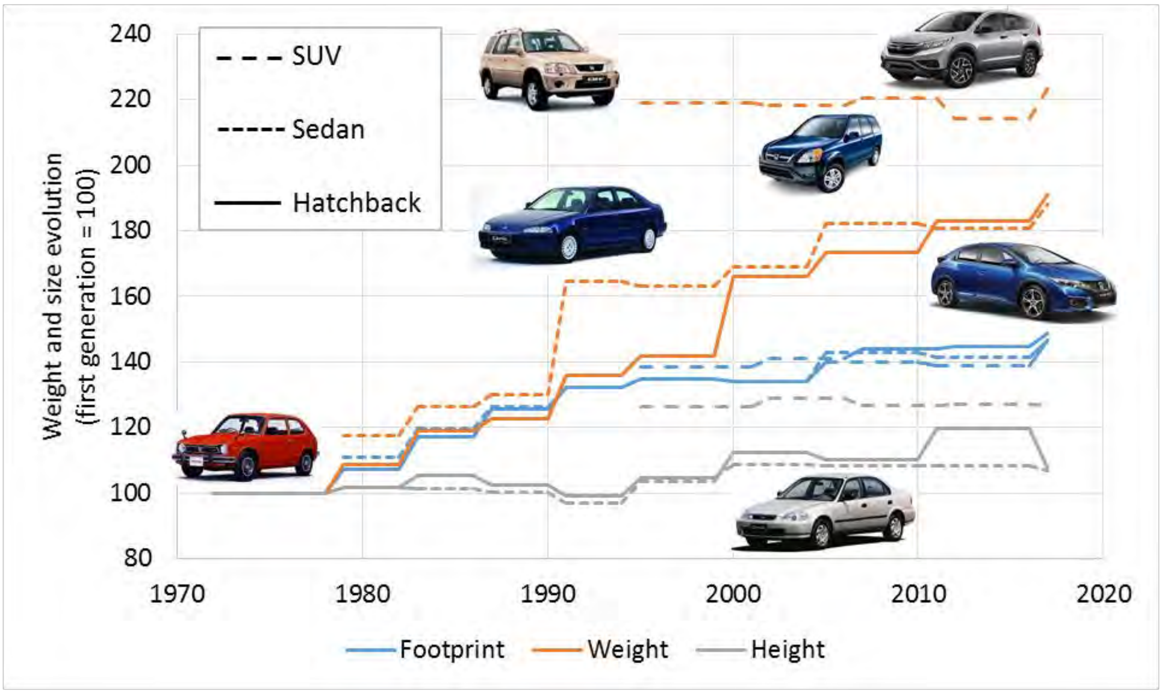

Figure 34: Honda Civic, CR-V weight and size evolution

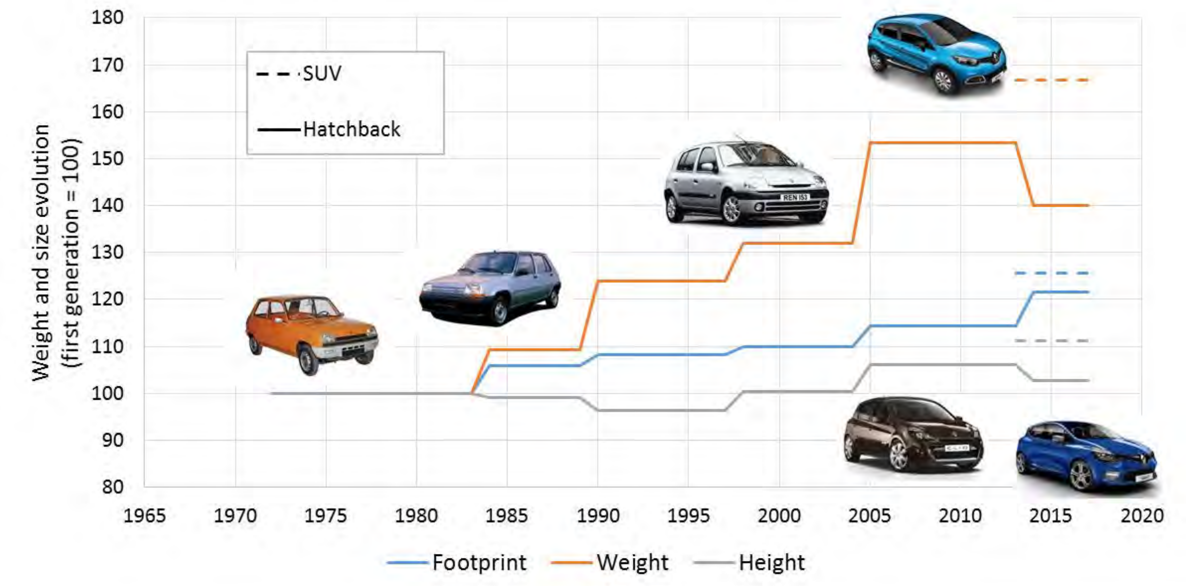

Figure 35: Renault 5, Clio and Captur weight and size evolution

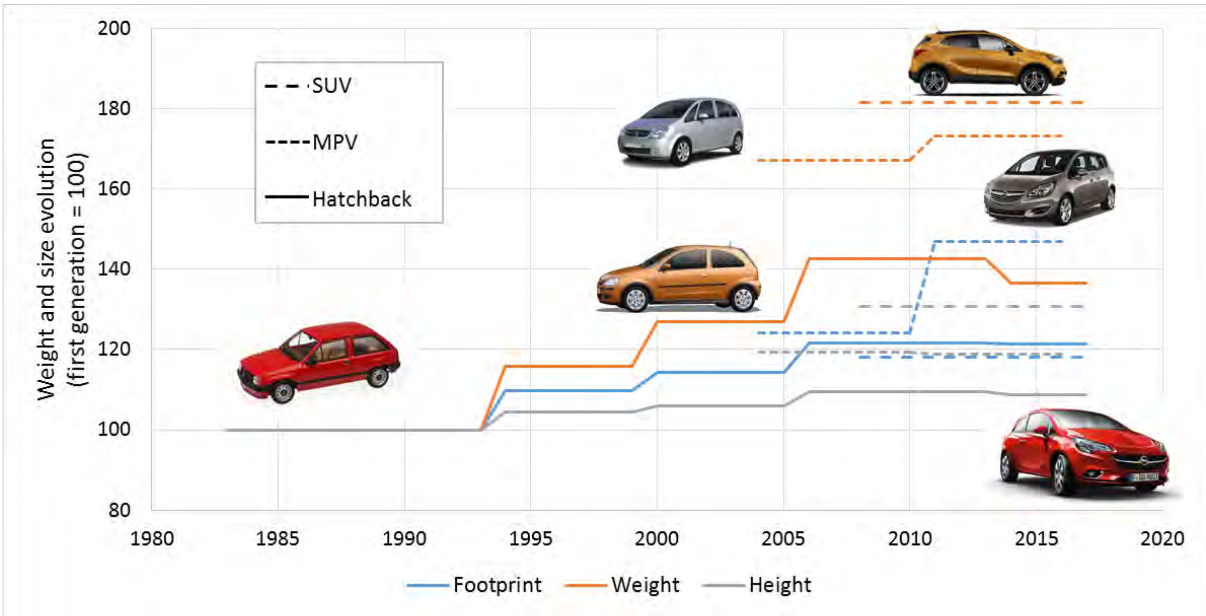

Figure 36: Opel Corsa, Meriva and Mokka weight and size evolution

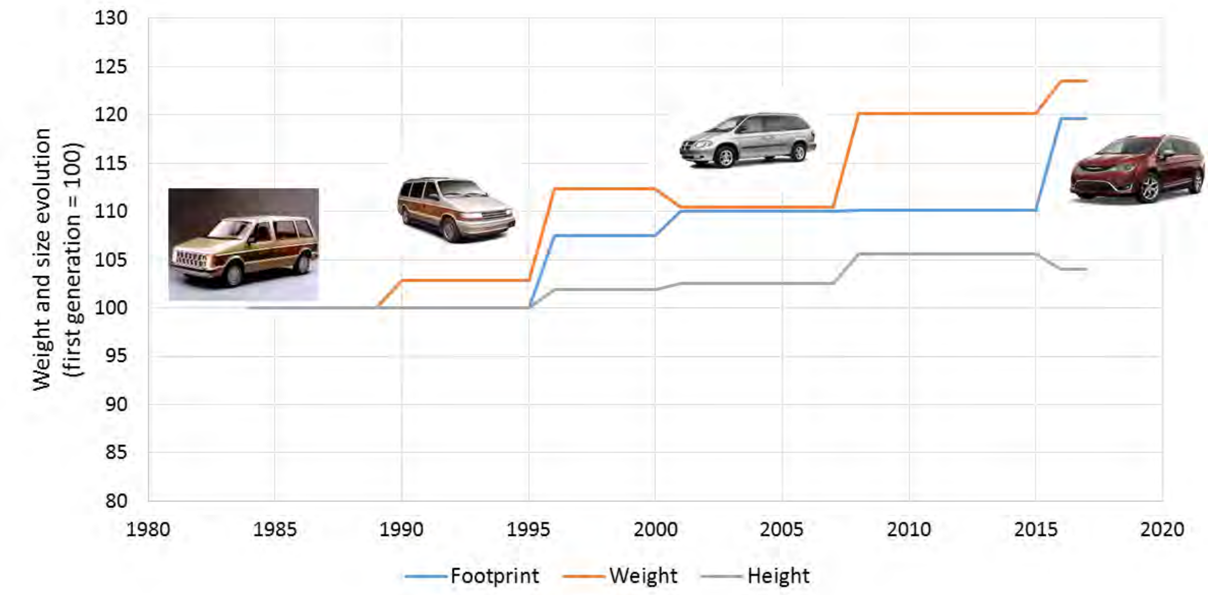

Figure 37: Chrysler Voyager / Town and Country and Pacifica weight and size evolution

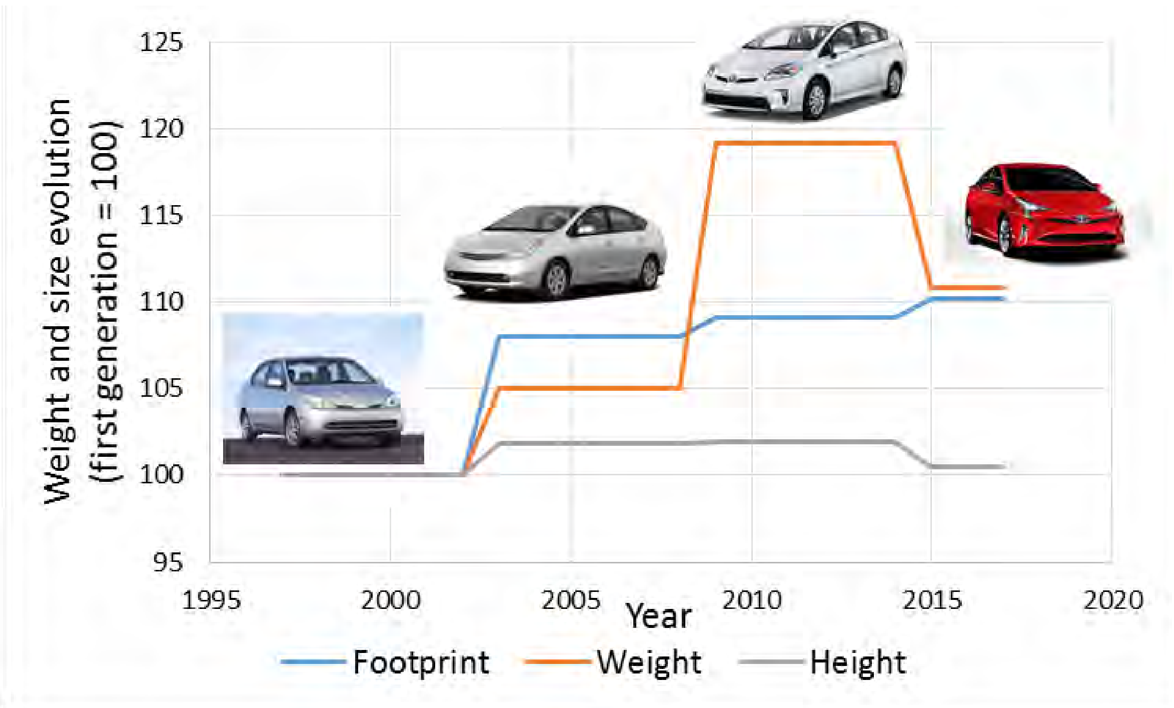

Figure 38: Toyota Prius weight and size evolution

What is the Global Fuel Economy Initiative?

The Global Fuel Economy Initiative believes that large gains could be made in fuel economy which would help every country to address the pressing issues of climate change, energy security and sustainable mobility. We will continue to raise awareness, present evidence, and offer support to enable countries to adopt effective fuel economy standards and policies that work in their circumstances and with their vehicle fleet.

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