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Market analysis of heavy-duty vehicles in India

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1. Introduction

India is currently considering establishing fuel efficiency regulation for new trucks and buses. This process formally started in July 2014 when the Ministry of Petroleum and Natural Gas officially constituted a Steering Committee to guide the regulatory development process (Minstry of Petroleum & Natural Gas 2014). In any regulatory development process, a thorough understanding of the new vehicle sales market is critical to design a program that is properly tailored to local conditions. Therefore, the primary objectives of this paper are to analyze HDV sales in India in terms of manufacturer market shares, and typical vehicle characteristics, and compare those to other major markets such as the European Union, United States, and China. In addition, engine attributes of Indian HDVs are explored in detail in order to develop a draft proposal for breaking engines into categories for the purpose of regulation.

This working paper is the second in a series of papers that touch on various aspects related to regulatory develop-ment for HDV efficiency in India. Previous ICCT working paper on HDV test procedure options, which recommends that India pursue an engine-based regulation as a first phase, with an eye towards transitioning to a more comprehensive (i.e., 'full vehicle') program in the future (Sharpe 2015). The engine analysis in this paper builds on this paper. Future papers will include results from an industry survey, a regulatory test cycle analysis, and an engine technology potential report.

2. Overview of India's HDV sales market

The sales market data referenced in this paper are for India's 2013-14 fiscal year (April 1, 2013 to March 31, 2014) and was acquired from Segment Y Automotive Intelligence.

In fiscal year 2013-14, total domestic sales of commercial vehicles greater than 3.5 tonnes ("HDVs" in this paper) were roughly 270,000. According to the ICCT's Global Transportation Roadmap model, heavy-duty vehicle sales have increased by a factor of 2.7 since 2000 (Facanha, Miller et al. 2014).

2.1 BREAKDOWNS BY MANUFACTURER MARKET SHARES AND GROSS VEHICLE WEIGHT

Figures 1 and 2 summarize manufacturer market shares for HDV sales in India. Figure 1 shows the percentage breakdowns for total sales, and the clear market leader is Tata Motors with over half of HDVs sold. Tata's share of the market is nearly three times as large as its nearest competitor, Ashok Leyland, which controls almost one-fifth of the market. VE Commercial Vehicles (VECV), a joint venture between the Volvo Group and Eicher Motors, is the only remaining company with a double-digit share of the market at 14%. The next largest players are Daimler, SML Isuzu, and Mahindra, who each represent roughly 3-4% of sales. The 3 manufactures that make up the "Other" category include AMW Motors, Volkswagen Commercial Vehicles, and the Volvo Group.
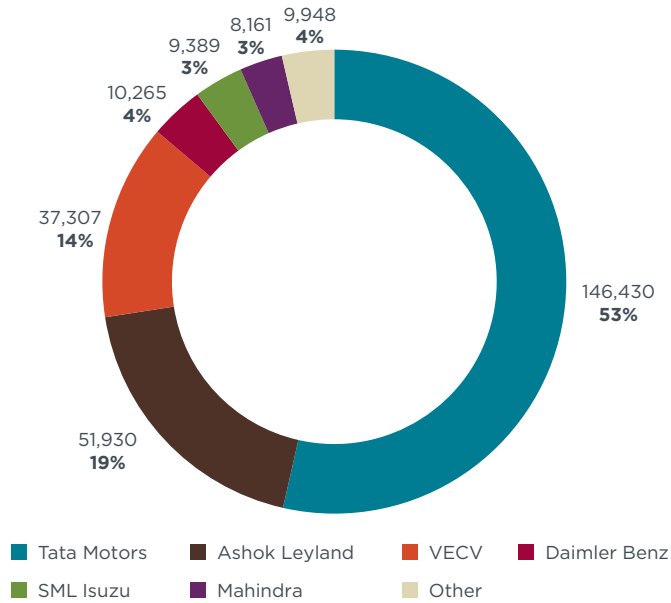
Figure 1: Manufacturer market shares for new heavy-duty vehicle sales

In Figure 2 the inner and outer rings represent market share breakdowns for buses and trucks, respectively. When breaking out sales by these broad vehicle categories, the top three manufacturer rankings for both trucks and buses match the ranking for overall sales (Figure 1), with Tata, Ashok Leyland, and VECV representing the best selling manufacturers.
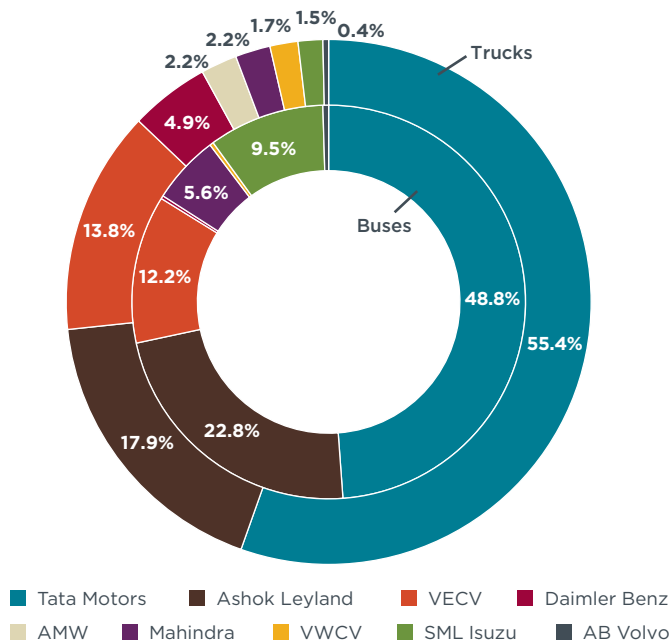

Figure 2: Manufacturer market shares for new truck and bus sales

Figure 3 summarizes the market shares of new HDVs in terms of gross vehicle weight rating (GVWR), which is the maximum recommended operating mass of a vehicle as specified by the manufacturer. This figure plots the cumulative market share as a function of vehicle GVWR for both trucks and buses. In these curves, vertical or near-vertical sections of the data points imply concentrations of vehicle sales at that particular GVWR value. For example, for trucks, there are high concentrations of sales at 25, 31, 12, and 16 tonnes. The percent of total truck sales at each of these points is roughly 23%, 15%, 14%, and 10%, respectively. For trucks less than 12 tonnes, there are no distinct spikes in market share at any given GVWR value, and the distribution of sales is relatively smooth. For buses, the most well-defined vertical segments of concentrated market share are at 16 tonnes (19% of sales), followed by 15 tonnes (13%). Below 15 tonnes, there are no individual GVWR values that represent more than about 8% of total bus sales.
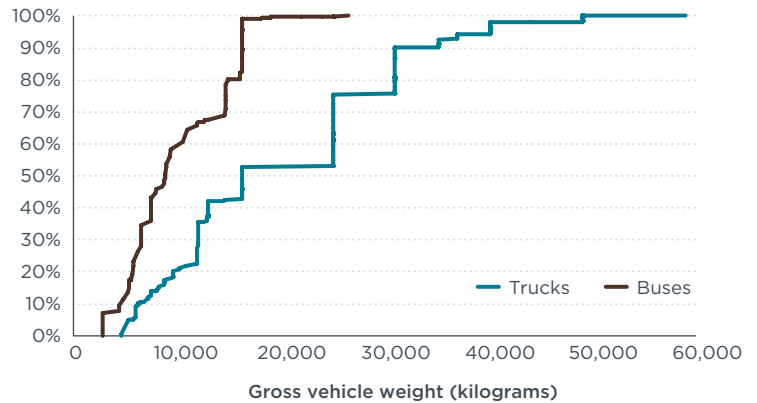

Figure 3: Cumulative market shares of truck and buses as a function of gross vehicle weight rating

Figure 4 breaks down each manufacturer's sales portfolio by vehicle type (i.e., truck or bus) and GVWR. Offering products in each of the eight vehicle class/weight categories, both Tata and VECV have the most diversity in their sales mix. All six of the highest-selling manufacturers offer vehicles in at least five of the eight vehicle categories, while the three lowest volume manufacturers have sales limited to 2-3 of the categories.
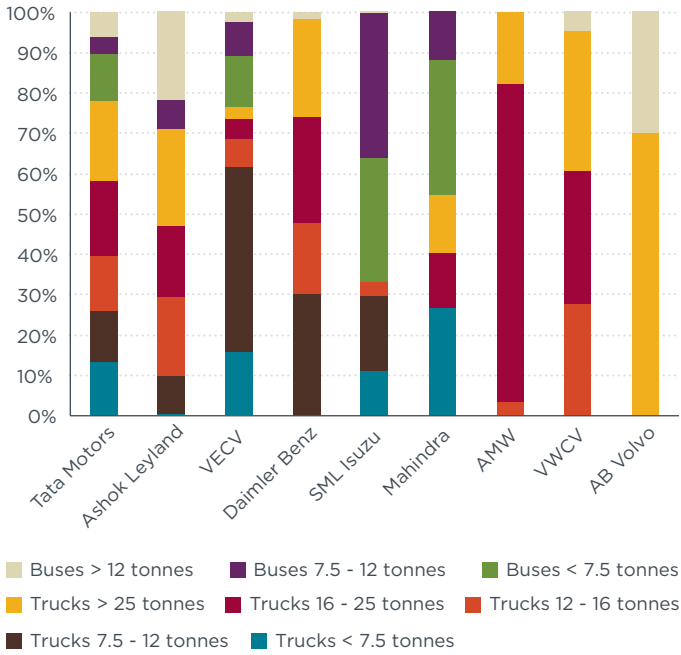
Figure 4: Manufacturer breakdown of sales by segment and gross vehicle weight

This dataset also contains information about the engines installed in HDVs in India and the specific company that manufactured each engine. Unlike the case of passenger cars, HDV manufacturing can be a highly fragmented process, with multiple manufacturers and suppliers responsible for various areas of the vehicle. Figure 5 has information about engine manufacturer market shares, and data on engine size distributions are discussed at length later in the paper.

Figure 5 shows the market breakdown for engine manufacturers. As in Figure 2, the outer ring has the truck breakdown, and the inner ring, buses. We're introduced to a new manufacturer, Cummins, which is not represented in any of the previous figures. Cummins' absence in the previous manufacturer market share data is due to the fact that they are an independent engine supplier. As such, Cummins sells its engines to a number of HDV manufacturers, and, overall, represents 30% of HDV engines sold in India. Figure 5 illustrates that Cummins' market share is much stronger in the truck segment with over one-third of engine sales. For buses, they are fourth in terms of engine sales behind Tata, Ashok Leyland, and VECV. As evidenced in Figure 6, most of the vehicle manufacturers are producing and selling the majority of vehicles with their own engines. The key exceptions are AMW Motors, which sold all of its trucks with Cummins engines in 2013-14, and Tata, which has roughly a 50-50 split between Cummins engines and its own engines.
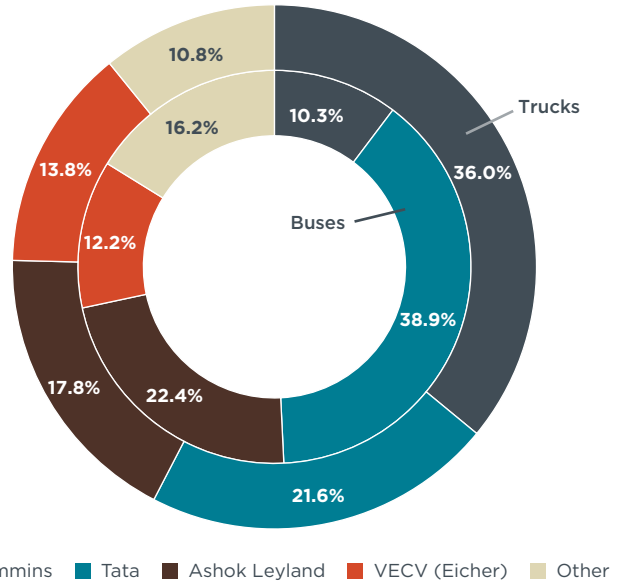

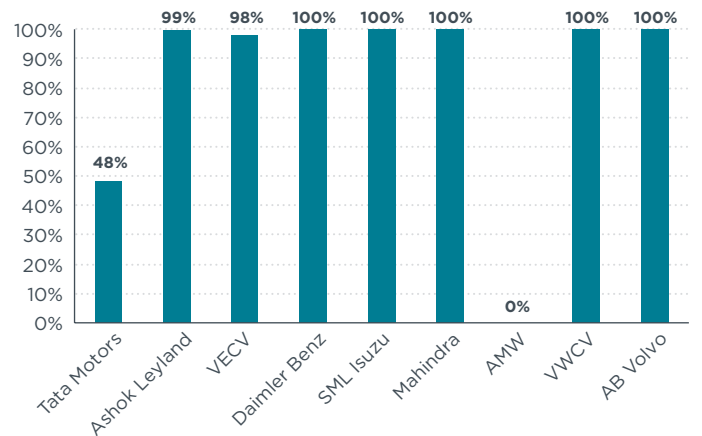**Figure 5**: Engine manufacturer market shares for new truck and bus sales

Figure 6: Manufacturer shares of self-made engines

2.2 TOP VEHICLE MODELS BY SEGMENT

Table 1 presents information about the top selling truck and bus models for various GVWR segments. As further evidence of their dominance in commercial vehicle sales, Tata has the best selling model for all truck categories as well as for the buses at the lightest end of the spectrum. For the larger buses, Ashok Leyland has the most popular models. For three of the truck categories the best seller represents roughly one-third of the total sales for that particular segment, and in the remaining three truck segments, the top model makes up between 16% and 26% of the segment's total sales. In general, the bus segments are less consolidated, with the top models representing between 13% and 24% of each segment's sales.

The right-hand columns of Table 1 has the percent of sales represented by the five and ten best selling models in each segment, respectively. Using this metric, we can ascertain the level of heterogeneity in each of these segments. The top five sellers constitute over half of segment sales in all but one of the truck categories (16 to 25 tonnes), but this is only the case for one of the three bus categories (7.5 to 12 tonnes). The heaviest bus category has the largest extent of model diversity, as the top five models combined are not quite 40% of the sales for the segment.

2.3 COMPARISONS TO OTHER MAJOR MARKETS

In this section, sales data for China, the EU, and US are for calendar year 2012 and come from Polk/IHS. Since the India data is for April 1, 2013 to March 31, 2014, the comparison of vehicle sales is not precisely aligned. However, for the purposes of this analysis, the close proximity of 2012 and 2013-14 provides a reasonable approximation for comparing the HDV markets across the four countries/regions.

Figure 7 gives total HDV sales volumes by GVWR bins for each of the four regions. Looking at the distributions for the four regions, the portion of sales in each bin is rather similar, with the heaviest vehicles accounting for the bulk of the market. The US stands out somewhat in that sales in the lightest weight bin (which roughly represents Class 3 pickup trucks and vans between 10,000 and 14,000 pounds GVWR) are a much larger percent of overall HDV sales. The widespread popularity of pickup trucks and vans in the US would be even more pronounced in this figure if the data included Class 2B (8,500 to 10,000 pounds) pickup trucks and vans, whose annual sales in 2012 were on the order of 340,000 (Lutsey 2015).
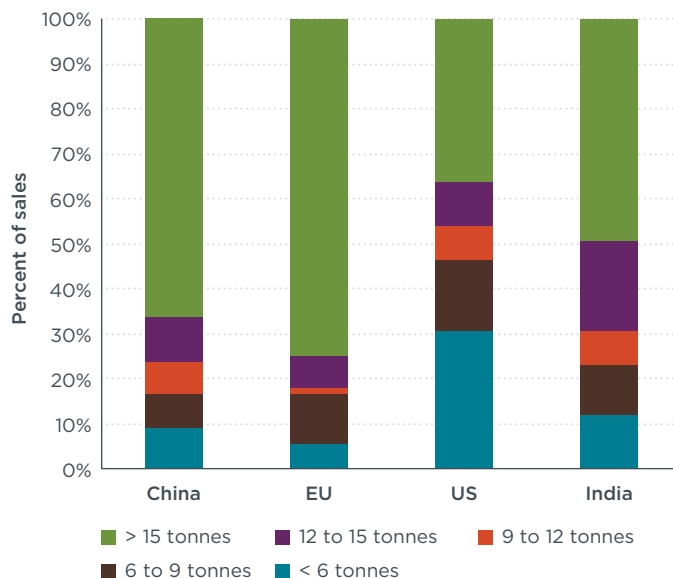

Figure 7: Distribution of heavy-duty vehicle sales by weight category in China, the EU, US, and India

Figures 8 and 9 show how the four regions compare in terms of types of HDVs sold. Figure 8 summarizes how the regions compare on percentage of sales in three broad categories: tractor trucks, rigid trucks[1], and buses and vans. From the bottom blue portion of the columns, the percentage of HDVs sold in India that are buses (25%) is approximately twice as large as the other regions (11 to 13%). While rigid trucks (middle brown bar) make up roughly 60% to 70% of HDV sales in all four markets, sales of tractor trucks in India make up a much smaller portion (5%) of the market than the other regions—particularly the US and EU.

In Figure 9, there is a breakdown of HDVs 15 tonnes and greater into tractor truck and non-tractor truck. In this comparison, India and China are fairly similar, with sales of

Table 1: Top selling vehicle models by gross vehicle weight segment

Segment	Model	Fiscal year 2013-14 sales	Top model's % of segment sales	Top 5 models: % of sales	Top 10 models: % of sales
Trucks < 7.5 tonnes	Tata LPT 407	9,078	32.0%	72.6%	87.3%
Trucks 7.5 – 12 tonnes	Tata LPT 1109	14,609	33.1%	56.6%	72.8%
Trucks 12 – 16 tonnes	Tata LPT 1613	8,262	23.1%	60.7%	80.1%
Trucks 16 – 25 tonnes	Tata LPT 2518	12,284	26.0%	41.7%	66.4%
Trucks > 25 tonnes	Tata LPT 3118	11,419	36.2%	71.3%	88.4%
Tractor trucks > 25 tonnes	Tata LPS 3518	2,811	16.2%	61.3%	79.1%
Buses < 7.5 tonnes	Tata Winger	4,685	17.7%	48.3%	74.0%
Buses 7.5 – 12 tonnes	Ashok Leyland Lynx	2,284	13.1%	51.0%	78.9%
Buses > 12 tonnes	Ashok Leyland Viking	5,424	24.9%	38.0%	60.2%

1   Rigid trucks are distinct for tractor trucks in that their cargo-carrying bodies are permanently attached to the cab, whereas tractor trucks can connect and disconnect from the trailer that carries goods.

non-tractors (i.e., rigid trucks, buses, and vans) outnum-bering tractors by a comfortable margin. This is in contrast to the US and EU, where sales favor tractors in the heaviest weight classes. These two figures evidence that tractor trucks are a much less important segment of the HDV fleet in India in terms of sales, but, more importantly, this is also likely the case for fuel consumption and emissions.
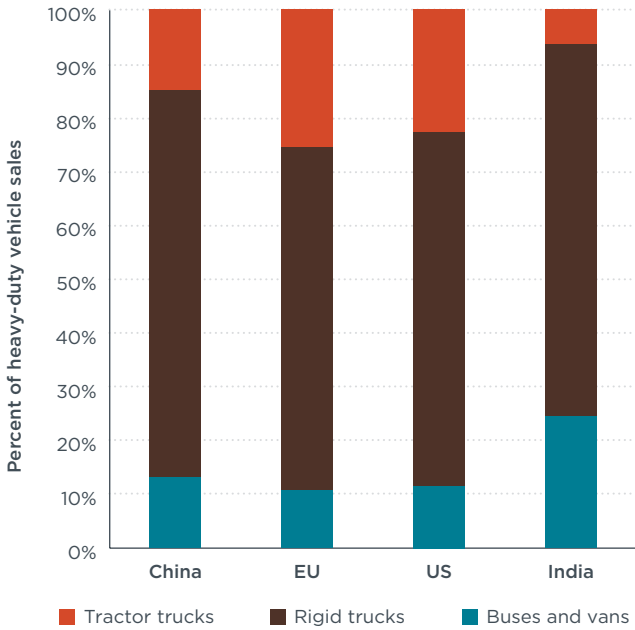

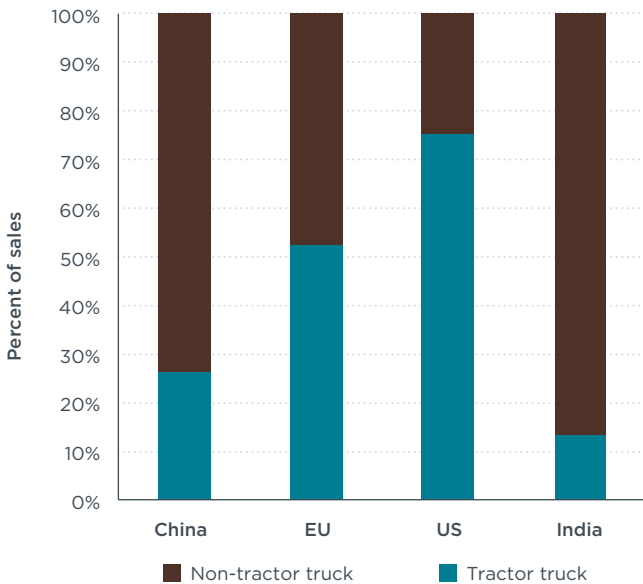**Figure 8:** Sales breakdown for commercial vehicles in the four regions

Figure 9: Tractor and non-tractor sales for vehicles over 15 metric tonnes in the four regions

While the mix of HDVs sold in India is different than the breakdown in these other three regions, the attribute that sets India apart by far from these other markets is a striking disparity in engine sizes. Figure 10 illustrates that, on average, HDVs in India have much smaller engines. The data in the figure is for vehicles over 15 tonnes GVWR, but this gap in engine sizes is also true for the lighter HDV classes (though, the disparity is most prominent in the heaviest HDV categories). As shown in the red column, virtually all of the engines sold for HDVs over 15 tonnes in India have engines with displacements of less than 9 liters. This is in stark contrast to the US and EU, where virtually all of the engines sold in this segment are at least 9 liters. Though China's largest HDVs are also underpowered when compared to the US and EU, they have larger engines than comparable vehicles in India, as nearly two-thirds of China's engines in this segment are 9 liters or more.
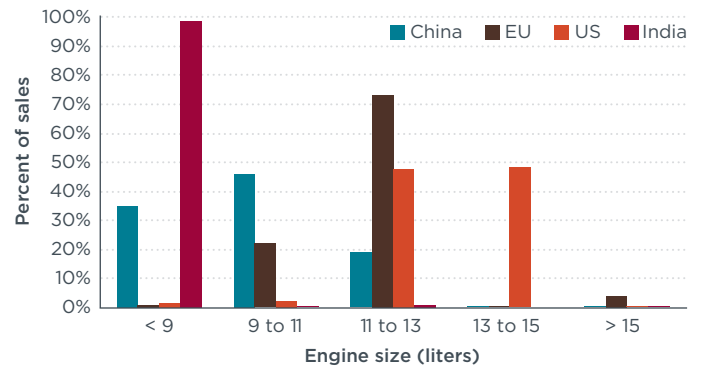

Figure 10: Regional engine size distribution for vehicles over 15 metric tonnes

The blue curve in Figure 11 shows cumulative market share for the entire HDV market as a function of engine size. In this curve there are two major vertical jumps: the first is at 3.8 liters and represents just over 20% of total HDV sales, and the second is at 5.9 liters and accounts for nearly 40% of the market. Engines that are 6 liters or less make up over 90% of the commercial vehicle market in India. Natural gas engines make up 2.8% of total HDV sales (roughly 7,500 sales in 2013-2014) but are limited to the bus market only. The brown curve in the figure shows the engine size distribution for natural gas engines. As shown, all of the natural gas engines sold are 6 liters or less, with the biggest market shares belonging to the engine models just below 4 and 6 liters.
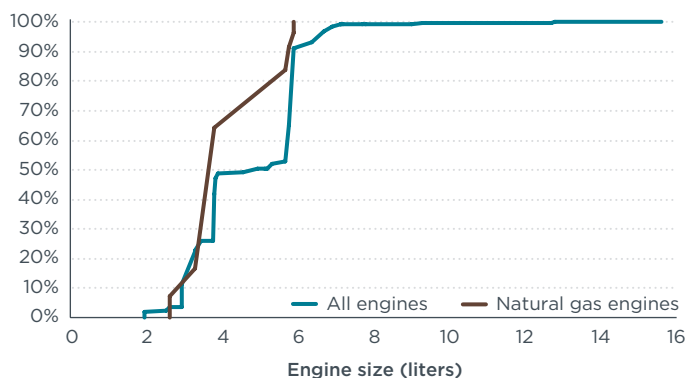
Figure 11: Cumulative market share as a function of engine size

3. Engine categorization

In order to properly design an engine-based regulation, engine-specific research on market conditions, test procedures and duty cycles, technology potential, and economic impacts are all critical to developing as robust a program as possible. The primary motivation for exploring engine characteristics of India HDVs in detail in this section is to suggest a possible classification scheme that can be used in an engine-based efficiency regulation. Based on evidence from engine-based standards in the US and Canada, using a sound classification approach in designing an engine regulation can help avoid unintended market disruptions.

This section expands on the data presented in the previous section on typical engine size and power characteristics of Indian HDVs, discusses why a categorization scheme for engines is warranted for regulatory purposes, and analyzes three example categorization approaches that that are plausible in the Indian context.

3.1 RATIONALE FOR ENGINE REGULATORY SUBCATEGORIES

When the US Environmental Protection Agency (EPA) first developed criteria pollutant emission standards for HDVs in the 1980s, it established standards for engines, based on the amount of work performed (i.e., grams of pollutant per unit of work, expressed as grams per brake horsepower[2] per hour or g/bhp-hr). In the many subsequent years since, numerous countries around the world—including India—have developed or adopted emissions standards based on this same grams per unit brake power approach (e.g., Euro or Bharat standards are in grams per kilowatt-hour or g/kWh). This method of evaluating the emissions of a HDV recognizes the fact that engine characteristics and

loading conditions are the primary determinant of the types and levels of pollutants generated, and engine technologies (including aftertreatment systems) need to be the focus for addressing those emissions. The engine testing approach acknowledges that there are a relatively small number of distinct heavy-duty engine designs as compared to the extremely wide range of HDV configurations and duty cycles. The EPA and other regulatory bodies decided that any incremental gain in real-world emission reductions that could be achieved through regulation of the complete vehicle would be small in comparison to the significant cost of addressing the many variants of complete trucks that make up the HDV sector.

In heavy-duty engine criteria pollutant regulations worldwide, the individual engine is evaluated on an engine dynamometer over a given cycle with standardized speed and load points. Engine duty cycles are defined in terms of percent of maximum rated speed and torque, as shown in Figure 12, which is the speed-load trace for the World Harmonized Transient Cycle (WHTC). Since the points are defined as percentages, the exact speed and load points for each test are unique for a given engine.

In 2011, the US became the first country to finalize a fuel efficiency and GHG emissions regulation for HDVs that contained a separate standard for heavy-duty engines[3]. This separate engine standard in the so called "Phase 1" regulation was designed to take advantage of existing engine testing for criteria pollutants, and, as such, the regulation evaluates engines over the steady-state ramped modal cycle (Supplemental Emissions Test or SET) and the transient heavy-duty Federal Test Procedure (FTP). Within the engine standard, there are three regulatory categories, each with its own numerical standard for CO_2 emissions and fuel consumption (U.S. Environmental Protection Agency 2011). These three engine categories—light heavy-duty (LHD), medium heavy-duty (MHD), and heavy heavy-duty HHD)—are based on the intended service class of the vehicle where the engine is ultimately installed, as summarized in Table 2. The two right columns of Table 2 show the stringency of the model year (MY) 2017 standards for tractor trucks and vocational vehicles compared to a MY 2010 baseline. The MY 2017 engine standards are the second series of standards in the Phase 1 program and come three years after standards for MY 2014, which is the first year of the US regulation.

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2   Brake horsepower is a measure of the power delivered at the output shaft of an engine. It is a measure of an engine's horsepower before the losses in energy caused by the transmission and drivetrain.

3   In 2013, Canada established a GHG regulation for HDVs that is harmonized with the US program and also has a separate engine standard.
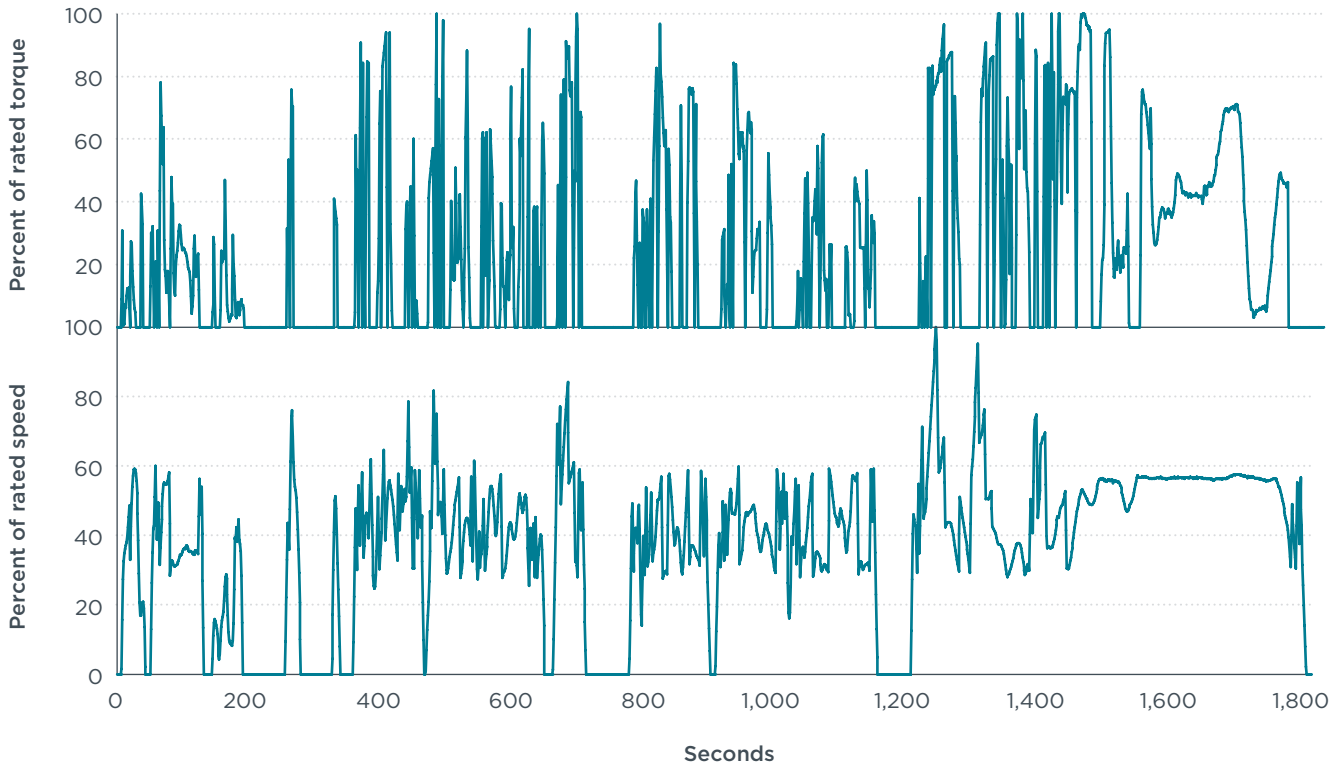
Figure 12: World Harmonized Transient Cycle (WHTC) for heavy-duty engines

Table 2: Regulatory categories and stringency values of the engine standard of the US heavy-duty fuel efficiency and GHG regulation

Vehicle class	Gross vehicle weight rating (pounds)	Engine regulatory category	MY 2017 stringency vs. MY 2010 baseline (tractor trucks)	MY 2017 stringency vs. MY 2010 baseline (vocational vehicles)
Classes 2b – 5	8,500 – 19,500	Light heavy-duty (LHD)	N/A	9%
Classes 6 – 7	19,501 – 33,000	Medium heavy-duty (MHD)	6%	9%
Class 8	> 33,000	Heavy heavy-duty (HHD)	6%	5%

The rationale behind using these three classes of engines in the regulation is to be able to take into account the fact that smaller displacement engines are inherently less efficient compared to larger engines. The reason that smaller engines have worse fuel consumption per unit of power produced relates to the heat transfer losses, which are proportional to the surface area-to-volume ratio of the cylinders. Larger engines can achieve higher efficiencies because their surface area-to-volume ratio is low, and the parasitics, and pumping losses represent a lower percentage of overall brake power.

Actual testing data helps to illustrate the intrinsic efficiency superiority of larger engines. These engine size dynamics are evidenced when looking at the certification data from the US EPA. Figure 13 presents CO_2 test data for 35 different MY 2014 heavy-duty engines. Each engine has two distinct results on the y-axis: the top circle point corresponds to the measured value over the FTP cycle, and the bottom square point is for the SET cycle. The blue data points on the left of the figure are for heavy heavy-duty (HHD) engines, the yellow points in the middle are for the MHD engines, and the green ones on the right are for LHD engines. The data points with the red outline are the straight averages for the HHD, MHD, and LHD engines over each cycle. From the data scatter, the points seem to be trending to the upper left, and this increase in CO_2 emissions going from heavy to medium to light heavy-duty engines is more clearly seen by looking at the three sets of average emissions with the red outline. For the FTP cycle, the MHD average CO_2 value is 5% higher than the HHD average, and this trend continues, as the LHD average is another 4% higher than the MHD average. For the SET cycle, these average increases from the HHD to MHD and MHD to LHD are 10% and 6%, respectively.
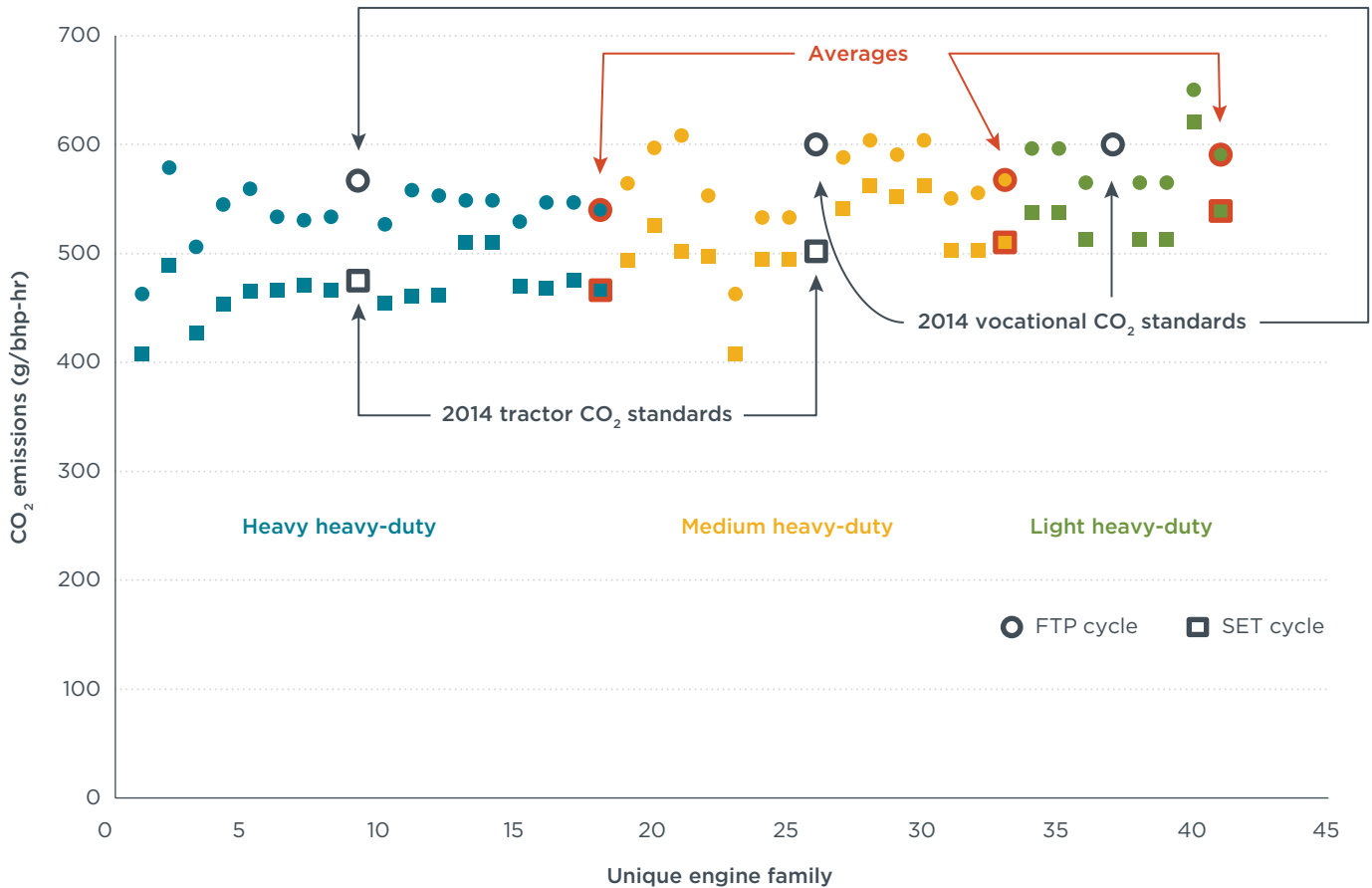
Figure 13: Testing data and CO_2 standards for model year 2014 US engines

If all of these engines were evaluated using the same numerical CO_2 standard, the larger displacement engines would have an advantage over the smaller engines. In this scenario, the engines at the larger end of the spectrum would be favored by the regulation. Creating regulatory categories of engines that are presumably comparable in size mitigates the inherent efficiency disadvantage of the smaller engines. So, staying with this US-based example, instead of all of the engines (which range from 3 to 16 liters and 120 to 450 kW) being evaluated together, individual regulatory standards for each of the three engine categories (i.e., LHD, MHD, and HHD) make for a much more equitable comparison. In Figure 13 the MY 2014 standards for heavy-duty engines are shown with the white data points in the black outline. Since the US regulation is based on sales-weighted averaging, some of the engine test points are below the standard, and some are above. Engines intended for tractor trucks are evaluated for CO_2 emissions using the SET cycle, and vocational vehicle engines are assessed over the FTP cycle.

3.2 RECOMMENDED ENGINE CATEGORIZATION SCHEME FOR INDIA

As discussed in Section 2, one of the defining characteristics of Indian HDVs is small average engine size compared to other markets. Figure 11 illustrates that the great majority of HDV engines in India are less than 9 liters, and Figure 14 shows the distribution of engine sizes with size bins shifted towards the smaller end of the spectrum. Engines between 3 and 7 liters make up almost 99% of the total sales market. The 5 to 7 liter category accounts for nearly half of sales, and just over one-quarter of all trucks and buses utilize the most popular engine model, the Cummins 5.9 liter.

Given this unique aspect of the Indian HDV market, an engine classification system should be tailored to local conditions and designed to minimize unintended market impacts. The remainder of Section 3 presents three different options to classify engines: (1) according to the intended vehicle GVWR and type of vehicle (Section 3.2.1), and (2, 3) according to engine size or power rating (Section 3.2.2). Finally, we compare the relative advantages and disadvantages of each of the three methods in Section 3.3.
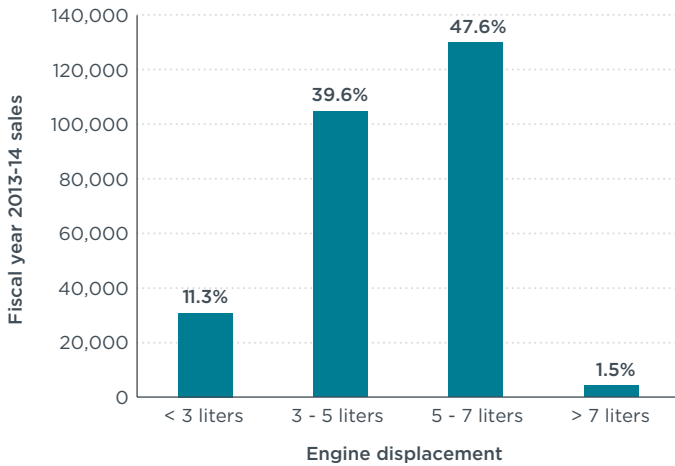
Figure 14: Engine sales by size bin for heavy-duty vehicles in India

3.2.1 Classifying engines based on vehicle size and type

Figure 15 displays each unique size and power combination for HDV engines broken into four categories: trucks less than 12 tonnes, trucks greater than 12 tonnes, buses less than 12 tonnes, and buses greater than 12 tonnes. The blue and orange points represent smaller sized trucks and buses, and these engines are fairly tightly bunched between 2 and 4 liters. However, engines used for trucks and buses larger than 12 tonnes span extensively, ranging all the way from 3 to 16 liters.

The data shown in Figures 15 and 16 are useful for determining how engines might be categorized and whether the US approach, which assigns engines to a category based on the intended service class (i.e., gross vehicle weight category) of the vehicle in which the engine is installed, is tenable for the Indian context. In Figure 15, the significant size range of engines utilized in large trucks and buses over 12 tonnes in India is evident. When weighting the unique points of Figure 15 according to sales volume, Figure 16 is the resulting plot, where the size of the bubble corresponds to the volume of units sold.

Figures 15 and 16 suggest that though an engine grouping strategy based on vehicle GVWR could result in wide ranges of engine sizes within the same category, if the regulation were based on sales-weighted averaging, the inherent efficiency advantages of the larger engines would be mostly negated by the very small sales volumes.

However, when investigating the merits of categorizing by vehicle characteristics, beyond GVWR, the ability to group engines based on vehicle *type* yields a very important benefit. Fundamentally, in designing a separate engine standard to evaluate fuel efficiency, the more closely that the engine test cycle can approximate in-use operations, the better. Using information about what type and size of vehicle the engine will ultimately be installed allows regulators to develop test
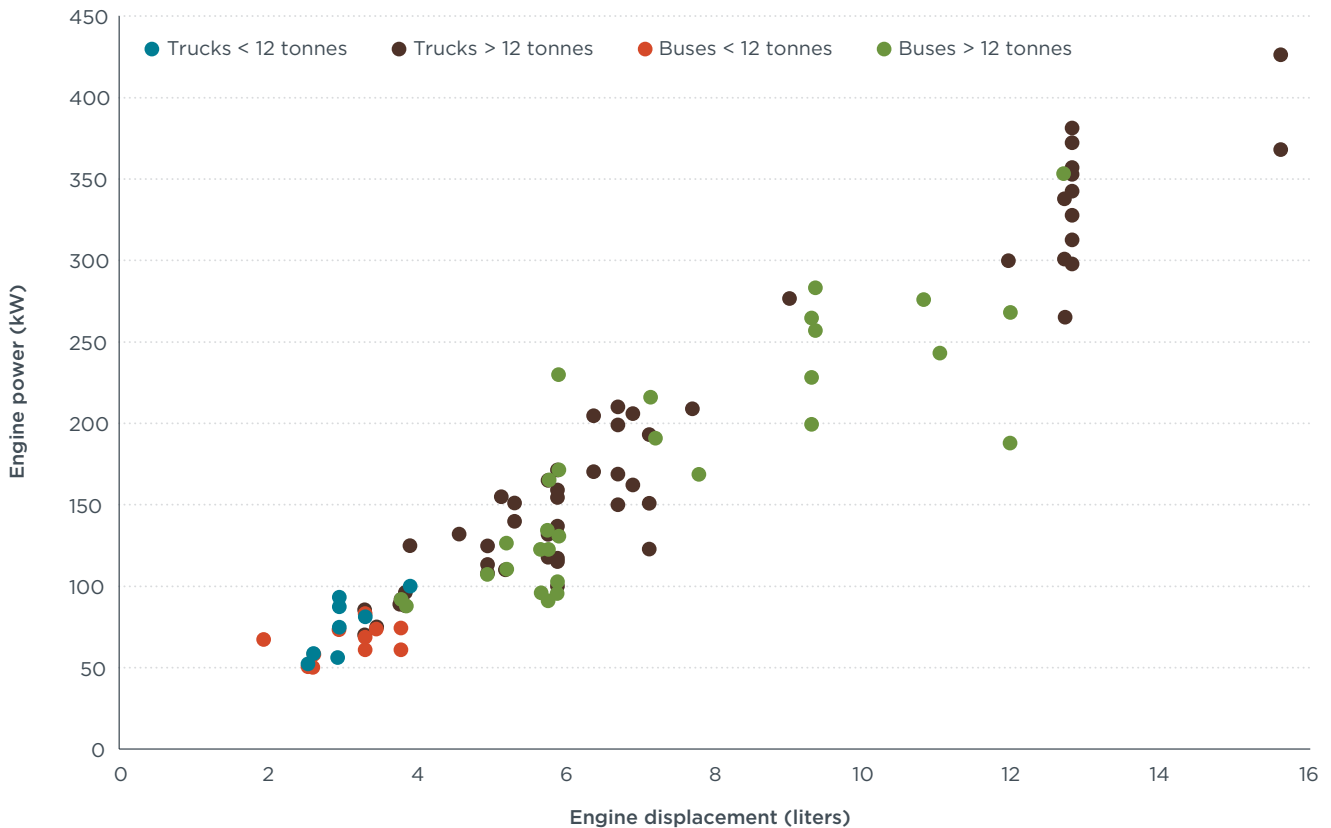

Figure 15: Unique engine size and power points for heavy-duty vehicles in India
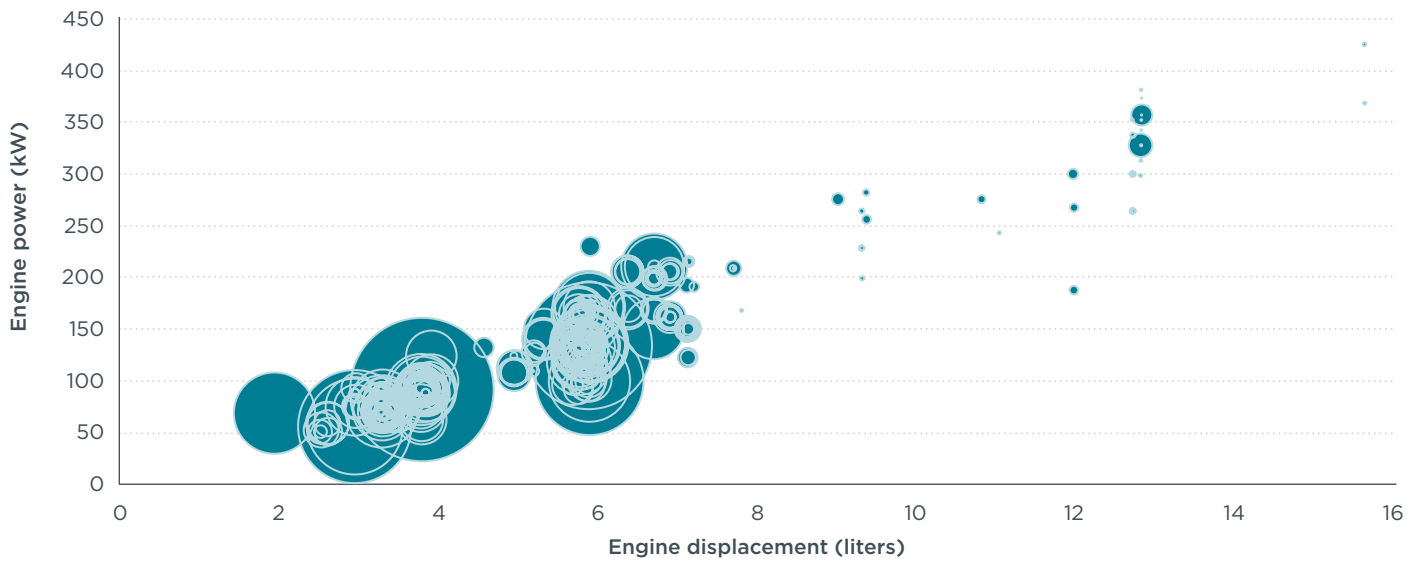
Figure 16: Sales-weight plot of engine size and power points

procedures that are better matched to real-world driving. The separate engine standards of the US and Canadian GHG regulations for HDVs offer an example of such an approach. As shown in Figure 13, engines are grouped not only by GVWR, but also on the basis of whether there will be utilized in a tractor truck or a vocational vehicle. In Figure 13, the white square and circle data points outlined in black represent the MY 2014 CO_2 standards for tractor trucks and vocational vehicles, respectively. In North America, tractor trucks usually spend the majority of their time on highways at constant speeds, whereas vocational vehicles generally operate in urban or suburban areas where more stop-and-go driving is typical. As such, the regulation requires that tractor truck engines are evaluated over the steady-state SET cycle, and vocational vehicles over the transient FTP cycle. This is advantageous to measuring all engines over the same test cycle. By categorizing engines by vehicle GVWR and type, an efficiency regulation can (1) mitigate the intrinsic efficiency advantages of larger engines, and (2) select engine test cycles that are more representative of the way that engines are used on the road.

Given the benefits of segregating engines according to both GVWR and type, we can use the Segment Y data set to propose an example classification system for engines. Choosing how to segment in terms of vehicle GVWR and type is somewhat arbitrary, so the following classification scheme is simply an example that allows us to illustrate what the distribution of engines would look like under such an approach. In this example, we chose for three weight classes for trucks and two for buses:

Trucks:

- Less than 12 tonnes
- Between 12 and 25 tonnes
- Greater than 25 tonnes

Buses:

- Less than 12 tonnes
- Greater than 12 tonnes

These bins are taken from a common classification system for commercial vehicles used by the Indian Society of Automotive Manufacturers (SIAM).

For vehicle type, the most straight-forward distinction is between trucks and buses. After more careful scrutiny of in-use driving behavior, it may be determined that more granular classifications are warranted, since there is presumably a fairly broad range of operating behaviors within both the truck and bus segment. However, at this juncture, erring on the side of simplicity seems reasonable. Future research can help to determine whether or not the added complexity of additional vehicle type distinctions and/or GVWR bins is merited and can allow regulators to design more representative test cycles.

Overlaying the GVWR pivot points onto Figure 3 gives Figure 17, which shows how sales are distributed between the weight bins for trucks and buses. For trucks, sales are reasonably well distributed between the three bins, with the trucks greater than 20 tonnes representing about 45% of sales, nearly 20% of the market for trucks between 12 and 25 tonnes, and the remaining 35% for trucks less than 12 tonnes. Looking at the bus data, about two-thirds of sales are models below 12 tonnes, with the remaining one-third going to the heaviest buses.

Figures 18 and 19 show the engine size distributions for each of the GVWR bins for trucks and buses. From Figure 18 it is evident that the engine sizes are most tightly grouped for trucks less than 12 tonnes, with the large majority of engines between 3 and 4 liters. Trucks between 12 and 25 tonnes
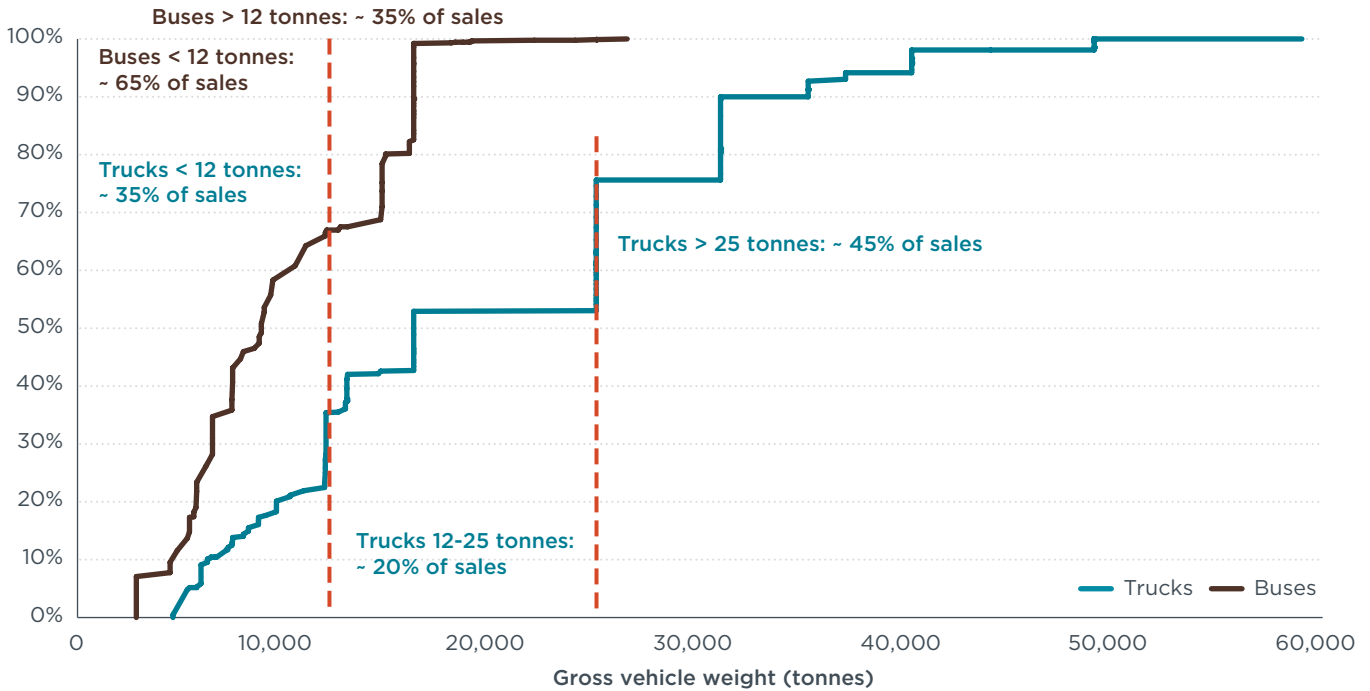
Figure 17: Market shares of truck and buses in each gross vehicle weight category

primarily have engines that range from 3 to 6 liters, and the heaviest truck engines are predominately between 5 and 7 liters. Figure 19 shows that engines generally fall between 2 and 4 liters for buses less than 12 tonnes. However, the engine size distribution for the heaviest class of buses shows a relatively large range from 5 up to 13 liters. However, buses greater than 16 tonnes make up only a miniscule portion of the bus market (0.7%). If we exclude these buses over 16 tonnes, the engine size distribution is tightly bunched between 5 and 6 liters.
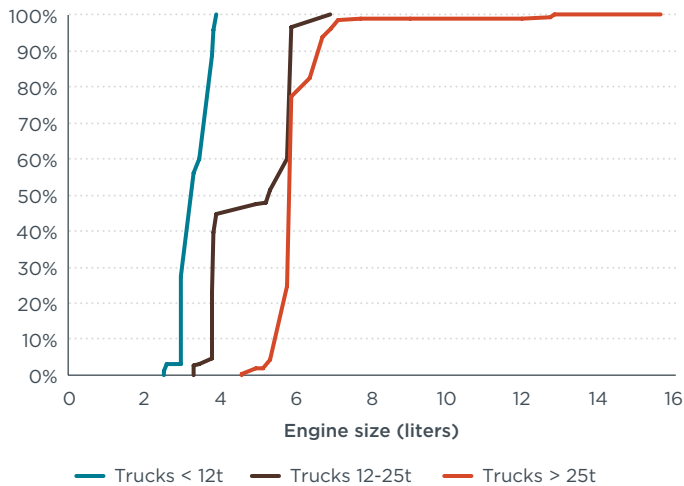

Figure 18: Engine size distributions for trucks in the three example vehicle weight categories
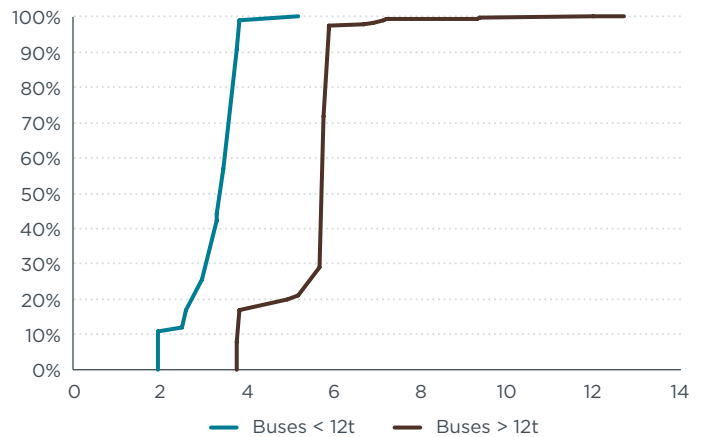

Figure 19: Engine size distributions for buses in the two example vehicle weight categories

3.2.2 Classifying engines based on engine-specific characteristics

Despite the benefits of grouping engines by vehicle GVWR and type, a potential downside of this approach is that a wide range of engine sizes would be in the same category, as shown in Figures 15, 18, and 19. An alternative strategy is to use an engine-specific parameter to group engines. In order to mitigate the advantage of large engines, it is necessary to group engines using rated power or a parameter highly correlated to power. In Figure 15, the R^2 value for all of the engine data points is 0.9, so engine displacement is fairly strong proxy for engine power. Since either size or power is likely a reasonable approach to grouping engines, we can

develop a categorization scheme based on engine displacement and one based on engine power to see how they compare. The basis for comparison is to see which approach yields the highest degree of homogeneity of engine classes within similar types of vehicles. Ideally, engines in similar types of vehicles are evaluated in the same regulatory category.

For simplicity, we've developed two categorization schemes, which are summarized in Table 3.

Table 3: Two engine categorization methods based on engine characteristics

Method 1 (size-based)	Method 2 (power-based)
Less than 4 liters	Less than 100 kW
4 to 7 liters	100 to 200 kW
Greater than 7 liters	Greater than 200 kW

Applying each of these two methods to the fleet, the breakdown of engine categories across the various vehicle segments is summarized in Figure 20 (grouping by size) and Figure 21 (grouping by power). Looking at both figures, each method produces similar results in terms of the distribution of the three engine categories. In both figures, there is a reasonable degree of uniformity within each vehicle segment, with trucks 12 to 16 tonnes and buses greater than 16 tonnes being the most notable exceptions. However, comparing the two figures, there is more uniformity in the columns of Figure 20. In Figure 21, there are six instances in which the non-majority engine category makes up more than 10% of the engines sold in that vehicle segment. In Figure 20, there are only two such occurrences. This implies that for this particular example displacement is a more effective parameter than power for engine categorization.

In addition, another rationale for grouping based on engine size is the fact that you can change the power rating of an engine relatively easily by changing the calibrations, and this does not require any hardware modifications. Conversely, you cannot change the displacement of an engine without doing a major overhaul to the hardware. Thus, binning by displacement reduces the risk of manufacturers 'gaming' the regulation by shifting their engines to one of the lower power engine categories, which would have a higher grams per kWh CO_2 standard.
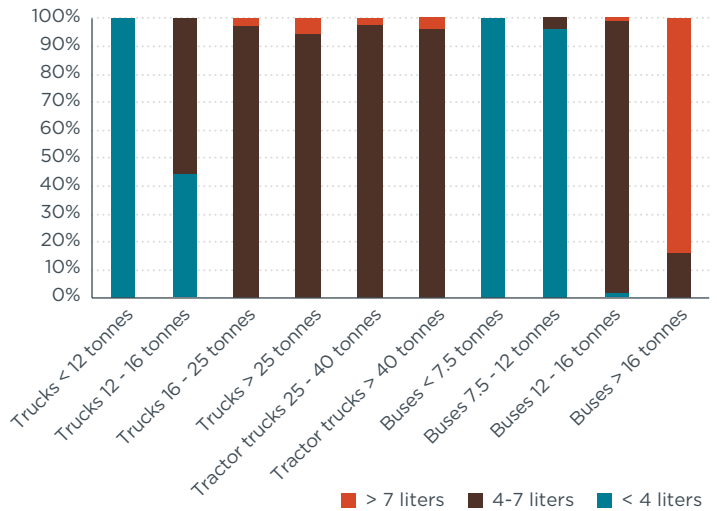

> 7 liters   4-7 liters   < 4 liters

Figure 20: Engine sales by the vehicle type and gross vehicle weight for three engine size-based bins
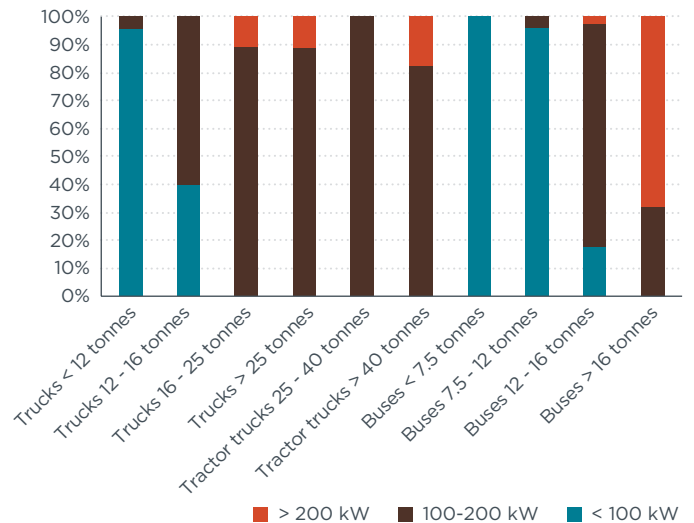

> 200 kW   100-200 kW   < 100 kW

Figure 21: Engine sales by the vehicle type and gross vehicle weight for three engine power-based bins

3.3 COMPARING ENGINE CATEGORIZATION OPTIONS

Table 4 summarizes the relative merits of each of the engine categorization approaches we developed for this analysis. The most significant benefit of classifying engines according to vehicle size and type is that unique test cycles can be used for each engine category to more closely correspond to how the engine will be operated over its lifetime. The downside of this method is that it would likely result in engine categories with large size and power ranges for vehicles at the heavier end of the spectrum (unless a large number of categories are developed, which would create added complexity to the regulation).

Grouping engines by displacement is slightly preferable categorization approach than doing so using rated power in the example. However, this is likely more of a function of the choice of size and power bins in this particular example rather than an indication that grouping by size is fundamentally more robust.

Table 4: Advantages and disadvantages of the three engine categorization methods

Grouping by	Advantages	Disadvantages
Vehicle GVWR and type	• Most attractive method for ensuring engines installed in similar types of vehicles are grouped in the same category • Unique engine cycles can be utilized to better reflect real-world operations	Could lead to wide ranges of engine size and power ratings in the same regulatory category → inherent efficiency advantage of large engines could incentivize trend towards bigger engines
Engine size	Parameter is very difficult to change without major hardware overalls → virtual eliminates opportunities for gaming	Very little opportunity to choose different test cycles to more closely match in-use operations
Engine power	Parameter directly corresponds to the grams per brake horsepower metric for evaluating engines	Same as above

From this comparison, our *preliminary* assessment is that grouping engines according to vehicle type and GVWR is the best choice amongst the three methods. The most important advantage of this approach is the ability to potentially utilize engine test cycles that better reflect how the engine will ultimately be used on the road. Given that certain stakeholders are already claiming that engine testing does a poor job of representing real-world operations, we think that it is vital to be able to use different engine test cycles (e.g., steady-state, transient, etc.) to simulate various kinds of HDV operations. Having engine cycles that are more tailored to specific driving patterns can give industry, government, and other stakeholders more confidence that the improvements achieved over the regulatory cycles will effectively translate to real-world benefits.

Given the importance of designing a regulation tailored to the unique aspects of the current Indian HDV market as well as changes anticipated in the future, we are reaching out to expert stakeholders for their input on this engine categorization issue. After soliciting feedback on each of these options from expert stakeholders, we will update this paper to reflect our recommended approach for India.

4. Conclusions and future work

One of the primary objectives of this paper is to build up the knowledge base of the new HDV sales market in India. In any regulatory development process, a robust understanding of the market is necessary to better forecast how any potential policy measure might affect the competitive balance, how to design a regulation that is tailored to local conditions, and how best to avoid unintended consequences.

The Indian HDV market is fairly consolidated, as the top three manufacturers account for roughly 85% of sales. By itself, Tata Motors represents over half of truck sales and almost half of bus sales. Tata's market share is almost triple that of the nearest competitor, Ashok Leyland, and following closely behind is VE Commercial Vehicles. After these three companies, market shares drop off to under 5% for all of the remaining manufacturers. Engine manufacturing is impacted strongly by the presence of Cummins, an independent engine supplier. Cummins' overall market share is 30%, and Tata represents over 90% of Cummins' sales.

Compared to China, the EU, and US, the most unique characteristic of commercial vehicles in India is that they have much smaller engines, on average. Another distinctive feature of the Indian HDV market is approximately double the proportion of bus sales compared to the other three regions.

In a recently published white paper (Sharpe 2015), we recommended that India should work towards establishing engine-based standards as a first phase efficiency regulation for HDVs. In designing an engine efficiency regulation, engine categories should be developed to mitigate the inherent efficiency advantage that larger engines have compared to smaller engines per unit of power produced. Otherwise, regulating all engines together would incentivize a shift towards larger engines, which would likely result in increased fuel consumption. Current HDV regulations in the US and Canada have separate engine standards, and both of these programs group engines into three distinct regulatory categories that have unique CO_2 targets.

In this paper, we have analyzed three distinct methods for grouping engines into regulatory categories for the Indian market. We present simple examples in which engines are classified according to:

• GVWR of the intended vehicle: less than 12 tonnes, 12 – 25 tonnes, and greater than 25 tonnes for trucks; less than 12 tonnes, and greater than 12 tonnes for buses

• Engine size: less than 4 liters; 4 – 7 liters; greater than 7 liters

• Engine rated power: less than 100 kW; 100 – 200 kW;

greater than 200 kW

In comparing the three approaches, our preliminary assessment is that grouping by vehicle type and GVWR provides the most benefits and the least downside. The most significant advantage of this approach is the potential to utilize different test cycles for the various regulatory categories in order to more closely correspond to in-use operations. However, we are in the process of engaging various stakeholders on this engine categorization issue and will abstain from making a final recommendation at this time. After this exchange with expert stakeholders, we will update this paper to reflect our recommended approach for India.

Future ICCT research will investigate the impacts of regulatory duty cycles, technology potential for the engine and full vehicle, and costs and benefits of various policy options. In addition, we are currently in the process of interviewing a diverse set of industry stakeholders to gain a deeper understanding about attitudes, experiences, and expectations of manufacturers and fleets around efficiency.

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