THE REAL URBAN EMISSIONS INITIATIVE

CASE STUDY

OCTOBER 2020

Emissions deterioration of U.S. gasoline light-duty vehicles and trucks

TRUE Initiative U.S. remote sensing database case study

Regulation of emissions generally relies on testing new vehicles under controlled conditions. In reality, vehicles on U.S. roads are, on average, 12 years old and are used in a wide range of environments.[1] To bridge the gap between certification and real-world conditions, U.S. policymakers have implemented a range of regulatory measures including in-use vehicle testing, durability requirements for emission control systems, and requirements for on-board diagnostics of emissions control systems.

Emissions deterioration—increasing emissions as a function of vehicle age and/or mileage—can occur for various reasons. In gasoline vehicles, decreased catalyst conversion efficiency due to aging and high exhaust temperatures, catalyst poisoning from contaminants in fuel or engine oil, and catalyst or sensor malfunctioning can lead to deterioration.[2] In addition, tampering with emissions control technologies can cause sharp increases in emission levels.

Emissions deterioration has been studied for decades using remote sensing technology. The most prominent example is longitudinal measurements collected in several locations by the University of Denver.[3] This case study expands on University of Denver work by analyzing large amounts of remote sensing measurements from the Colorado Department of Public Health and Environment and the Virginia Department of Environmental Quality compiled in the TRUE Initiative U.S. remote sensing database.[4]

In theory, the TRUE U.S. database is ideal for measuring deterioration trends because of its vast size and geographical and temporal coverage. In practice, not all of its datasets and records are appropriate for measuring long-term trends. The Colorado dataset is the largest sample and covers 8.5 years of measurements, but instrument effects—the change from Opus RSD 4600 to Opus RSD 5000 around 2015—interfere with comparing carbon monoxide emissions over time. Virginia also collects large amounts of measurements—more than one million records per year—but data were only available for 2015 onward, making the dataset less suitable for estimating long-term deterioration trends.

Despite these limitations, the TRUE U.S. database provides a short-term glimpse of carbon monoxide (CO), hydrocarbon (HC), and nitric oxide (NO) emissions deterioration in gasoline light-duty vehicles (passenger cars) and light-duty trucks in Virginia, and a long-term trend in HC and NO emissions in Colorado (see Figure 1). Each point in the figure represents average fuel-specific emissions from at least 4,000 measurements. The results indicate that average fuel-specific levels of all pollutants decreased in new model years and increased with vehicle age. Model year reductions are particularly pronounced after model year 2003, when Tier 2 emission standards were being phased in. Moreover, the figure shows an approximately linear increase in emission levels over vehicle age. The rate of increase declines with model year,

1 Average Age of Automobiles and Trucks in Operation in the United States, accessed June 15, 2020, https://www.bts.gov/content/average-age-automobiles-and-trucks-operation-united-states.

2 Tao Zhan, Chris R. Ruehl, Gary A. Bishop, Seyedehsan Hosseini, John F. Collins, Seungju Yoon, and Jorn D. Herner, An Analysis of Real-World Exhaust Emission Control Deterioration in the California Light-Duty Gasoline Vehicle Fleet, *Atmospheric Environment* 220,1(2020): 117107, https://doi.org/10.1016/j.atmosenv.2019.117107.

3 Gary A. Bishop, "Measuring Emissions from the On-Road Vehicle Fleet in West Los Angeles," (California Air Resources Board, November 5, 2019), http://www.feat.biochem.du.edu/assets/databases/Cal/Univ_Denver_ARB_17RD015_Final_Report_2018.pdf; Gary A. Bishop, "On-Road Remote Sensing of Automobile Emissions in the Chicago Area: Fall 2018," (Coordinating Research Council, June 2019), http://www.feat.biochem.du.edu/assets/databases/Illinois/Arlhghts/Chicago_Year_10_CRC2018.pdf; Gary A. Bishop, "On-Road Remote Sensing of Automobile Emissions in the Tulsa Area: Fall 2017," (March 2018), http://www.feat.biochem.du.edu/assets/databases/Oklahoma/CRC-123%20Tulsa%202017%20Final%20report.pdf; Gary A. Bishop and Molly J. Haugen, "On-Road Remote Sensing of Automobile Emissions in the Denver Area: Winter 2017," (Coordinating Research Council, August 2018), http://www.feat.biochem.du.edu/assets/databases/Colorado/6th_I25/Denver_Year_9_CRC17.pdf.

4 Yoann Bernard, Tim Dallmann, Uwe Tietge, Huzeifa Badshah, and John German, *Development and application of a United States real-world vehicle emissions database*, (ICCT: Washington, DC, 2020), https://theicct.org/publications/true-us-database-development-oct2020.

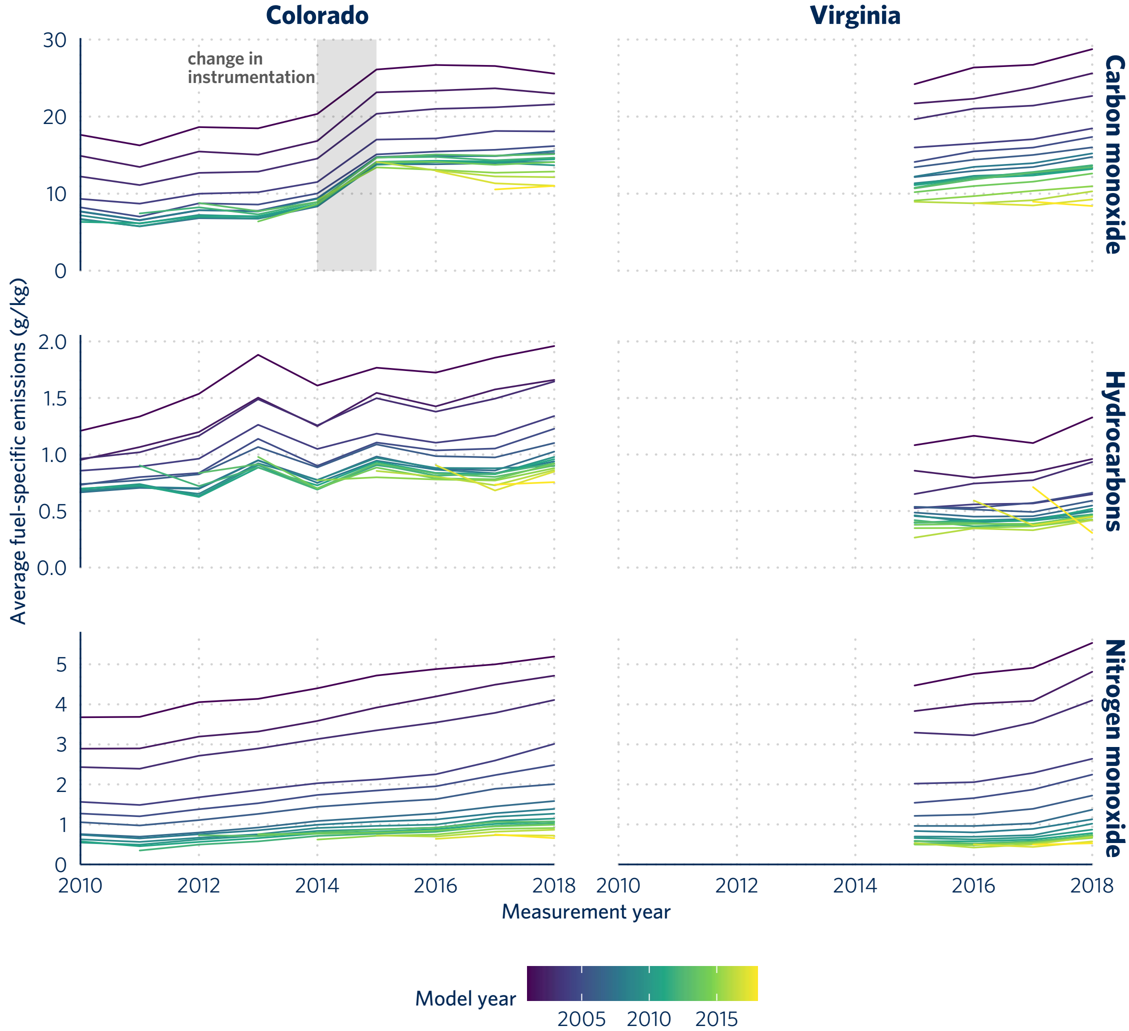

Figure 1. Average fuel-specific CO, HC, and NO emissions of gasoline light-duty vehicles (passenger cars) and light-duty trucks per data source, model year, and measurement year.

suggesting that emissions deterioration is less pronounced in modern vehicles, although this may simply indicate that deterioration impacts are proportional to the baseline emissions, not additive.

Figure 2 estimates annual deterioration rates for HC and NO emissions from light-duty vehicles (LDVs) and light-duty trucks (LDTs).[5] Each marker is based on more than 2,000 measurements and represents the slope of a univariate linear regression of fuel-specific emissions on vehicle age for each model year. This method of estimating deterioration effects was developed in previous studies.[6] Data for model year 2016 onward were not included because more time needs to pass before meaningful deterioration trends can be extracted for recent vehicles.

The results indicate that both HC and NO follow clear downward trends in deterioration rates over model years for both vehicle classes, indicating that emission regulations have become increasingly effective at limiting emissions deterioration. The level and trend in deterioration rates match findings based on University of Denver measurements in West Los Angeles, suggesting that results are valid outside of Colorado.[7]

Despite the improvements over time in the NO deterioration rate for LDVs and LDTs, we find that measured remote sensing deterioration rates are much higher than deterioration projections submitted by manufacturers during the certification process. Manufacturers have long been responsible for establishing their own deterioration factors for each engine family, following procedures established by U.S. Environmental Protection Agency (EPA). The procedures include

5 CO emissions were not studied due to aforementioned instrument effects in Colorado CO measurements.

6 Zhan et al., An Analysis of Real-World Exhaust Emission Control Deterioration in the California Light-Duty Gasoline Vehicle Fleet; Bishop, "Measuring Emissions from the On-Road Vehicle Fleet in West Los Angeles."

7 Bishop, "Measuring Emissions from the On-Road Vehicle Fleet in West Los Angeles."

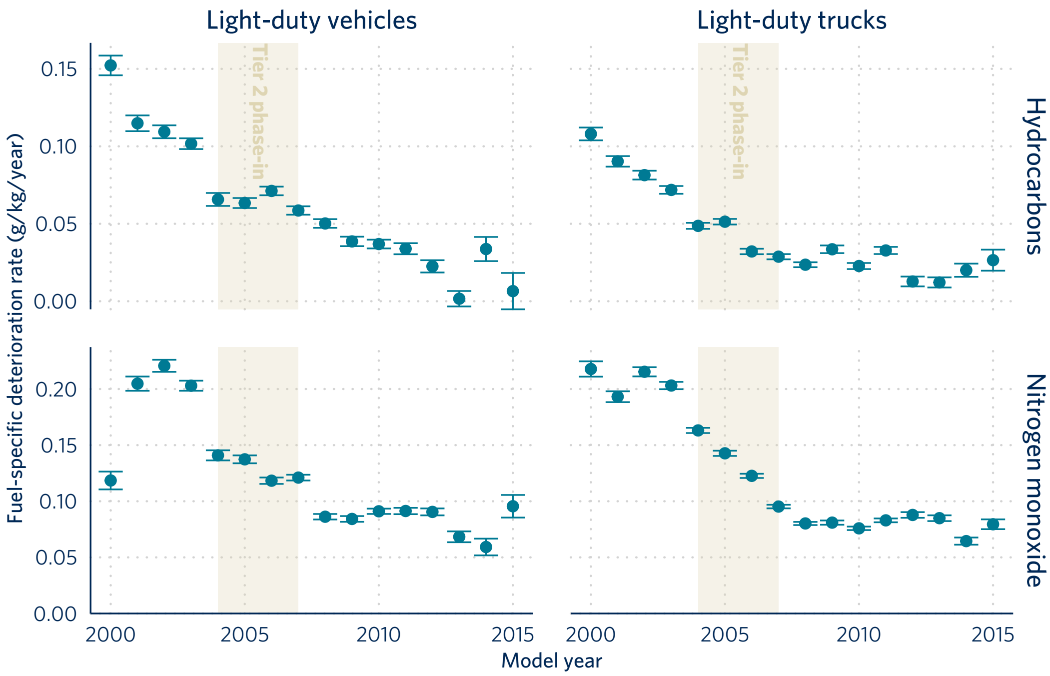

Figure 2. Estimated annual deterioration rates in fuel-specific NO emissions of gasoline light-duty vehicles and light-duty trucks. Each marker represents the slope of a linear regression of NO emissions on vehicle age. Error bars represent the standard error of the slope.

confirmatory checks based on in-use vehicle testing of properly maintained vehicles with millage up to 80,000, with enforcement measures and remedies if the in-use testing does not confirm the manufacturer-specified deterioration factor. The EPA publishes all certification testing information submitted by the manufacturers, including the manufacturer-claimed deterioration factor.[8]

We extracted certification test results published by the EPA for MY 2010 vehicles certified to 120,000 mile NO_x standards of 0.07 g/mi (EPA Tier 2 bin 5, CARB LEVII-LEV, and CARB LEVII-ULEV). These vehicles averaged 0.018 gNO_x/mile on the FTP certification test and the manufacturer-submitted deterioration factor to 120,000 miles averaged 0.010 gNO_x/mile. The certified and submitted deterioration averages for LDVs and LDTs were similar. With the useful life of the vehicles assumed to be 10 years or 120,000 miles, the average manufacturer-submitted deterioration rate is about 0.001 gNO_x/mi per year.

To compare the EPA averages to the remote sensing data, two adjustments to the data were made: the EPA data were converted to grams per kg fuel using an assumption of the average light-duty CO_2 emissions and the remote sensing NO results were converted to NO_x. Here, we assume real-world CO_2 emissions of 346 gCO_2/mi for MY 2010 LDVs[9] and a NO_2 to NO_x ratio of 5%.[10]

After applying these adjustments, the resulting EPA average manufacturer-specified deterioration rate is 0.009 gNO_x/kg per year. This is about an order of magnitude lower than remote sensing deterioration rates for MY 2010 LDVs (0.09 gNO_x/kg per year) and LDTs (0.08 gNO_x/kg per year). The large difference between the manufacturer-reported and measured remote sensing deterioration rates is due, at least in part, to manufacturers only reporting emissions from properly operating and maintained vehicles. Any in-use vehicle that cannot demonstrate proper ongoing maintenance or with any kind of emission-related malfunction is excluded from the regulatory in-use vehicle testing program. Thus, vehicle emission impacts due to malfunctions, less than ideal maintenance, or tampering likely explain much of the difference. There are also possible operating and ambient impacts on emissions, as the FTP is conducted at 75°F (24°C) over a fixed route with mild accelerations and no accessory loads. Remote sensing measures vehicles over a wide range of ambient temperatures, traffic congestion levels, vehicle speeds and accelerations, cargo loads, and air conditioning and accessory use, which likely contribute to higher in-use

8 U.S. EPA Annual Certification Data for Vehicles, Engines, and Equipment, accessed July, 2020, https://www.epa.gov/compliance-and-fuel-economy-data/annual-certification-data-vehicles-engines-and-equipment

9 U.S. EPA Automotive Trends Report, accessed August 1, 2020, https://www.epa.gov/automotive-trends/explore-automotive-trends-data

10 Yoann Bernard, Uwe Tietge, John German, and Rachel Muncrief, *Determination of Real-World Emissions from Passenger Vehicles Using Remote Sensing Data*, (ICCT: Washington, DC, 2018), https://theicct.org/publications/real-world-emissions-using-remote-sensing-data

emissions. Further work is needed to better understand these discrepancies and the causes.

The analysis of deterioration trends in the TRUE U.S. database highlights the value of large-scale, long-term remote sensing measurements as a key source of empirical data on real-world emissions from vehicles. Results indicate that U.S. emissions regulations have become increasingly effective at preventing emissions deterioration, though remote sensing deterioration rates appear to be elevated compared to manufacturer deterioration projections. The results echo findings from smaller remote sensing samples collected in California by the University of Denver, suggesting that the deterioration rates presented here could also apply in other areas of the United States. Future investigations should compare these empirical deterioration rates with deterioration rates assumed in air quality tools such as the Motor Vehicle Emission Simulator (MOVES) model[11] and compare deterioration rates across vehicle manufacturers.

11 MOVES2014b: Latest Version of Motor Vehicle Emission Simulator, U.S. Environmental Protection Agency, (2016), https://www.epa.gov/moves/latest-version-motor-vehicle-emission-simulator-moves.

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This case study is based on an analysis of the TRUE Initiative U.S. remote sensing database.

For more information, please see:
"Development and application of a United States real-world vehicle emissions database"
https://theicct.org/publications/true-us-database-development-oct2020

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