Impact of Engine Regulations on Heavy-Duty Vehicle Manufacturing Employment, Production, and Sales

October 2022

The business of sustainability

ERM

Acknowledgements

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This report was developed by ERM for the National Resource Defense Council, the Sierra Club, and the Union of Concerned Scientists.

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EXECUTIVE SUMMARY

ERM was commissioned by the Natural Resources Defense Council, Sierra Club, and the Union of Concerned Scientists to evaluate the connection between the implementation of heavy-duty engine emission regulations and changes in heavy-duty vehicle (HDV) manufacturing employment, production, and sales. Since the regulations are finalized years in advance of their implementation, consumers may anticipate the regulation and change the timing of their purchases of Class 4 to 8 HDVs. To achieve the reduced emissions required by the regulations, original equipment manufacturers (OEMs) need to install new pollution-control technologies that may increase the cost of the vehicle and create some uncertainty about long-term operations and maintenance (O&M) costs for vehicle owners. As a result, consumers may view the pre-regulation vehicles as more desirable and purchase vehicles earlier than they would have otherwise, increasing the number of sales ahead of the regulation and depressing sales once the regulation goes into effect. This phenomenon is termed “pre-buy/low-buy” and has potential to cause disruptions in the HDV manufacturing industry.

The hypothesis is that a pre-buy/low-buy caused by a regulation would show significantly higher sales in the period prior to a regulation going into effect and significantly lower sales in the period after the regulation goes into effect. The pre-buy/low-buy hypothesis is based on the assumption that HDV demand is shifted forward, such that HDV purchases are made earlier than they would be without the regulation. However, this hypothesis necessitates that both effects occur because the regulation is not materially creating nor destroying vehicle demand; it is simply shifting that demand from one period to another. The hypothesis also often asserts that production and employment will see similar, significant effects during the same time periods, due to the increased and then depressed sales.

This study primarily focuses on HDV (Classes 4 through 8) manufacturing employment, to investigate and address the claim that HDV environmental regulations are detrimental to employment because vehicle manufacturers hire then lay off workers in response to the added volatility of vehicle demand due to the regulation. However, because pre-buy/low-buy employment effects cannot occur without a shift in demand that affects first sales, then production, this analysis also looks for evidence of pre-buy/low-buy in the production and sales data.

This study first analyzes the regulation that began with model year (MY) 2007 vehicles. The 2007 regulation is cited most frequently by other studies because large changes to the vehicles were required to accomplish the required emission reductions. Our results show that there is no statistically significant pre-buy/low-buy impact on HDV manufacturing employment as a result of the 2007 regulation. Even when the length of the pre-buy/low-buy periods and the effective date of the regulation are changed, there is no evidence of employment impacts from the regulation. For production and sales, the main model results indicate significantly higher than expected sales and production in 2006, but there is no corresponding period of significantly lower sales and production in 2007 that would indicate a pre-buy/low-buy effect. Thus, the higher sales and production in 2006 is likely caused by other factors than the regulation.[1]

The study also investigates the 2004, 2010, and 2014 regulations for evidence of potential pre-buy/low-buy effects. None of these regulations have results that support the pre-buy/low-buy hypothesis. A review of the pre-buy/low-buy literature shows that other studies that find pre-buy/low-buy effects have results

[1] In the sensitivity analysis, there was one model with results consistent with a pre-buy/low-buy pattern, but when taken with the other models, the likelihood this indicates an impact from the regulation decreases.

that are inconsistent across studies in terms of the timing, duration, and magnitude of the effects, in spite of studying the same regulations, often with the same data.

The results of this study demonstrate that there is no material impact of the 2004, 2010, 2007, and 2014 HDV emission regulations on industry employment. Moreover, our results and the lack of consistent results from other studies indicate that there is also no firm basis for concluding that there is a material pre-buy/low-buy impact on sales or production as a result of HDV engine regulations.

In summary, the results of this analysis and evaluation show the following:

1) There is no evidence of a pre-buy/low-buy impact on HDV manufacturing employment around the 2004, 2007, 2010, and 2014 engine emission standard regulations.
2) The models for production and sales generally do not support the pre-buy/low-buy hypothesis. While some significant effects are observed, there is insufficient evidence to definitively attribute the impacts to the regulation.
3) Pre-buy/low-buy patterns for Class 8 vehicle sales surrounding the 2007 regulation suggest the effects are due to factors other than the regulation including HDV sales being a leading indicator for recessions.
4) A comparison of the results from previous studies that have estimated the pre-buy/low-buy effect of the 2007 engine standard regulation shows that the results are inconsistent across studies with respect to the timing, duration, and magnitude of the impacts, casting doubt on the robustness of the results.

INTRODUCTION

Heavy-duty vehicles (HDVs) are essential for the economy. They include a diverse set of commercial vehicles: school and shuttle buses; sanitation, construction, and other types of work trucks; and freight trucks ranging from local delivery trucks to tractor-trailers that often weigh 80,000 pounds when loaded. Trucks transport the vast majority (71.6 percent) of goods moved in the U.S. and HDV manufacturing creates thousands of jobs and adds billions of dollars to the U.S. economy.

However, HDVs are currently responsible for a disproportionate amount of pollution from on-road vehicles. Despite making up only 3.5 percent of the on-road fleet, Class 4 to 8 vehicles emit an estimated 469 million metric tons (MMT) of greenhouse gas (GHG) emissions annually—approximately 22 percent of all GHGs from the on-road vehicle fleet. HDVs are also responsible for 52 percent of the nitrogen oxides (NOx) and 56 percent of the particulate matter (PM) emitted by on-road vehicles. These pollutants contribute to poor air quality and cause negative health impacts in many areas, including more densely populated urban areas. Low-income neighborhoods and communities of color are often disproportionately affected by emissions from freight movement due to their proximity to transportation infrastructure exacerbating existing environmental inequality.

Criteria pollutant emissions from HDVs have decreased substantially in the last half century in large part due to increasing engine emission standards set by the U.S. Environmental Protection Agency (EPA). As an example, when EPA set the first NOx-only emission HD engines for model year (MY) 1985, the limit was 10.7 grams per brake horsepower-hour (g/bhp-hr); the current standard is 0.2 g/bhp-hr which fully phased into effect in 2010, a substantial decrease in per unit of vehicle activity. Even though these standards are set using lab tests and the real-world reductions in pollution is not quite as large, they have generated enormous social benefits from improved air quality. However, the implementation of the regulations has led some parties to express concerns about perceived impacts on the economy and truck manufacturing employment. Due to the current heavy-duty engine standard EPA is considering, concerns have reemerged regarding the potential impacts on the truck manufacturing industry.[2] This study investigates those concerns.

Previous Regulations

As previously mentioned, this is not the first time the EPA has strengthened the emissions standards for heavy-duty engines. Since 1975, there have been numerous changes to emission standards for heavy-duty engines which required modifications to either the engine or its exhaust system to meet the standards. The following subsections describe the major emission regulation changes for compression-ignition engines based on the first model year it was introduced.

Pre-2004

Emission regulations were first adopted by EPA for MY1974 and were focused on carbon monoxide and hydrocarbon emissions. Over time, EPA introduced higher standards for heavy-duty engines requiring them to meet lower NOx and PM emissions standards. These standards necessitated internal modifications to manufacturers engines to meet the requirements. Standards continued to be strengthened through the 1980s and 1990s with in-engine changes. Starting with MY1994, EPA required a significant reduction in PM exhaust emissions from heavy-duty engines, resulting in a standard of 0.10

[2] Truck and Engine Manufacturers Association, *Potential Jobs Impacts Expected with EPA Rule* (Chicago, 2021).

g/bhp-hr. For some manufacturers, this standard required the use of exhaust aftertreatment to achieve the lower emission threshold.

2004-2006

Prior to the 2004 regulations, EPA along with the Department of Justice, California Air Resources Board (CARB) and the majority of heavy-duty engine manufacturers reached a court settlement over an issue of high NOx emissions when engines were operated at certain driving speeds. As part of the court settlement, heavy-duty engine manufacturers agreed to meet the 2004 regulations starting in October 2002.For the remainder of this report, this is called the 2004 regulation. For the new regulations, EPA focused on NOx and hydrocarbon emissions, stipulating a significant reduction from 1990 levels. To meet this level, manufacturers could no longer rely on engine timing or component changes to comply with the standards and most redesigned their engines with exhaust gas recirculation (EGR) to reduce the amount of NOx emitted. EGR equipped engines were most often paired with diesel oxidation catalysts to maintain compliance with both the NOx and PM standards under all driving conditions.

2007-2009

Starting with MY2007, EPA enacted heavy-duty engine standards to enable significant reductions in NOx and PM emissions. The emission regulations required heavy-duty engines to meet a PM standard of 0.01 g/bhp-hr and a NOx standard of 0.2 g/bhp-hr, the latter which was phased in over the 2007-2010 time period. Both of these standards were approximately 98 percent less than the standards required in the 1980s. To meet the PM standard, manufacturers introduced advanced exhaust filters, such as catalytic diesel particulate filters (DPFs). For the NOx standard, most manufacturers opted for a compliance strategy where all manufacturer engines produced could meet a family emission limit (FEL) of approximately 1.2 g/bhp-hr. Because of the averaging and banking provisions of the standard, this allowed engines produced prior to 2010 to avoid the use of selective catalytic reduction (SCR) while complying with the phased-in 0.2 g/bhp-hr NOx standard.

2010

Although there was not a regulation change in 2010, there were two substantial changes in the required standards: first, 100 percent of vehicles were required to meet the 0.2 g/bhp-hr standard, as opposed to just 50 percent during the 2007-2009 time period; second, the FEL afforded to manufacturers between 2007-2009 was no longer available, reducing emissions from the heaviest polluting new vehicles. This lower FEL required manufacturers to add SCR to the vehicle’s exhaust system and necessitated advanced vehicle and engine controls to monitor and regulate engine power based on exhaust emission performance. The use of SCR required an additional dosing chemical called diesel exhaust fluid (DEF) to be injected into the exhaust stream to enable the catalytic activation of the SCR system. If the vehicle ran out of DEF, the engine control system was required to de-rate (i.e., reduce) power of the engine until the DEF tank was refilled.

2014 (Phase 1 GHGs)

Unlike the previous standards discussed, EPA’s 2014 regulation focused on GHG emissions, most notably carbon dioxide (CO_2) emissions from vehicle exhaust. Under the GHG regulation, different vehicle categories were required to meet unique standards depending on their size or use. For tractors, this meant achieving a 7 to 20 percent reduction in CO_2 emissions by MY 2017 over a MY 2010 baseline. All vocational vehicles, as well as gasoline commercial vans and pickups, were required to achieve a 10 percent reduction in CO_2 emissions from the MY 2010 baseline by MY 2017. While criteria pollutant emission standards create a large social benefit from reduced air pollution, GHG emission standards decrease the fuel use of vehicles and thus make operating the vehicle cheaper. Because of the lifetime savings associated with more efficient vehicles, it is uncertain whether a pre-buy/low-buy period would even be reasonable to expect since the regulation compliant vehicles might be more desirable to customers.

Proposed Regulation

On March 28, 2022, the EPA proposed new heavy-duty engine and vehicle standards aimed at reducing NOx for new vehicles starting with MY2027.[3] The proposed rule not only strengthens the emissions limits applicable for heavy-duty vehicles and engines, but also extends the period to which these limits would be applicable. To achieve the levels of reduction required by the regulation, engine manufacturers will likely need to rely on advanced exhaust aftertreatment, sophisticated engine control strategies, and cylinder deactivation to achieve the standards. The suite of technologies proposed are nothing new – these strategies have been tested and implemented on heavy-duty engines stepwise as EPA has ratcheted down emission standards.

Pre-Buy / Low-Buy

The trucks driving on the roads today are much cleaner than several decades ago, in large part due to the progressive emission standards EPA has put in place for heavy-duty engines. However, like many regulations, vehicle standards can have unintended economic consequences which can influence vehicle purchase decisions.

If the regulations require the installation of new pollution control technology, which many have, the regulations may increase the upfront cost of a HDV as well as increase operation and maintenance (O&M) costs. For vehicle owners, this can make purchasing and owning a HDV more expensive. To avoid the potentially higher costs and uncertainties, some HDV buyers may choose to purchase vehicles ahead of the regulation implementation. This is called the “pre-buy” effect. For HDV manufacturers to accommodate the increase in demand of vehicles, they may choose to increase production and employment ahead of the regulation (assuming they have the resources, capacity, and interest to do so).

Pre-buying vehicles requires HDV owners to either retire their current vehicles early or stockpile new vehicles. Of course, there are costs associated with both of these actions. A pre-buy would only occur as long as the cost savings from buying less expensive vehicles ahead of the regulation is greater than the cost of retiring functional vehicles early or stockpiling new vehicles that cannot be put into use. Thus, the effect, if it occurs, would be short-lived.

If a pre-buy effect occurs, a corresponding low-buy period should follow, as HDV owners that pre-bought vehicles have reduced their need to purchase new vehicles. Essentially, a pre-buy would indicate that HDV owners are shifting their vehicle purchases earlier in time, and this shift would create lower vehicle demand in the months following the regulation.

Previous literature has evaluated sales data, mostly focused on Class 8 vehicles, to investigate the potential pre-buy/low-buy effects. However, the results of that research have been extended to support claims that environmental regulations are detrimental to employment in the heavy-duty truck

[3] The proposal also considers extending manufacturer warranties, affording new benefits to purchasers from reduced maintenance costs and more durable products (though the impact of extended warranties was not considered in this analysis since other regulations did not include similar provisions).

manufacturing industry, causing disruption in the labor force as additional workers are taken on to meet the pre-buy demand and then laid off as demand decreases again. (See the section "Other Studies" below for more discussion of the previous literature.)

Thus, this analysis investigates whether pre-buy/low-buy effects are evident in the U.S. HDV manufacturing employment data. It also reviews the production data (which reflects the number of HDVs produced in the U.S.), and the sales data (which reflects HDVs sold in the U.S. regardless of where they are manufactured) to see whether there are pre-buy/low-buy effects evident in that data that are not seen in the employment data. Although these three datasets are closely related, each is analyzed separately because demand shocks will not necessarily affect them all in the same ways.

METHODS

The impact of regulations on economic activity is sometimes evaluated using an event study model. For example, if the goal is to evaluate how a regulation affected employment, an event study model would look like this:

$$Employment_t = c + \beta_{pre} * Pre + \beta_{post} * Post + \beta_{exg1} * Exg1t + \cdots + \beta_{exgn} * ExgNt$$

Where:

$Employment_t$	= number of full-time employees in the industry at time t
Pre	= 1 for the months just prior to event (regulation) and 0 otherwise
$Post$	= 1 for months just after the event and 0 otherwise
$Exg1t... ExgNt$	= other exogenous macroeconomic variables 1 through N that might affect employment at time t (e.g., GDP, year or month)

If β_{pre} and β_{post} are statistically significant, it indicates that there was a statistically significant change in employment during those periods.

The challenge with this type of model is to make sure that all exogenous variables that could affect employment are included in the model. Otherwise, it is unclear what the Pre and Post variables are measuring. The potential list of exogenous variables could be lengthy. For example, it could include variables that affect the industry or general economic conditions and might need to consider leading and lagged variables (e.g., an increase in output prices might affect employment for several months). Further, the relevant factors in one period may be different from those in another period, further diminishing the value of creating this type of model. Other studies, discussed in more detail below, have used fixed effect or "dummy variables" to get around the problem of trying to include all of the exogenous variables. In most cases, dummy variables do not provide any information that helps explain what the model is showing.

Difference-in-Difference Model

To reduce the inaccuracies with specifying all of the exogenous variables that should be included, this analysis relies primarily on a difference-in-difference (DiD) model. The DiD approach is widely used in economics because it provides a parsimonious method for controlling for the impact of conditions that are unrelated to the topic being studied but could affect the reliability of the model. The DiD approach compares impacts across two groups: the potentially affected group that may be impacted by an event and a control group that is similar to the potentially affected group but is not affected by the event. The

DiD model assesses whether there is a difference in the potentially affected group at the time of the event *and* whether that difference is significantly different from changes in the control group. Evaluating both differences (i.e., Pre vs. Post and potentially affected vs. control groups) provides a more reliable assessment of the event impact.

The DiD model for employment looks like this:

$$Employment_{t,g} = c + \beta_{pre} * Pre + \beta_{post} * Post + \Delta_{pre} * DiDpre + \Delta_{post} * DiDpost + \beta_{exg1} * Exg1t + \cdots + \beta_{exgn} * ExgNt$$

Where:

$Employment_{t,g}$	= number of full-time employees in the industry at time t for group g (potentially affected, control)
Pre	= 1 for the months just prior to event (regulation) and 0 otherwise
$Post$	= 1 for months just after the event and 0 otherwise
$DiDpre$	= 1 for the pre months, but only for the potentially affected group, 0 otherwise
$DiDpost$	= 1 for the post months, but only for the potentially affected group, 0 otherwise
$Exg1t... ExgNt$	= other exogenous variables that might affect employment at time t

Now the test becomes whether Δ_{pre} and Δ_{post} are statistically significant.

The three key modeling decisions for the DiD model are:

- The selection of the control group;
- The selection of exogenous variables; and
- The timing of the pre-event and post-event periods.

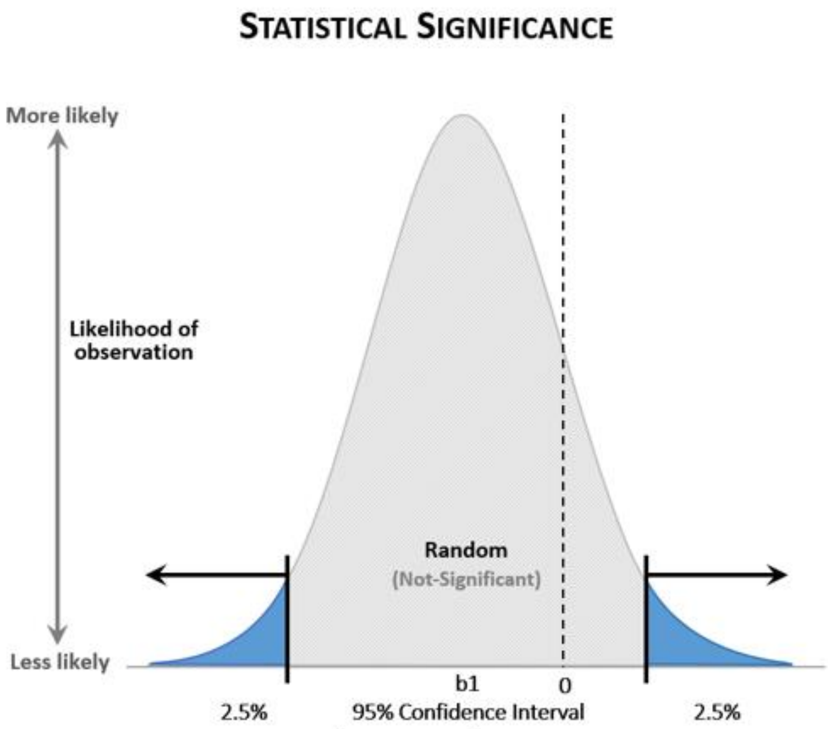
For this analysis, the potentially affected group is heavy-duty trucks and the control groups are light-duty trucks and automobiles.[4] The regulations are specific to heavy-duty trucks, so light-duty trucks and automobiles would be unaffected. For this analysis, we use oil prices, monthly GDP, and fixed effects variables for year and month as the exogenous variables, and use the control groups to help capture other exogenous influences.

In terms of timing, there is uncertainty about when the regulation might affect the components of the HDVs and the duration of any Pre and Post impacts, given that the regulation affects specific MYs and vehicles are ordered several months in advance of delivery. (See “Other Studies” below for more discussion about the timing uncertainties.) This analysis uses a 6-month period surrounding the implementation of the regulation, which we assume went into effect in January 2007[5] for MY2007. Therefore, DiD_{pre} covers July through December 2006 and DiD_{post} covers January through June 2007. We test alternative periods in the sensitivity analysis section.

[4] A parallel trends test established that light trucks and automobiles are an appropriate control group for HDVs.

[5] Edward Carr et al, “Analysis of Heavy-Duty Vehicle Sales Impacts Due to New Regulations,” ERG and EERA, prepared for EPA, May 2021, https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P101246N.pdf.

Statistical Significance



Statistical significance is key to interpreting model results. If Δ_{pre} and $\Delta_{post,}$ the parameters on the DiDPre and DiDPost variables, are statistically insignificant, it means that predicted HDV manufacturing employment, production, or sales during that period is not identified as being different from other periods after the exogenous influences controlled for in the model are taken into account. Conversely, if the coefficient is statistically different from zero, it signifies that predicted employment, production, or sales during that period is different from other periods for reasons not identified by other variables in the model.

Figure 1. Statistical Significance

From one time period to the next, it would not be expected that employment predicted by a model (the "expected" employment) and actual employment would be exactly the same. There are always going to be random fluctuations that cause them to be different. The key question is whether the difference between expected and actual employment in the time period surrounding the event reflects normal random variation or, instead, something unaccounted-for in the model. In statistics, whether a result falls within the expected range of random variation or falls outside that range, and therefore is deemed significant, is determined by the confidence interval and the p-value. The test for statistical significance is illustrated in Figure 1.

The bottom axis of Figure 1 shows the difference between actual and expected employment for a given time period surrounding the event, as measured by Δ_{Pre} and Δ_{Post} in the statistical model. The dotted line illustrates where there is no difference between the actual and expected employment (in other words, it is where the value of Δ is 0). If this "zero value" falls within the grey area (the 95 percent confidence interval in Figure 1), it is statistically reasonable to conclude that any difference is due to random fluctuations and is not statistically meaningful.[6] If instead the zero value falls in one of the blue areas, that means there is only a 1 in 20 chance that the difference is due to random fluctuation, and it can be inferred that the change in employment is statistically meaningful.[7]

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[6] A 95 percent confidence interval equates to a 5 percent p-value.

[7] Similarly, a 90 percent confidence interval means that there is a 1 in 10 chance that the difference is due to random fluctuation, and a 99 percent confidence interval means that chance is 1 in 100.

Importantly, when the predicted change is statistically significant, it means that factors not included in the model may account for the difference over that time period; however, it does not identify which particular factor *is* accountable for the difference. For example, the difference could be caused by the regulation, or it could be caused by some other factor that occurred during that same time period. It could also simply be caused by normal random variation.

DATA

The datasets used in this analysis are publicly available, monthly datasets that generally divide automobiles, light-duty trucks, and heavy-duty trucks using NAICS definitions. The time series used in this analysis starts in February 1992[8] and continues through 2019. See Table 1 below for more detail about the source of each of the datasets used in this analysis.

Table 1 – Data Sources

	Source	Description	Notes
Sales†	Bureau of Economic Analysis, originally from Ward Intelligence and American Automobile Manufacturers Association	Monthly vehicle unit sales within the U.S.	Heavy trucks includes Class 4-8 vehicles. Prior to 2003, heavy trucks also included Class 3.
Production†	Board of Governors of the Federal Reserve System, Industrial Production and Capacity Utilization–G.17 Table 3, originally from Ward's Communications, Chrysler, and GM	Monthly vehicle unit production within the U.S.	
Employment†	Bureau of Labor Statistics, Quarterly Census of Employment and Wages	Monthly vehicle manufacturing employment within the U.S.	"Employment is the count of only filled jobs, whether full or part time, and temporary or permanent, by place of work. The quarterly reports include the establishment's monthly employment levels for the pay periods that include the 12th of the month."
GDP	Macroeconomic Advisors, IHS Markit	Monthly U.S. Gross Domestic Product, a measure of national economic activity, adjusted for inflation to Jan. 1990 dollars.	Macroeconomic Advisor's GDP methodology is aligned with the National Income and Product Accounts (NIPA), but also provides monthly GDP, instead of quarterly.
Real Oil Price	Energy Information Association	U.S. Crude Oil First Purchase Price (Dollars per Barrel), adjusted for inflation to Jan. 1990 dollars.	

† Three separate series are available for heavy-duty trucks, light-duty trucks, and automobiles. All three metrics are not seasonally adjusted.

[8] This is the first month for which monthly GDP data was available.

RESULTS

For pre-buy/low-buy analysis, we believe it is reasonable to expect both the Pre and Post DiD variables to be significant in order to support the pre-buy/low-buy hypothesis. This hypothesis is about shifting demand from one period to another. A related report by ACT Research (2022), discussed further below, states "our fundamental thinking is each pre-bought unit is pulled forward from the future and will not recur"[9], indicating their belief that for an event to be a "pre-buy", it needs a corresponding decrease in sales or "low-buy". If only one of the variables is significant, then other, non-modeled factors are affecting the results. The models use the natural log for employment, production, and sales, so the DiD coefficients can be interpreted as the approximate percentage impacts.[10] The significant percentages indicate how much higher or lower the predicted metric (i.e., employment, production, or sales) is than would be predicted without that variable. For example, if the PreDiD variable is 25 percent, then sales are 25 percent higher than we would predict them to be without taking into account the Pre period for HDVs. The percentages do *not* indicate an increase over the period prior.

MY2007 Regulation

The model results for the 2007 regulation are summarized in Figure 2 for monthly employment, production, and sales. If there were a pre-buy/low-buy impact on employment, we would expect the coefficient for the Pre period, Δ_{pre}, to be positive and significant, while the coefficient for the Post period, $\Delta_{post,}$ would be negative and significant.

Figure 2 shows that the Pre and Post coefficients for HDV employment are both statistically insignificant, thus the results reject the hypothesis that a pre-buy/low-buy event occurred for manufacturing employment. The model results indicate that the 2007 regulation did not materially change HDV manufacturing employment.

For production and sales, Δ_{pre} is positive and significant, but $\Delta_{post,}$ is not, which also does not support the pre-buy/low-buy hypothesis, because both need to be significant to indicate a shift in sales or production. Although not supportive of pre-buy/low-buy, the positive results in the latter half of 2006 are indicative of higher than predicted sales and production. Regardless of what is causing the high production and sales levels in 2006, the effect does not carry through to affecting employment levels.

[9] "Pre-Buy / Low-Buy: Analysis of Heavy-Duty Sales Effects from Emissions Regulations," ACT Research, April 2022, http://www.truckandenginemanufacturers.org/file.asp?F=Exhibit+D+ACT%2Epdf&N=Exhibit+D+ACT%2Epdf&C=documents

[10] For large coefficients, direct interpretation of the coefficients as percentages causes a loss of precision. Thus, the results are reported by using the formula exp(β)-1 to calculate the precise percentage impact for each coefficient.

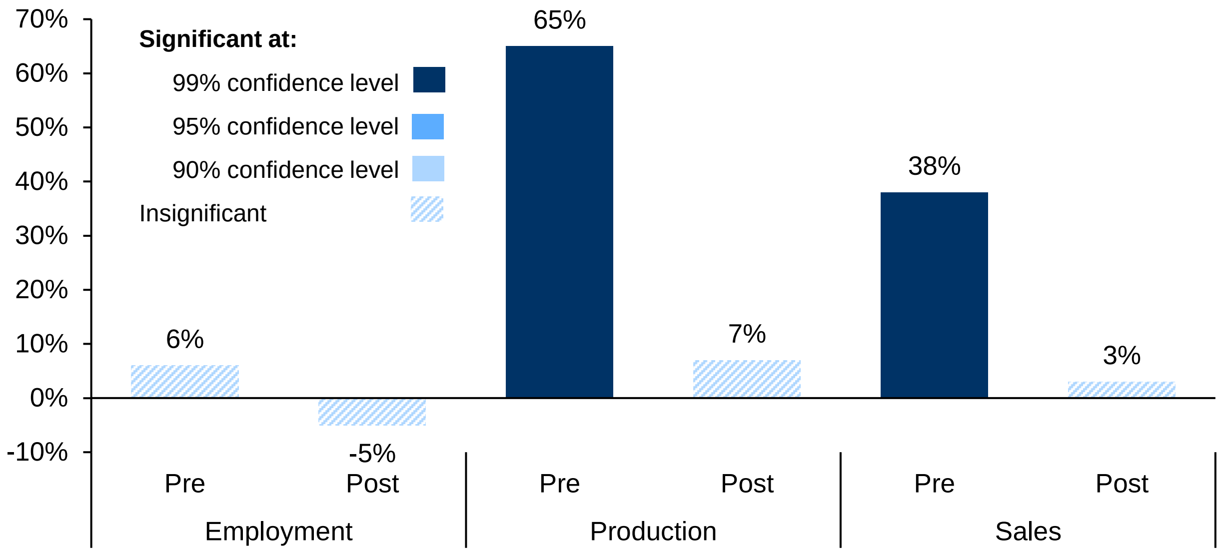


Figure 2. DiD Model Coefficients for 2007 Regulation

Each bar represents the value of the coefficient on the Pre and Post variables specifically for heavy-duty trucks. The cross-hatching indicates coefficients that are insignificant; solid color columns indicate significance, with more significant impacts in darker colors.

Figures A1 to A3 in the Appendix show HDV manufacturing employment, production, and sales for 1990 to 2019. The volatility seen in production and sales is missing from the employment data. The average absolute month-to-month change in employment was 2 percent during this period, compared to 14 percent and 9 percent for production and sales, respectively. Given what is known about employment and the HDV manufacturing industry, this is not surprising. It is expensive to fire and hire people due to the required training and resources to recruit. Thus, factors that impact sales and production will not necessarily translate into employment impacts.

Sensitivity Analysis for Timing and Duration of Potential Impacts of 2007 Regulation

To test the sensitivity of our results, we varied the length of the impact period and the month when the regulation took effect. We tested three periods:

- 12 months before and after the regulation took effect in January 2007, such that Pre includes January through December 2006 and Post includes January through December 2007;
- 12 months before and after the regulation took effect if the regulation came into effect in July 2007 (as indicated in Rittenhouse and Zaragoza-Watkins (RZW) 2018[11]), such that Pre includes July 2006 through June 2007 and Post includes July 2007 through June 2008; and
- 6 months before and after the regulation took effect if the regulation came into effect in July 2007 (as indicated in RZW 2018), such that Pre includes January through June 2007 and Post includes July through December 2007.

Table 2 shows the coefficient results for the DiD variables in these models. For the employment data, the Pre and Post DiD coefficients are consistently insignificant and very small, indicating that changes in HDV

[11] Rittenhouse and Zaragoza-Watkins, “Anticipation and environmental regulation.”

employment are not statistically different from zero, regardless of the timing and duration of the Pre and Post periods.

The 12-month January 2007 model has similar results to our primary model.

The 12-month July 2007 model has two notable differences. The first is the Post period is negative and significant for the sales data, showing a pattern consistent with pre-buy/low-buy, although it does not appear for the production or employment data. The second is the positive coefficients on the Pre period are smaller. This is logical since it includes the first six months of 2007 when there is no positive effect.

If there is a pre-buy/low-buy impact on sales, then a comparison of the coefficients across these models indicates that the pre-buy must occur almost entirely in 2006, with a period of neither negative nor positive impacts on sales in the first six months of 2007, and the low-buy occurring in the 12 months starting in July 2007.

The 6-month July 2007 model has only one significant impact, a negative impact in the sales Post period that is significant at the 90 percent level. These results are consistent with the previous two models, indicating no impact in the first half of 2007 and a negative impact after July 2007 of similar magnitude to that seen in the 12-month January 2007 model.

Ultimately, the lack of significant impact in the employment data indicates that regardless of fluctuations in sales and production levels, employment was unaffected by the regulation. Employment effects remain both very small and insignificant across model specifications.

Table 2: Sensitivity Model Results‡

Effective Date of Regulation	January 2007	July 2007	Jul 2007
Duration of pre and post periods	12 months	12 months	6 months
Employment			
Pre	3%	1%	-5%
Post	-3%	0%	-1%
Production			
Pre	58% ***	32% ***	6%
Post	-1%	-8%	-11%
Sales			
Pre	36% ***	19% ***	2%
Post	-5%	-12% **	-14% *

* Significant at 90% confidence level;

** Significant at 95% confidence level;

*** Significant at 99% confidence level.

‡ The significant percentages in this table indicate how much higher or lower the predicted metric (i.e., employment, production, or sales) is than would be predicted without including that variable (i.e., Pre or Post). Insignificant coefficients are interpreted as no different from zero.

MY2010 Regulation

Figure 3 summarizes the results for models concerning the 2010 period, when manufacturers were required to fully comply with the 0.2 g/bhp-hr NOx standard. As with the 2007 regulation, the Pre and Post periods are the 6 months before and after January 2010. Similar to the 2007 regulation, there are no statistically significant impacts on employment during the 6-month Pre and Post periods.

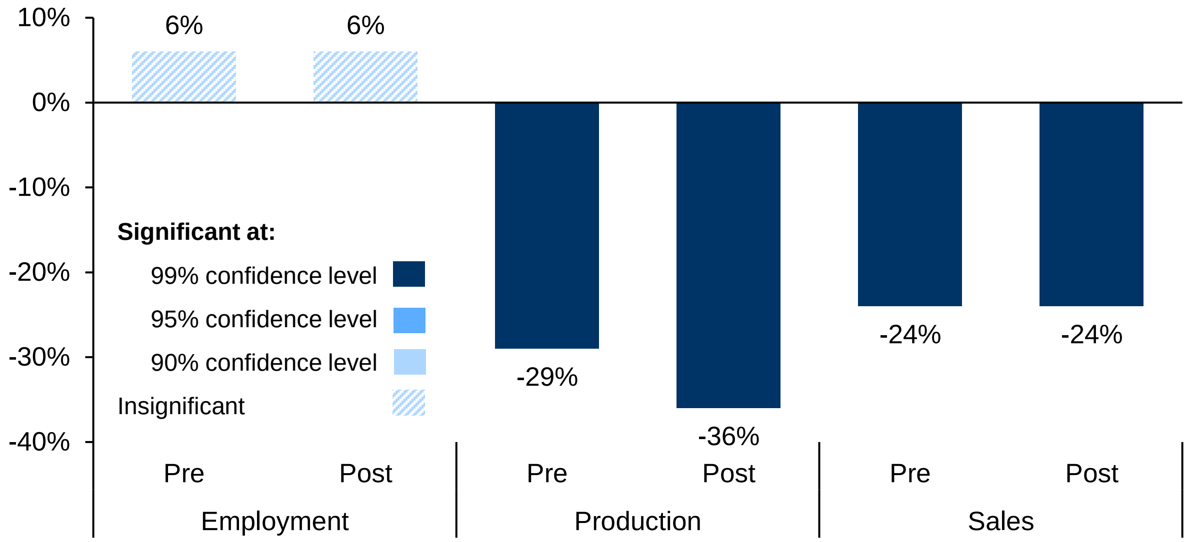


Figure 3. DiD Model Coefficients for 2010 Regulation

Each bar represents the value of the coefficient on the Pre and Post variables specifically for heavy duty trucks. The cross-hatching indicates coefficients that are insignificant; solid color columns indicate significance, with more significant impacts in darker colors.

Production and sales show lower than expected values for both the Pre and Post periods. These results do not support a pre-buy/low-buy effect. Further, the sales coefficients are essentially the same for both the Pre and Post period, belying any fluctuations due to the regulation.

MY2014 Regulation

Figure 4 below shows the same analysis for the 2014 regulation, again with Pre and Post representing the 6 months before and after January 2014. The only statistically significant impact is on employment in the Post period. This impact is not consistent with the pre-buy/low-buy pattern. First, there is no accompanying positive effect on employment in the Pre period. Second, sales and production show no significant impact in either period, and any pre-buy/low-buy effect should be driven by sales. Thus, the results indicate that the decrease in employment is due to factors other than pre-buy/low-buy.[12]

[12] Furthermore, the negative employment impact in the Pre period is insignificant at the 90 percent level but would be significant at the 80 percent level, suggesting that employment was becoming close to significantly lower than expected in the period prior to the regulation enactment.

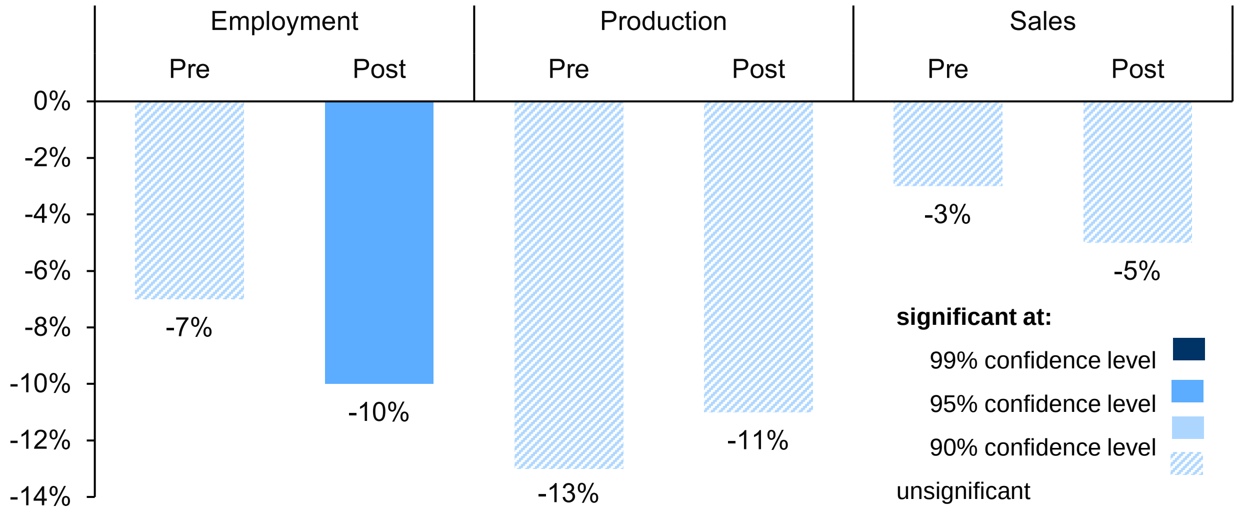


Figure 4. DiD Model Coefficients for 2014 Regulation

Each bar represents the value of the coefficient on the Pre and Post variables specifically for heavy duty trucks. The cross-hatching indicates coefficients that are insignificant; solid color columns indicate significance, with more significant impacts in darker colors.

2004 Regulation

Lastly, Figure 5 below shows the analysis for the 2004 regulation which went into effect in October of 2002. Unlike the regulations previously discussed, the effective date for this regulation is October. Thus, the Pre variable covers April through September 2002 and the Post variable covers October 2002 through March 2003. As shown in Figure 5, there are consistent, significant, negative impacts in both the Pre and Post period. These results reject the pre-buy/low-buy hypothesis, but do indicate that 2002 had lower than expected employment, production, and sales due to factors unaccounted for in the model.

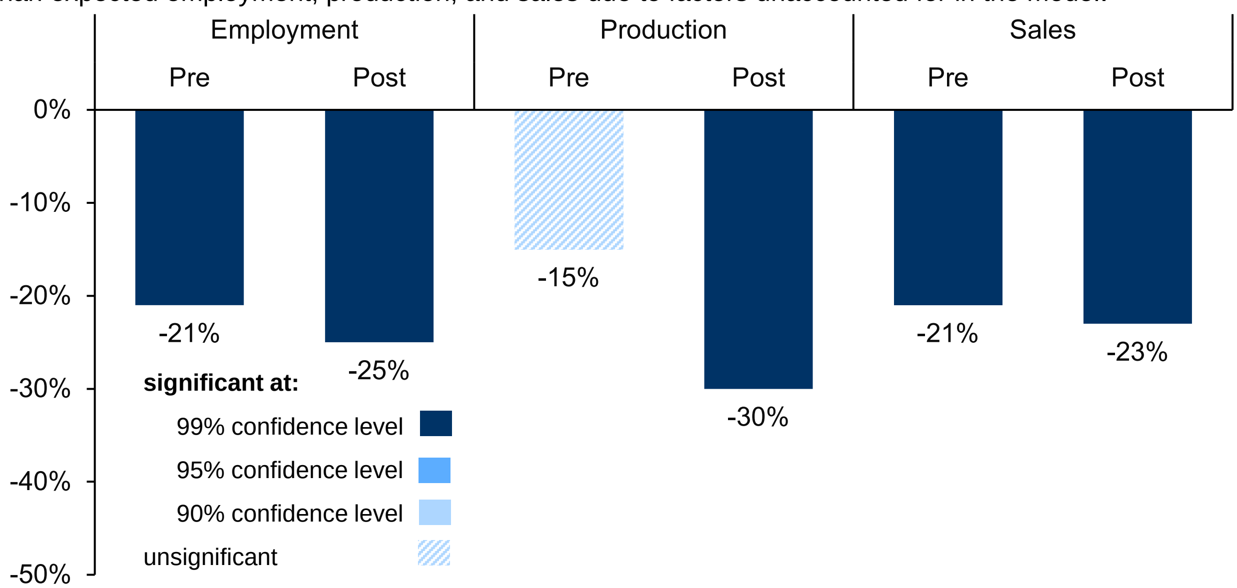


Figure 5. DiD Model Coefficients for 2004 Regulation

Each bar represents the value of the coefficient on the Pre and Post variables specifically for heavy duty trucks. The cross-hatching indicates coefficients that are insignificant; solid color columns indicate significance, with more significant impacts in darker colors.

Class 8 Sales Analysis

Most previous analyses focused primarily on Class 8 vehicles and, in some cases, solely Class 8 tractors. Class 8 is the largest class of HDVs, comprising between 40 and 56 percent of sales in the last several decades.[13] They are also understood to be the class most impacted by engine emission standards with the greatest increase in price associated with complying with the regulation. Unlike vocational HDVs which are often facilitating a non-transportation related business, tractors are the profit center which may drive more pre-buy/low-buy behavior.[14]

Although the primary focus of this analysis, employment, does not have data available at the vehicle class level, there are class-level sales data available.[15] We conducted two analyses to evaluate the potential impact of vehicle class on our results. First, we used a DiD approach to determine whether Class 8 vehicles were affected differently from Class 4-7 vehicles (although all classes 4 through 8 were affected by the regulation). Generally, the results show that Class 8 vehicles had lower than expected sales in 2007 when compared to Class 4-7 sales. However, the Class 8 sales in 2006 were not significantly different from Class 4-7 sales.[16]

Table 4. DiD model results for sensitivities around the 2007 regulations for Class 8 and Class 4-8

	Model A	Model B	Model C	Model D
Effective Date of Regulation	January 2007	January 2007	July 2007	July 2007
Duration of pre & post periods	6 months	12 months	12 months	6 months
DiD Model with **Combined Class 4-8** Data				
Pre	38%***	36%***	19%***	2%
Post	3%	-5%	-12%**	-14%*
DiD Model with **Only Class 8** Data				
Pre	49%***	45%***	13%*	-13%
Post	-11%	-23%***	-30%***	-33%***

Second, we repeated our primary and sensitivity analysis models for sales, substituting the Class 8 sales data for the Class 4-8 combined sales data and using the same control groups as above, automobiles and light trucks. The results are broadly similar with those discussed in our Results section above (Table 3). However, the Post period of the 2007 regulation is more likely to show a significant decrease in sales, such that both 12-month models now have results that are consistent with a pre-buy/low-buy pattern. This difference does not occur around the 2004, 2010, or 2014 regulations; for those years, the Class 8 results are similar to those for the Class 4-8 sales, and show no evidence of pre-buy/low-buy effects.

[13] Stacy C. Davis and Robert G Boundy. Transportation Energy Data Book: Edition 40, Table 5.3. Oak Ridge, TN: Oak Ridge National Laboratory 2022. https://doi.org/10.2172/1878695.

[14] "Pre-Buy / Low-Buy," ACT Research.

[15] Ward Intelligence, "Monthly U.S. Automotive Sales by GVW (1990-2020)," 2022.

[16] For 2010 and 2014, the Class 8 sales were not significantly different from Class 4-7 sales, but the Post 2002 period Class 8 were significantly lower.

Table 5. DiD model results for 2010, 2014, and 2004 regulations for Class 8 and Class 4-8

Effective Date of Regulation	January 2010	January 2014	October 2002
Duration of pre & post periods	6 months	6 months	6 months
DiD Model with **Combined Class 4-8** Data			
Pre	-24%***	-3%	-21%***
Post	-24%***	-5%	-23%***
DiD Model with **Only Class 8** Data			
Pre	-24%***	7%	-25%***
Post	-27%***	3%	-34%***

When looking at all the sensitivities together for the 2007 regulation Class 8 sales, an image emerges (illustrated in Figure 6). Only the results of the two 12-month sales models (Models B and C) are consistent with a pre-buy/low-buy pattern. However, comparing Models A and B, sales are only significantly lower than expected when the second half of 2007 is included, indicating that the lower than expected sales actually occur in the last half of 2007. If the regulation went into effect in January of 2007, one would expect the first six months post regulation to show a greater low-buy effect than the second six months - but that is not what the data indicates.

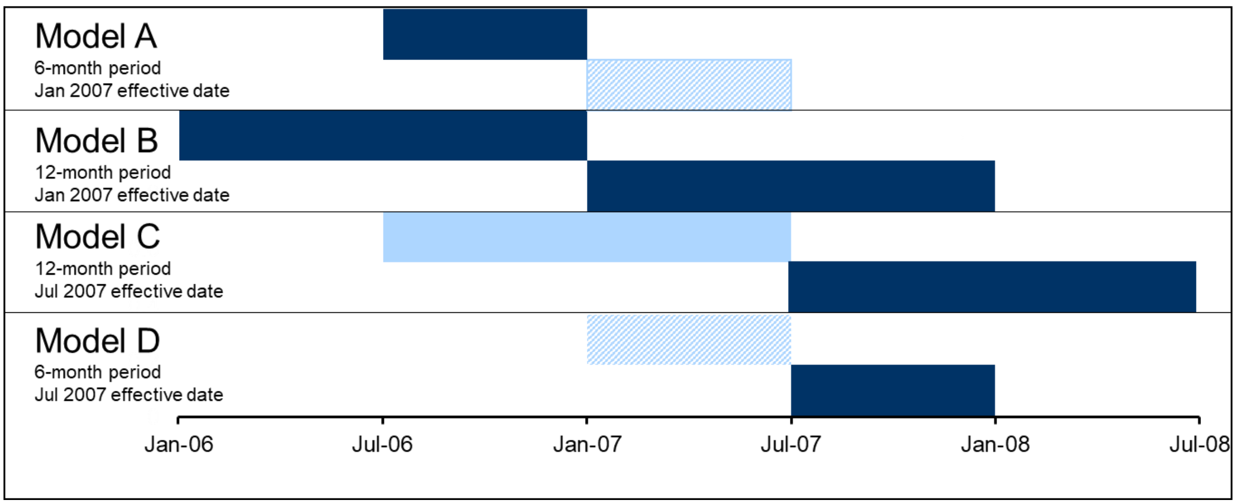


Figure 6. Graphical representation of the timing and significance of the sensitivity analysis for Class 8 sales around the 2007 regulation

Further, although Model C (which assumes a 12-month long period and an effective date of July 2007) is consistent with a pre-buy/low-buy pattern, in comparison with Model D (same effective regulation date but 6-month impact periods), the pre-buy goes away. Once again, if the effective date of the regulation was July 2007, one would assume the six months before the regulation goes into effect would be more significant, yet that is not what the data shows.

Taking all the models together, they suggest that if a pre-buy occurred, the effects were in 2006 alone. Similarly, the low-buy effect appears to be limited to the latter half of 2007, with 6 months in between that had no effect. This 6-month gap is unexpected; it may be evidence that the effects are due to factors other than the regulation.

Finally, it is notable that none of the other regulations show any evidence of pre-buy/low-buy effects. The lack of consistent impacts across models in our analysis, as well as the literature, suggest that other explanations may be behind the perceived pre-buy/low-buy data results.

Truck Sales as a Leading Indicator for Recessions

One factor to consider in interpreting the model results is that HDV sales may be a leading indicator of recessions (Figure 7). A downturn in the purchasing of capital good is often used as a leading indicator for recessions[17] or included in leading indicator indices[18], because, when businesses feel that the economy is doing poorly, they are less likely to invest in large new purchases. Heavy-duty trucks are considered capital goods purchases. Figure 7 shows that heavy truck sales peak and begin to fall well in advance of the start of each recession since the early 1970s.

If HDV sales are a leading indicator, it may explain the results seen in the sensitivity analysis and Class 8 sales models for the 2007 regulation. EPA 2021 claims that the low-buy they identify in 2007 was "not affected" by the Great Recession since the recession "began around Q1 of 2008."[19] However, if heavy truck sales decline in months leading up to a recession, it would be reasonable to ascribe the significant and negative Post period seen in Class 8 sales in Models B, C, and D above to the recession depressing sales. While we would expect this phenomenon might be true for all HDVs, it would be especially true for Class 8 vehicles. Since the control groups, automobiles and light trucks, are primarily purchased by individuals and not businesses, they would not be expected to see the same decline prior to the beginning of the recession.

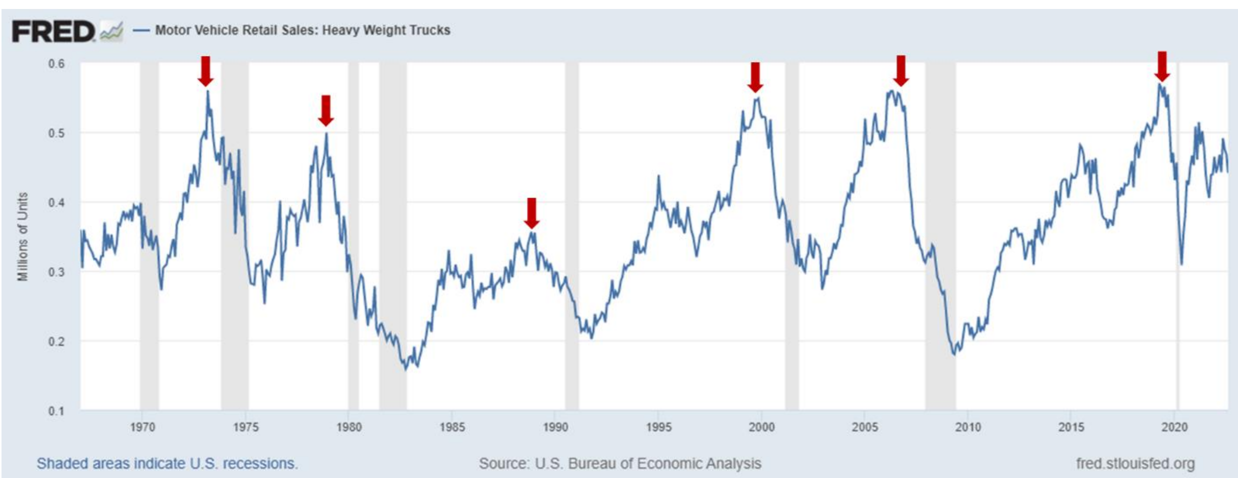


Figure 7. Heavy-duty truck sales from 1967 to 2022

Peaks in advance of recessions shown with red arrows and recessions shown as gray shaded areas.

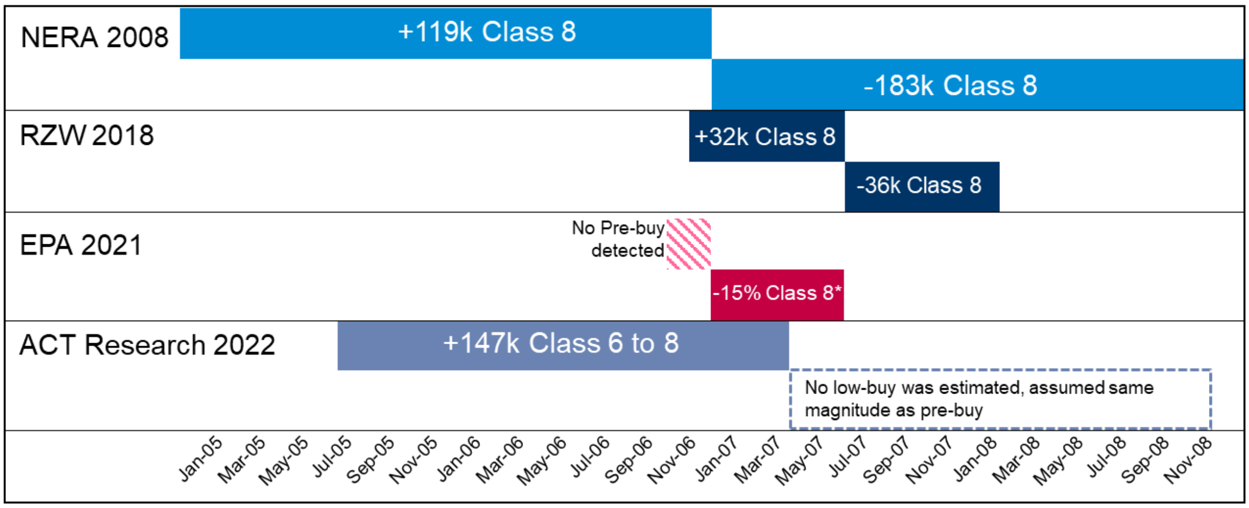
[17] James Stock and Mark Watson, "How did Leading Indicator Forecasts Perform During the 2001 Recession?," Federal Reserve Bank of Richmond Economic Quarterly Volume 89/3 (Summer 2003): 80. http://ssrn.com/abstract=2184936

[18] Jonathan Liu, "US Leading Indicators," The Conference Board. September 22, 2022. https://www.conference-board.org/topics/us-leading-indicators

[19] Carr et al., "Analysis of Heavy-Duty Vehicle Sales," pg 73.

OTHER STUDIES

We reviewed four other studies that attempted to estimate the pre-buy/low-buy effects of heavy-duty engine regulations: NERA 2008, RZW 2018, EPA 2021, and ACT Research 2022 (Figure 8). The analysis methods, including vehicle classes evaluated, and results vary widely across the studies. The timeframe, magnitude, and significance of the impacts differ considerably for the same regulation, challenging the premise that engine standards cause a large and sustained pre-buy/low-buy effect. No other study evaluated the regulatory impact on HDV manufacturing employment.



*Assuming 87,300 Class 8 sales from January to June of 2007, a 15% reduction equals 15,400 Class 8 vehicles

Figure 8. Summary of timing, magnitude, and duration of pre-buy/low-buy periods due to the 2007 regulation from previous studies

The regulation effective date used to evaluate pre-buy/low-buy periods varies among the studies. This may be driven by uncertainty about when the regulation impacts will occur. Engine regulations impact a specific model year, but model years and calendar years do not necessarily line up. MY2007 vehicles could potentially be purchased in 2006 and MY2006 vehicles could potentially be delivered in 2007. As discussed in EPA 2021, sales data represents when a vehicle was delivered to the customer but since most vehicles are made to order, the order for that vehicle occurred several months before. The lag between order and delivery is not constant, though it typically ranged from 2 to 6 months. If there is a slowdown in delivery due to high demand, decreased production capability, or other supply chain issues, the lag can be longer.

For the 2007 regulation, RZW 2018 estimated a pre-buy/low-buy effect surrounding July 2007 with higher than expected sales for early 2007, and lower than expected sales for late 2007. In contrast, EPA 2021 used an effective date of January 2007 and found a significant *decrease* in sales for early 2007.[20] Thus, for the same timeframe that RZW 2018 found higher than expected sales, EPA 2021 found lower than expected sales.

NERA 2008 used the same regulation effective date as EPA 2021 (i.e., January 2007), but found a pre-buy/low-buy effect that spans the two years before and after the regulation goes into effect, making the

[20] Carr et al., “Analysis of Heavy-Duty Vehicle Sales.“

low-buy period four times longer than the one identified by EPA 2021.[21] The studies also found wildly different magnitudes for the reported effects. For pre-buy, the impacts range from 0 (EPA 2021) to 119,000 (NERA 2008) Class 8 vehicles. For low-buy, the impacts range from 15,400[22] to 183,000 (NERA 2008) Class 8 vehicles.

For studies investigating the same phenomena, in many cases with the same datasets, these results appear to be inconsistent and cast doubt on the individual findings. The lack of robustness in these findings is affirmed by the alternative analysis presented earlier using the difference-in-difference model and upholds the conclusion that economic analyses of heavy-duty sales, production, and employment data provide no conclusive evidence of any pre-buy/low-buy effect related to any of the recent EPA HDV engine regulations.

[21] David Harrison and Mark LeBel, "Customer Behavior in Response to the 2007 Heavy-Duty Engine Standards: Implications for the 2010 NOx Standard," NERA Economic Consulting, November 14, 2008, https://www.regulations.gov/document/EPA-HQ-OAR-2019-0055-0556.

[22] EPA 2021 estimated a 14.9% reduction for the first six months of 2007 for Class 8 vehicles. We estimate that this is approximately 15,400 vehicles, calculated using Ward Communication sale data indicating that 87,300 Class 8 vehicles were sold in those six months.

APPENDIX

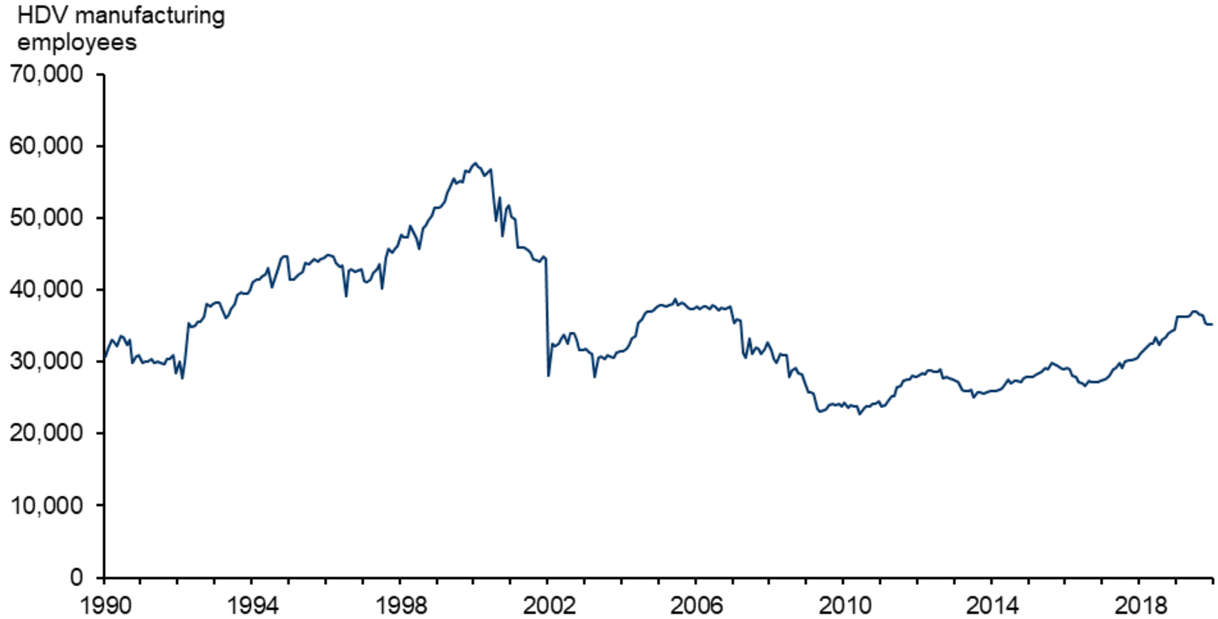


Figure A1. Heavy-duty vehicle manufacturing employment data

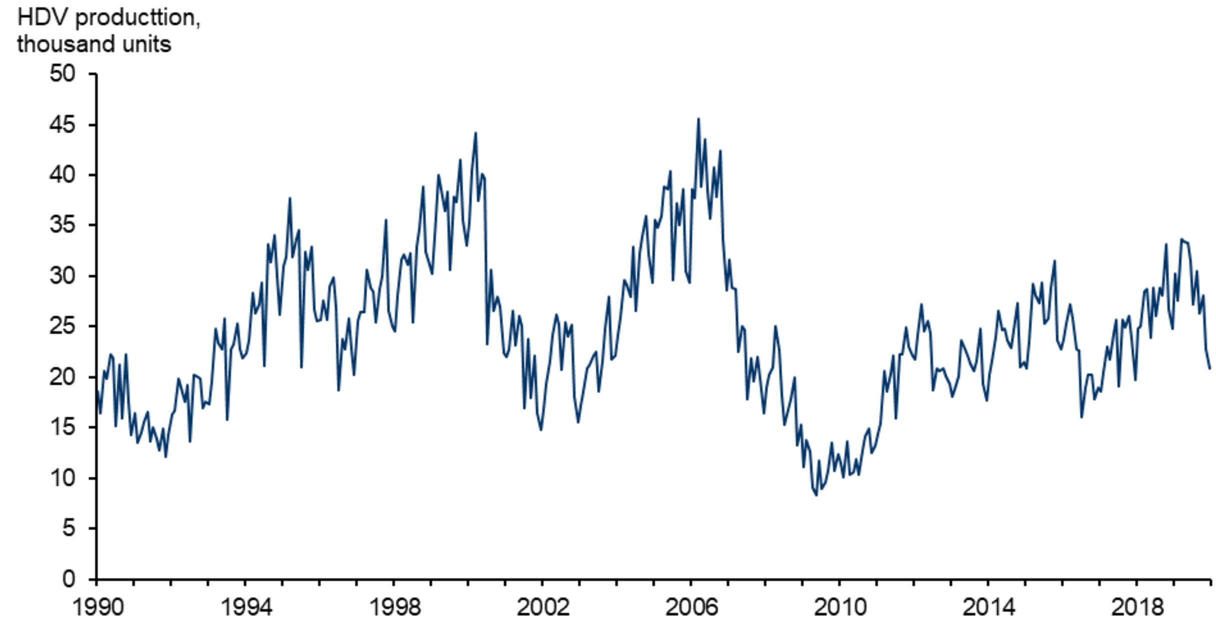


Figure A2. Heavy-duty vehicle production data

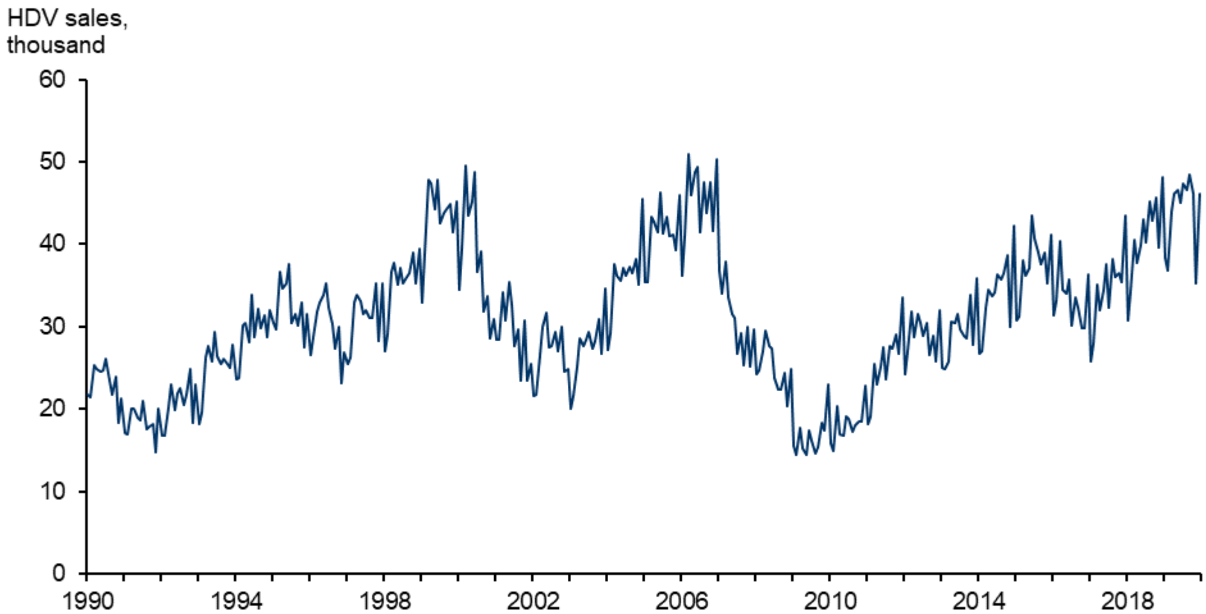


Figure A3. Heavy-duty vehicle sales data

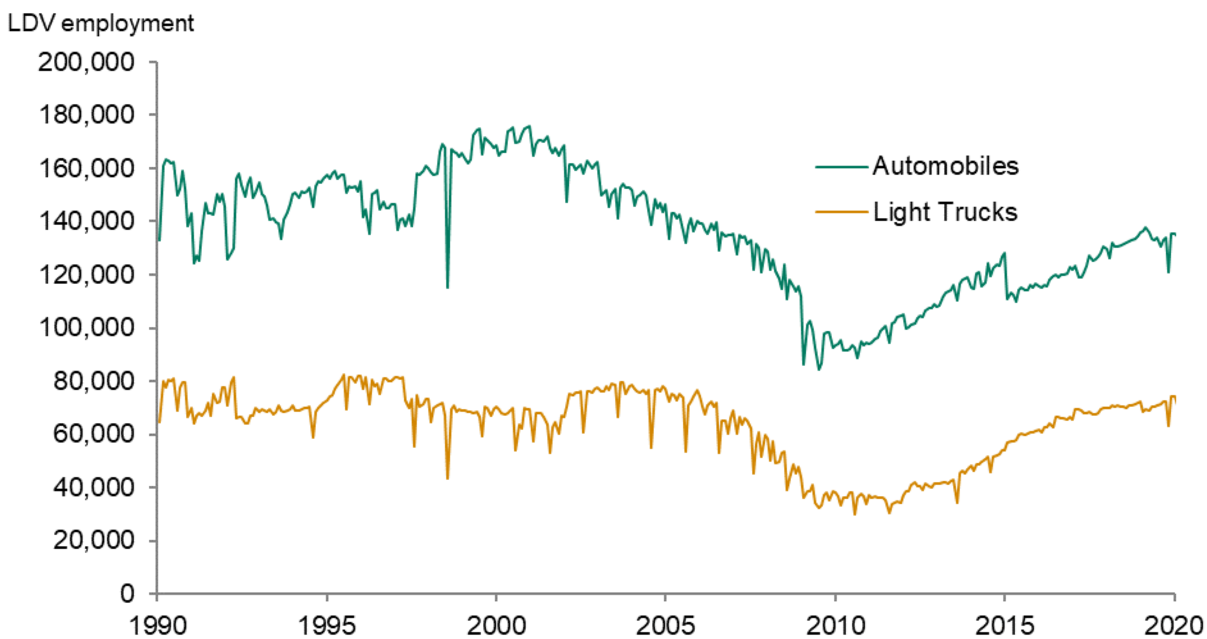


Figure A4. Light-duty vehicle manufacturing employment data

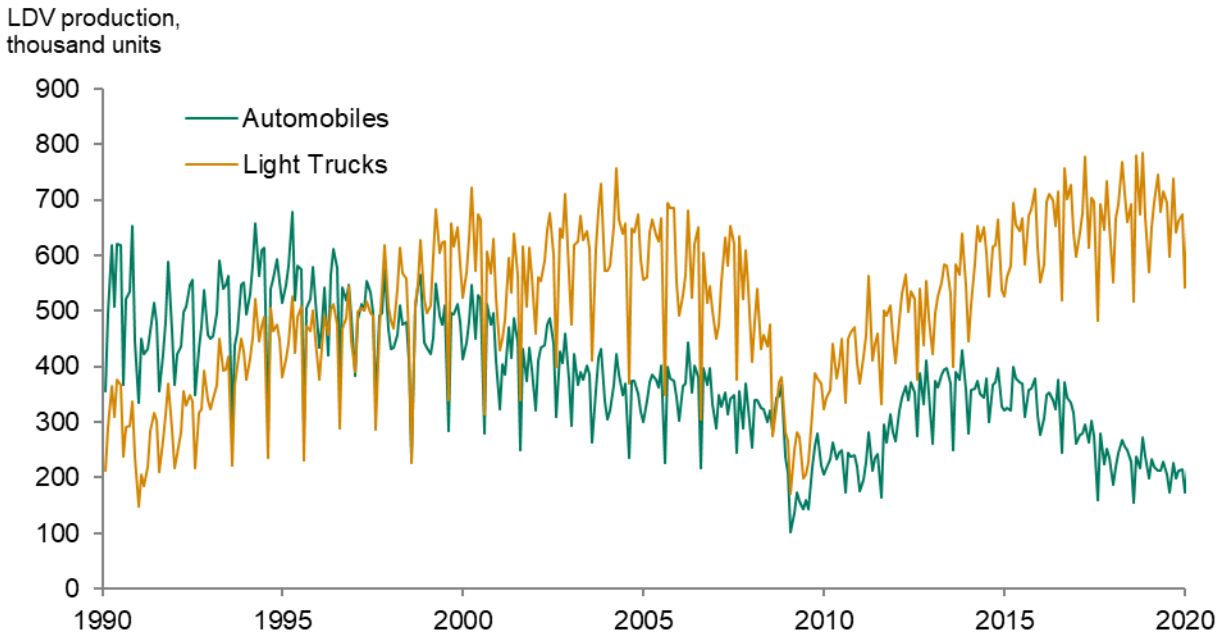


Figure A5. Light-duty vehicle production data

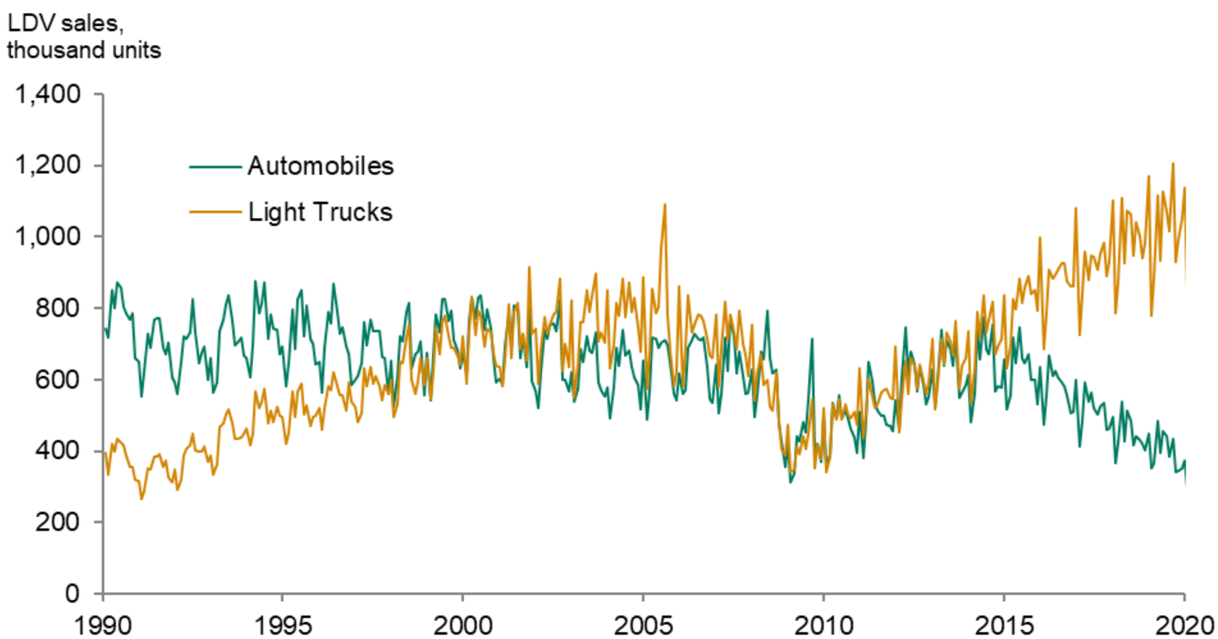


Figure A6. Light-duty vehicle sales data

Table A1 Description of other studies investigating pre-buy/low-buy effects on sales from HDV engine regulations

Study	Type of Vehicle Analyzed	Regulations Covered	Presumed Effective Date of Regulation	Duration of Pre and Post Periods	Net Impact	Analysis Method
NERA 2008, Harrison and LeBel	Class 8	2007	January 2007	Pre-buy: 24 months ahead of the regulation Low-buy: 24 months after regulation	Pre-buy: 119,072 Class 8 vehicles Low-buy: -182,749 Class 8 vehicles	Estimation used difference in Ward's U.S. Retail Sales of Trucks compared to "EPA baseline" with static 2% increase in sales each year starting in 1995. This method does very little to control for changes in economic conditions.
Rittenhouse and Zaragoza-Watkins 2018	Class 8	Mainly 2007, briefly touch on 1998, 2002, and 2010	Specify July 2007 but no other regulation effective dates specified in the paper	Pre-buy: 7 months ahead of regulation Low-buy: 7 months after regulation	Pre-buy: 32,000 Class 8 vehicles for 2007 reg Low-buy: -36,000 Class 8 vehicles for 2007 reg	Regression using quarterly GDP and real oil prices as controls on U.S. truck sales with monthly and yearly dummy variables included. Analysis indicates large reliance on dummy variables to replicate sales.
ERG & EERA 2021, prepared for EPA	Class 6-8, focused on Class 8	2002/4, 2007, 2010, and 2014	Assume January for all regulations expect 2002/4 where assume October 2002	Varied for each regulation. For 2007, Pre-buy: none identified, Low-buy: 6 months	Varied for each regulation. For 2007, Pre-buy: none identified, Low-buy: -15% Class 8 sales	Regression using quarterly GDP and real oil prices as controls on U.S. truck sales with monthly dummy variables included.
ACT Research 2022	Class 6-8, focused on Class 8 Tractors	2007	April 2007	Pre-buy: 21 months ahead of regulation Low-buy: None was estimated	Pre-buy: 147,000 Class 6 to 8 vehicles Low-buy: None was estimated, assumed same size as pre-buy	Use several methods, none well described. These methods include a stock replacement model and a regression using truckload carrier new income margins collected from nine fleets.