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Improving Fuel Economy in Heavy- Duty Vehicles

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Abstract

In September 2011, the National Highway Traffic Safety Administration and U.S. Environmental Protection Agency promulgated the first-ever federal regulations mandating fuel economy improvements for heavy-duty commercial vehicles. While the performance-based approach to these rules offers familiarity and assurances of fuel economy improvements, it also has some well-known weaknesses. In this paper, we describe fuel economy technologies for the trucking sector, its economic structure, the details of the new fuel economy regulations, and the controversies they sparked. We then address issues raised in reviewing the accompanying regulatory impact analysis. Next, we highlight some flaws of this form of regulation and suggests a variety of alternative, more market-oriented approaches that might work better.

Key Words: fuel economy, CAFE, trucks, heavy-duty vehicles, technology-based standards, regulatory impact analysis, RIA

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Winston Harrington and Alan Krupnick*

1. Introduction

In November 2010, the National Highway Traffic Safety Administration (NHTSA) and the U.S. Environmental Protection Agency (EPA) jointly proposed the first-ever federal regulations mandating improvements in fuel economy among heavy-duty commercial vehicles (HDVs)—that is, heavy-duty trucks, buses, and vans (U.S. EPA and NHTSA 2010). After taking comments from interested parties for about 10 months, the agencies promulgated these rules, called the Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles, in September 2011 (USEPA and NHTSA 2011).

The issuance of these regulations is the first step of what promises to be a long regulatory journey. The requirements spelled out in the regulations do not become effective until 2014–2018 so that manufacturers have the lead time necessary to respond. Moreover, we can expect more regulation in the future. Regulators expect the new rules to impose only modest costs and require reductions in fuel intensities of 7–24 percent by 2018, depending on vehicle category. By comparison, a recent study by the National Research Council (NRC) identified a suite of technologies that could become available in the 2015–2020 time frame that would reduce fuel intensities in various truck classes by much more—almost 50 percent, albeit at much higher cost (NRC 2010). Thus, the real significance of the new regulations may not be in their immediate contribution to fuel savings, which will be modest. Rather, if the past is any guide, future regulations will seek to exploit the available fuel efficiency technologies and follow the regulatory approach laid out in this first set of HDV fuel economy regulations.

That path will be familiar to students of government environmental regulation, especially those who have paid attention to the 32-year history of the CAFE policy for light-duty vehicles. That is not to say the HDV fuel consumption regulations are a rerun of the LDV CAFE standards; they are much more complex. Nonetheless, those who study the proposed HDV rules will see many of the same concepts and regulatory strategies employed in the CAFE rules.

Regulatory familiarity can be advantageous for almost all interested parties. Regulators have experience implementing and enforcing the rules, the regulated parties and other interested

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parties know what to expect, and there are also shared assumptions and a common vocabulary. Familiarity also can breed consensus. While the firms to be regulated, environmental groups pushing for more stringent regulation, and other interested parties have submitted comments that are highly critical of many details, they accept the broad approach for reducing fuel use among HDVs.

The confidence of stakeholders in the overall approach might be well placed. Besides its familiarity and the support it enjoys in the regulated community, it appears to offer reassurances that something actually will be done to improve fuel economy. But this regulatory approach also has weaknesses that are well known to the regulators and regulated parties. In the first place, despite heroic attempts by regulators to introduce features that promote economic efficiency and provide much-needed flexibility, the approach cannot take complete advantage of the heterogeneity of either vehicle characteristics or the needs of vehicle purchasers. Moreover, the very act of introducing flexibility risks creating incentives with unintended consequences. That is precisely what happened with LDVs, when the much more lenient CAFE standard, together with an exceedingly loose definition of “truck,” allowed manufacturers to market small pickups and SUVs that appealed to households but were considered trucks for regulatory purposes. The ratio of light trucks to cars in the household vehicle fleet was increasing prior to the introduction of CAFE, but the rules no doubt gave it a powerful shove.

More importantly, the current approach is problematic because it regulates fuel intensity rather than fuel use itself. Total fuel use depends not only on the rate of fuel use in each vehicle but the total size of the vehicle fleet, the speed with which the new fuel-efficient vehicles are introduced into the fleet, and the intensity of use in all vehicles. Fuel intensity regulation can conceivably delay the rate of replacement because new vehicles are more expensive, and it can induce greater use of the new vehicles because the improved fuel economy reduces the cost of a given trip (the so-called rebound effect). It also can affect the share and types of goods hauled by truck rather than by rail and barge, although the effect of these shifts on fossil fuel use is uncertain. The combined effect of these mechanisms probably is not powerful enough in the short-to-medium term to reverse the downward effect of fuel economy regulation on total fuel use, although it can affect fuel use noticeably.

In this paper, we describe fuel economy technologies for the trucking sector, its economic structure, the details of the new fuel economy regulations for heavy-duty trucks—no easy task given its length and complexity—and the controversies they sparked. We then address issues raised in reviewing the accompanying regulatory impact analysis (RIA). Next, we highlight some flaws of this form of performance-based regulation and suggests a variety of alternative, more market-oriented approaches that might work better. These policies differ from the current

approach by addressing fuel use directly rather than by addressing the design fuel use rates in new vehicles. Finally, the last section offers some conclusions.

2. Background

Before discussing the regulations themselves, it is useful to discuss briefly several background topics: truck classifications, fuel economy metrics, how energy is used in HDVs, and the structure of the truck-manufacturing industry.

Truck Classifications. Table 1 shows the vehicle classes defined by the U.S. Department of Transportation, which are based primarily on weight. Heavy-duty trucks start with class 2b (large pickups and utility vans in the 2.5–3.2 ton range when empty) and end with the largest trucks in class 8b (large tractor trailer, bulk tanker ranging from 11.6 to 17 tons). When full, the smallest heavy-duty trucks can about double their weight to 3.5–5 tons, while the largest can more than double their weight to 16.5–40 tons.

Fuel economy metrics. The Federal Highway Administration categorizes trucks by gross vehicle weight, as shown in Table 1. The table also lists typical fuel consumption rates using two metrics. The relevant metric for HDVs, in the right-most column, is gallons per ton-mile. Gallons per 100 miles, which is essentially the reciprocal of the vehicle fuel economy in miles per gallon, is the metric typically used for LDVs. It is interesting to note that as gross vehicle weight increases, fuel consumption rates in gallons per 100 miles increases, but gallons per ton-mile decreases, partly because the loads increase faster than fuel economy falls.

Energy Use in HDVs. To begin to understand the options available for reducing fuel use in HDVs, it is useful to examine how they use energy. Table 2 shows an energy audit for one very important type of truck—the class 8 combination tractor, which is the typical large semi one sees on the interstate—under two different drive cycles or usage patterns, urban and intercity. As shown, in each duty cycle, about 60 percent of the chemical energy stored in the fuel is lost in the engine itself; the remainder is the mechanical energy that propels the vehicle. This “brake” energy is dissipated in moving the vehicle, and here the differences in the pattern of losses is substantial. Outside of the engine there are big differences between energy losses in urban versus high-speed driving. In urban driving, braking losses account for nearly half the remaining energy, but this drops to nearly zero on the open road. For rolling resistance and aerodynamic losses, the pattern is reversed: low-speed urban driving accounts for small losses, while losses are much larger on the highway. This is not surprising, since the power required to move a body through a fluid increases with the cube of velocity. Power to overcome rolling resistance

increases linearly and exceeds aerodynamic losses at speeds below about 50 miles per hour (NRC 2010).

Potential fuel economy improvements from technologies. The last column of Table 2 shows estimates from the NRC (2010) report of percentage reductions in fuel consumption from applying the technologies recommended by the NRC in each energy loss category for the combination truck. The percentage reduction in fuel use for a given level of output has become the most common method for displaying and comparing the fuel-saving potential of various technologies. If, for example, all the engine technologies in a category recommended were adopted, and technology in all other categories were held constant, the reduction in the fuel consumption per mile of travel of the vehicle would be reduced by an estimated 28 percent. Combining estimates for a pair of technologies, however, is not linear, but multiplicative, whether within the same category or not. In other words, if technology 1 reduces specific fuel consumption by p_1 and technology 2 reduces it by p_2 , then the reduction when both are applied is

$$1 - (1 - p_1)(1 - p_2). \quad (1)$$

Thus if all the technologies in Table 1 are applied at once, the estimated reduction in specific fuel consumption is 47 percent, not the 57.5 percent obtained from adding up the figures in the column.

The potential energy savings will be specific to the truck's design and how it is used. For a class 8 combination tractor, the potential savings from better aerodynamics and tires is far more important than for other trucks because so much energy is expended in highway driving. For HDVs with a duty cycle dominated by urban driving—or even more so, an HDV heavily used off-road—these categories will be much less important. Nonetheless, in all HDVs, the engine is the largest user of energy, and fuel-savings technologies for engines will be important. In fact, for vehicles intended principally for urban and other low-speed uses, engine technologies will be even more important than for other categories because opportunities do not exist in other categories. Hybrid engines are an especially attractive technology in such vehicles because they are able to reduce braking losses through regenerative braking.

For the various types of vehicles examined, the NRC committee found that potential energy reductions of around 45 percent to more than 50 percent in the 2015–2020 time frame were achievable. In every case, though, the estimated costs of various technology options was highly variable, and the cost-effectiveness (cost per unit fuel consumption rate reduction) even more so. Moreover, the least costly technologies are not concentrated in the engine, the

aerodynamics, or any other one component or feature, so that a cost-effective approach to regulation requires a broad-based approach.

Finally, Table 2 provides further insight into our earlier observation that the larger the vehicle, the better the fuel consumption rate in gallons per ton-mile. While large diesel engines and vehicles to some extent are inherently more fuel-efficient, in the ton-mile metric, than smaller engines and vehicles, a more important consideration is that the weight of the empty vehicle, which is fixed regardless of load size, is about half the gross vehicle weight. Moreover, in highway driving, a significant fraction of the energy loss is due to aerodynamic and tire losses, which do not strongly depend on vehicle load. It follows that one of the most effective ways to reduce fuel consumption in HDVs is to increase permissible loads, something the trucking industry has advocated for years. To be sure, increasing maximum loads may raise issues of safety, road wear, and perhaps congestion, but it makes the point that fuel consumption depends on much more than vehicle and engine design—it depends on how vehicles are used.

2.1. Complex Industry, Complex Products

Several features of the HDV manufacturing industry complicate regulation of fuel consumption rates.

Tables 3 and 4 show the principal manufacturers of heavy-duty vehicles and trucks, illustrating that the industry is dominated by a small number of large manufacturers. Indeed, the number of independent engine and truck manufacturers is even smaller than Tables 3 and 4 might suggest, because of affiliations, partnerships, and outright ownership of one company by another. Freightliner, Mercedes Benz, and Detroit Diesel, for example, are owned by Daimler; Mack is a Volvo company; and Kenworth and Peterbilt are units of PACCAR International. Cummins Diesel is the only major engine manufacturer without a truck-manufacturing affiliate.

Tables 3 and 4 also suggest that commercial vehicle manufacturing is a very dynamic industry and that its dynamism creates problems for obtaining the fuel economy levels suggested by the new regulations. For both trucks and engines, annual production swung between 39 percent above and 35 percent below the five-year average. Some of this variability is a result of the economic cataclysm that began in 2008, but in fact sales had begun a major decline at least a year before. A likely reason that contributed to the 2005–2006 increase followed by the 2007 decline is that many buyers bought ahead of an anticipated major price increase in 2007—an “announcement effect.” Truck and engine prices increased primarily because in that year, costly new regulations to curb emissions of nitrogen oxides (NO_x) and fine particulate matter (PM_{2.5}) from heavy-duty engines began to take effect. At the same time, this pattern also was influenced by what Gruenspecht (1982) called “new source bias,” which is the lengthening of ownership of

older vehicles when prices on new vehicle rise. To the extent the new fuel economy regulations raise new vehicle prices, similar effects can be expected.

Another important feature of the truck industry is its fragmentation. The market for trailers and truck bodies is quite different from that of tractors and engines. This sector contains many manufacturers who design, manufacture, and service equipment for a wide variety of users and uses, from refuse collection to cement mixers to school buses. The typical manufacturer of truck bodies produces specialty items for special tasks, and the size of many of them places them in the category of “small businesses” even though they may have a substantial market share of their particular niche. Because of policy imperatives to protect small businesses, these specialty manufacturers can have regulatory advantages over larger manufacturers producing a variety of products. Many environmental regulations already have exemptions or less onerous regulations for businesses meeting some size criteria. The number of firms and the heterogeneity of products complicate the design of efficient and effective regulation in this sector.

The simple weight-based categorization of HDVs shown in Table 1 and the list of engine and vehicle manufacturers in Tables 3 and 4 also conceal a remarkable diversity of product designs and uses, which also makes HDVs hard to regulate. In the higher weight classes, some integrated vehicles are sold, notably by Navistar and Volvo, but a buyer typically purchases an engine, a vehicle, and a trailer or body separately.

It is not clear whether integrated manufacturers have an advantage in responding to fuel intensity regulation. While integrated vehicles may be able to take advantage of complementary technologies that are not available to engines and vehicles produced separately, manufacturers may not get credit for such innovations unless the regulations are sufficiently flexible—for example, as they would be in a rule allowing averaging across vehicle and engine sectors.

Finally, tractors, diesel engines, and trailers and bodies are durable goods and have long, useful lives. In addition to the new equipment market, therefore, there is a strong secondary market in trucks, engines, and truck bodies. Regulation of products in these secondary markets is much less extensive than in the primary market. The products may be modified in ways that either improve or compromise their fuel economy performance. For examples, fairings or hoods may have been damaged and removed from cabs or trailers, or removed undamaged to reduce weight. Engines may be altered to improve fuel economy or compromise it to meet emissions standards. Engines also may be altered to trade off fuel economy for greater power. These alterations may be beyond the purview of the regulator so that even successful implementation of new HDV standards may be at least partly undone over time.

3. The Regulations

Federal agencies usually do not issue joint regulations, but they did in the case of HDV fuel economy standards because of an overlap in responsibility at EPA and NHTSA. NHTSA historically has administered motor vehicle regulation generally and fuel economic regulation in particular. More recently the agency was directed to produce fuel consumption regulations for HDVs by the Energy Independence and Security Act of 2008. EPA's involvement began with the Supreme Court decision in *Massachusetts v. EPA* in 2008, which first gave EPA the authority—and also the responsibility—to regulate greenhouse gases under the Clean Air Act. The Court directed EPA to initiate an “endangerment” finding under Section 202 of the act, which governs emissions regulations for new vehicles (Richardson 2011). The result was a finding that greenhouse gases do in fact endanger the public health, which obliged EPA to initiate rulemaking for HDVs. At that point, the tight relationship between fuel consumption and emissions of carbon dioxide (CO₂) assured that the two agencies would have to work closely together during rulemaking.

The proposed HDV regulations are one of the most recent—and complicated—examples of a style of environmental policymaking called technology-based standards. In the past, technology-based regulation most often has been applied to emissions from industrial processes, but in this case the subjects of the regulations are products. These regulations share a number of common elements. Here we describe those elements and give examples from the HDV rules.

Categorization. Targets of regulations are categorized (and frequently subcategorized) such that different products in the same subcategory must meet the same standard. At the top level of the categorization are three vehicle types. One is the class 2b and 3 heavy-duty pickups and vans, which are primarily sold as integrated vehicles and are treated in the same manner as the light-duty CAFE standards. They will receive no further discussion here. The other two are class 7 and 8 combination tractors, and class 2b–8 vocational vehicles.

Tractor cabs are classified by two weight classes and three roof heights. In addition, for class 8, there are both “day cabs” and “sleeper cabs” at each roof height, making a total of nine tractor categories. These nine categories differ by weight and aerodynamic qualities, both of which are adversely affected by height. In addition, two engines subcategories are defined: a “heavy heavy-duty” engine, which primarily for class 8, and a “medium heavy-duty” engine for class 7.

The class 2b–8 vocational vehicles are so called because of the enormous range of tasks—transport-related and not—they are called on to perform. The agencies gave up developing a positive definition for this category. Instead, they defined it as all heavy-duty

vehicles that were neither class 7–8 combination trailers nor class 2b–3 heavy-duty pickups and vans.

A large number of truck body builders in the vocational class will be responsible for assembly, integrating truck body with a purchased engine and chassis from other manufacturers. EPA and NHTSA decided not to regulate the design of the truck bodies, only the engine and chassis components of these vehicles. This decision saved the agencies from having to deal with a huge number of small equipment manufacturers and an equally larger number of equipment configurations. In addition, the agencies argued that it is not likely to sacrifice many fuel-saving opportunities because these vehicles are typically operated at low speeds on local roads or off-road. Furthermore, there is only one chassis category for each of three class aggregations: light heavy-duty (class 2b–5), medium heavy-duty (classes 6–7) and heavy heavy-duty (class 8), and three engine categories: light, medium, and heavy heavy-duty.

Performance metrics. The principal performance metric for determining compliance with the NHTSA’s fuel consumption standards is the fuel consumption rate in gallons per 1,000 ton-miles (for vehicles) and gallons per horsepower-hour (for engines). For EPA’s carbon emissions standard, it is grams CO₂ per ton-mile (vehicles) or per horsepower-hour (engines). The performance standards in both metrics are chosen to be consistent so that achievement of the one implies the achievement of the other (with appropriate allowance made for alternative fuels).

Baselines. The baseline is defined as current or typical performance by the engines and vehicles in the industry to be regulated. The baseline can refer either to the designated performance level or the equipment capable of achieving it. For example, the baseline engine for class 8 tractors is a heavy heavy-duty 15-liter engine producing 455 horsepower. In class 7, the baseline engine is a medium heavy-duty 11-liter engine producing 350 horsepower. Both baseline engines use a sophisticated NO_x and PM_{2.5} aftertreatment system called selective catalytic reduction (SCR) to comply with the 2007 Heavy Duty Highway Rule (U.S. EPA 2001). Likewise, three baseline engines with similar equipment (light, medium, and heavy heavy-duty) are defined for the three engine categories of the class 2b–8 vocational vehicles, and all use SCR to comply with the 2007 rule.

The current vehicles or engines of some manufacturers in some categories do not meet the baseline performance criteria values. In those cases, manufacturers were granted some flexibility. They may use an alternative baseline that equates to the performance of its average product in that category for meeting the 2014 standards, but by 2018 they must meet the more stringent common baseline. This is one of several flexibility measures built into the regulations.

In principle, baselines are not required to formulate technology-based standards because compliance can be determined via an absolute performance metric, in terms of gallons per 1,000 ton-mile, for instance. In practice however, fuel economy standards are developed in terms of percentage reductions in fuel use of CO₂ emissions relative to a baseline.

Deciding on the fuel economy standards. The Energy Independence and Security Act lays out three criteria for setting the fuel economy standards. Quoting from the preamble of the rule, “The program must be (1) designed to achieve the maximum feasible improvement; (2) the various required aspects of the program must be appropriate, cost-effective, and technologically feasible; and (3) the standards adopted under the program must provide not less than four model years of lead time and three model years of regulatory stability. In considering these various requirements, NHTSA will also account for relevant environmental and safety considerations” (U.S. EPA and NHTSA 2011).

Criteria (1) and (2) generally are at odds. Usually, the maximum feasible improvement exceeds that which is cost-effective (or, alternatively, reaches maximum net benefits if the CO₂ reductions, etc. are monetized) because costs rise faster than emissions reductions.

By a remarkable coincidence, the maximum feasible technologies considered in this rulemaking process turn out also to have the largest net benefits. The agencies demonstrated this by first building technology cost curves reflecting CO₂/oil-use reductions from a no-action baseline for the three categories of trucks. Then they constructed four scenarios (plus the baseline, scenario 1). Working from scenario 5 backward, scenarios 4 and 5, which push fuel savings technologies beyond their current limits, are by definition “infeasible” against criteria (3) above. Scenario 3 is the maximum feasible technologies in all three categories. Scenario 2 strips away the least-cost-effective technologies in each category (presumably the marginal technologies in scenario 3). This procedure weakens the standards relative to alternative 3 by about 12 percent. Details of the cost–benefit analysis will be discussed later in this paper.

The Fuel Economy Standards. In each subcategory, the performance standards are the schedule of regulatory targets to be met. For the HDV regulation the targets are expressed in fuel consumption rates (in gallons per 1,000 ton-mile) and CO₂ emissions rates (in grams per ton-mile). Deadlines are set for 2014 and 2018, although for engines the 2014 standards are voluntary until 2015. As shown in Tables 5 and 6, the anticipated improvement is 7–10 percent for all categories except class 8 sleeper cabs, which are to achieve up to 14 percent improvement in 2014 and 24 percent improvement in 2018. Standards are more stringent in this last category because the ground has been prepared by EPA’s Smartway Program, a collaborative agency–

industry program to improve the tires and aerodynamic characteristics of tractors and intercity trailers.

Demonstration of feasibility. For each product, the agencies identify a suite of technologies available within the time frame that, if applied to a vehicle, will allow the relevant performance standard to be met. For example, domestic tractor manufacturers already offer products with some of the aerodynamic features identified and developed as part of the Smartway Program. A more controversial issue involves the use of post-combustion technologies in the baseline engine. This is discussed more fully in section 4.1.

Certification. To demonstrate compliance of vehicles, engines, and other components with the standards, vehicles and engines must be tested and their performance quantified. A great deal of ink is spilled in the regulation to discuss these methods. The tests must be appropriate not only to the equipment tested but to its probable use. For example, tests for class 7–8 combination trailer engines use a Supplemental Engine Test (SET) test, which is heavily weighted toward steady-state, high-speed highway operation typical of this class of vehicles. In contrast, engines used in vocational vehicles will be tested on the heavy-duty Federal Test Procedure (FTP), which has a driving cycle typical of urban driving, with frequent acceleration, deceleration, and stops.

Flexibility. In addition to the alternative baseline, an array of flexibility measures are available to manufacturers to make it easier to comply with the regulation. Probably the most important of these are provisions allowing averaging, banking, and trading of emissions credits within vehicle or engine subcategories. For example, in the subcategory of medium heavy-duty engines for class 2b–8 vocational vehicles, credits can be traded with other engines in the subcategory, even across manufacturers, but they cannot be traded with other tractor, chassis, or engine categories. Despite having the same name, for example, credits in this category cannot be traded for those in the medium heavy-duty engine subcategory for class 7–8 combination tractors. Indeed, trading across category boundaries is especially prohibited because the different duty cycles and annual mileage make it difficult to calculate exchange ratios, which could lead to unpredictable and perverse outcomes.

Credit also can be received for early adoption, demonstration of improvements before they become requirements, and “advanced” or “innovative” technology. Four technologies are available for advanced technology credits, which can then be used in other subcategories if desired. This is the only category where credits can be traded across subcategories.

Alternate-fueled vehicles. The regulations provide credits for alternative-fueled vehicles according to the carbon content of their fuel relative to diesel. Thus, a natural gas vehicle, with 30 percent less CO₂ emissions per gallon equivalent than the identical vehicle fueled by diesel,

would be presumed to be 30 percent more efficient. For some alternative-fueled vehicle types, this degree of improvement would be enough to meet the standards or, if more than enough, would generate credits to offset necessary fuel economy improvements in other vehicles.

4. Controversies

EPA and NHTSA received many comments on the proposed HDV fuel economy regulation from a variety of sources: engine manufacturers, chassis and body manufacturers, tire makers, nongovernmental organizations, state and local air quality authorities, and private citizens. The agencies' responses took up more than 1,000 pages of text. As is usually the case, the most extensive comments came from those most directly and significantly affected—the manufacturers. We briefly describe some of these comments, grouped around what we think are a few significant decisions that generated controversy and some degree of pushback.

4.1. Baselines

The engine baseline definitions described in the previous section may end up being one of the most contentious issues of the regulation.

In early 2001, EPA promulgated the 2007 Heavy Duty Highway Rule (EPA 2001), which stringently regulates NO_x, hydrocarbons, and particulate emissions from heavy-duty vehicles manufactured in 2007 and beyond. To meet the new NO_x standards, most manufacturers opted to use SCR, a treatment of exhaust gas that uses ammonia in the presence of a catalyst to chemically reduce oxides of nitrogen to harmless nitrogen gas. In diesel applications, direct use of anhydrous ammonia is ruled out by safety and storage concerns. Instead, diesels use urea, which is not an effective reducing agent until it is thermally decomposed to yield ammonia. SCR systems must have a method for continuous injection of diesel exhaust fluid (DEF), consisting of at least 30 percent urea. The substantial volume of DEF required amounts to 3–5 percent of the volume of diesel fuel.

The chief NO_x-reducing alternative to SCR is exhaust gas recirculation (EGR), which entails recycling part of the exhaust stream back through the engine to lower combustion temperatures and thus the prevalence of “hot spots” in the engine where NO_x is likely to form. The result is lower emissions of NO_x coming out of the engine. The 2007 standards, however, were so stringent that conventional EGR was no longer effective enough to meet the new standards, hence the need for an aftertreatment technology.

At least one manufacturer—Navistar—took a different approach to meeting the new NO_x and PM standards: a major redesign of heavy-duty engines, including “enhanced” EGR, to

reduce engine-out NO_x. But Navistar may in the end find itself effectively required to employ SCR anyway: SCR allows other manufacturers to take advantage of a variety of performance-enhancing engine alterations that have a side effect of increasing engine-out NO_x emissions, which can then be removed in aftertreatment. Having committed to a no-SCR solution, Navistar cannot take advantage of these other measures.

In the company's comments on the proposed regulation, Navistar (2011) argues against the incorporation of SCR in the baseline technology, saying that the extant SCR-equipped engines identified by EPA and used to construct the baseline do not meet the NO_x standard and therefore do not in fact comply with the 2007 Heavy-Duty Highway Rule. Thus the standards built on this baseline technology are infeasible.

Navistar offers several arguments for the infeasibility of the baseline. First, it claims that EPA does not calculate the environmental effects of the manufacture of DEF, pointing to a specific recommendation to that end by a National Academy of Sciences committee (NRC 2010). Second, EPA authorizes extended operation without the SCR system engaged, and thus there is no NO_x control for extended periods of operation. Navistar also claims that present onboard diagnostic systems are unable to distinguish between use of DEF and water during operation, creating the potential for fraud and willful noncompliance. Third, it claims that vehicles in stop-and-go driving do not reach high enough operating temperatures to decompose the urea into ammonia so that the SCR system can work properly. As shown in Table 4b, Navistar engines are primarily found in light and medium heavy-duty engines used in vocational vehicles, most of which have an urban duty cycle.

In its replies to these comments, EPA noted that the feasibility requirement did not mean that all designated technologies had to be now available, only that they had to be available before the effective date of the regulations. It was also pointed out that Navistar and other manufacturers could resort to the alternative standards for an engine, which required a 3 percent improvement over the engine's performance by the effective date. Generally the agencies' view was that the lead times gave all manufacturers time to achieve compliance.

4.2. Technologies in Vocational Vehicles

The proposed class 2b–7 vocational vehicle standards only reflect two things: the improvements in engine fuel intensity and an anticipated improvement in rolling resistance. As numerous commenters pointed out, fuel-saving technologies potentially could apply to other vehicle components, including transmissions, advanced drive trains, weight reduction and improved auxiliary systems. Many of those commenters urged the agencies to set the standards so as to force adoption of these technologies for new vehicles. The agencies declined to do so,

claiming that little was known about the baseline performance of currently feasible technologies, information deemed critical to the setting of the regulations. Because these are performance standards, the agencies could not simply mandate the use of these technologies—an inadvisable approach in any case because it is tantamount to picking technological winners.

At the same time, the Notice of Proposed Rulemaking received a great many comments on the decision to base vocational vehicle performance in 2017 on improved rolling resistance as well as engine technologies. Part of the justification for this position is the relatively large percentage of energy losses due to rolling resistance at low speeds (see Table 2). Based on their comments, vehicle and tire manufacturers are dubious of this approach, arguing that the industry would need more than six years to develop new tire designs and prove they were safe and effective on the wide range of vocational vehicle types.

In response, the agencies granted that the market for vocational vehicle tires faced some obstacles that were not present for the combination trailers. For one thing, vocational vehicle use tends to be more demanding: more varied terrain and road conditions and typically tighter turning radii, for example, increases tire wear in this category. Also, frequent use off roads and on unimproved roads puts a premium on adequate traction, which could raise safety issues if or as rolling resistance is improved. Market structure also conspires against improved rolling resistance for vocational vehicles. A much larger variety of tire types is needed for much smaller market niches, which means there is less return on innovation investment in particular applications. This is especially true when compared to the combination trailers, where relatively few large market segments tend to have relatively simple duty cycles dominated by high-speed intercity travel. It is no surprise that rolling resistance of tires used in combination trailers is already better than those of the typical vocational vehicle.

Nonetheless, after surveying the range of products available, EPA and NHTSA concluded that a sufficient range of products was available to lead to significant reductions in rolling resistance. The requirements were left unchanged in the final regulation.

4.3. Categorization

As noted, two of the three vehicle categories had more or less natural definitions depending on vehicle characteristics, uses, and duty cycles. The exception—vocational vehicles—were defined as “everything else.” In this category, the agencies declined to regulate the large array of truck bodies that fit on the three chassis in the vocational vehicles category (light, medium, and heavy heavy-duty).

Categorization exists most fundamentally because it would neither be fair nor efficient to lump all vehicles in a single group subject to a single regulation. Ideally, perhaps, each vehicle type should be in its own category so that the regulation can be precisely tailored to its particular characteristics, but that approach is unmanageable. But too much categorization can lead to adverse and unintended consequences if, for example, the job done by one vehicle can be done by a vehicle in a different category that is subject to less stringent regulation. In this case, vehicle purchasers could change vehicle types to save costs and subvert to some extent the goals of the rulemaking. The agencies were aware of these possibilities and in at least one instance took action to prevent it. In the Notice of Proposed Rulemaking, the agencies classified all vocational vehicles with sleeper cabs as “tractors.” The argument for doing so was to prevent vocational vehicles from being modified to serve as intercity combination trailers. However, numerous commentators objected, arguing that the agencies had underestimated the cost and difficulty of making vocational sleeper cabs suitable for intercity use. Those costs, it was said, were at least as great as the savings available from access to the less stringent regulation. (Of course, if the rule’s cost and benefit estimates are correct, there would be no savings from doing so anyway.) In response to the new information, the agencies removed the tractor designation from all vocational vehicles.

4.4. Alternate-Fueled Vehicles

The rule giving credit equal to the difference in CO₂ emissions between an alternate-fueled vehicle and its diesel counterpart generated many comments from producers of alternate-fueled trucks and exposed a fault line between NHTSA and EPA’s responsibilities. EPA’s mandate is to focus on reducing CO₂ emissions, and the rule on alternate-fueled vehicles fully reflects the appropriate incentive for these types of vehicles according to that metric. However, under NHTSA’s mandate to reduce oil consumption and energy dependence, credits for some alternate-fueled vehicles, such as all-electrics or natural gas vehicles, should be much larger because they use no petroleum. Indeed, with U.S. shale gas estimates and production rising so quickly that the expectation is to begin exporting liquefied natural gas instead of importing it, there is even more reason for crediting natural gas as good for energy security. In any event, the agencies say that they will revisit this issue in the future.

4.5. The Final versus Proposed Standards

The final rules were issued on August 9, 2011, only nine months after the proposed regulations. Tables 5 and 6 compare the proposed and final fuel intensity standards for combination tractors and vocational trucks, respectively. As shown, the engine standards in both categories remain unchanged between the proposed and final regulations. The vehicle standards

show some movement in both the baselines and standards themselves, which in the final rule are on the order of 5–10 percent higher than in the proposed rule. This is typical in agency rulemaking, reflecting improved knowledge among the regulators as they receive comments and new data. The apparent exception in the heavy heavy-duty vocational vehicle standards, where both the baselines and the standards approximately doubled, is explained by a change in the payload assumption for these vehicles, from 38,000 pounds in the proposed rule to only 15,000 pounds in the final rule. Apparently the 38,000-pound figure in the Notice of Proposed Rulemaking resulted from confusion among empty weight, gross weight, and payload that was corrected in the final rule.

5. The Regulatory Impact Analysis

Because the fuel economy standards are a “major” rule, the EPA and NHTSA were required by Executive Order to undertake a cost–benefit analysis of their proposed rule and alternatives. In this section, we present some results from that analysis and offer some observations.

Alternatives considered. Office of Management and Budget guidelines indicate that agencies should develop a number of options for a rule, evaluate them, and then pick a preferred option, carefully justifying their choice. For the fuel economy rule, as indicated in the RIA and Federal Register (FR), the agencies considered the five options discussed in section 3, only two of which were substantive (scenarios 2 and 3). The agencies found that net benefits are higher in scenario 3, and accordingly, they chose that option. Given the many dimensions of this complex regulation and the many decisions the agencies made, their choice of alternatives to analyze seems perfunctory.

Costs. The RIA presents the cost of the proposed regulations in several different ways: costs per truck by category over its lifetime, costs per ton CO₂ reductions in any given year of the policy, and total costs of the program by category. Although the latter are required to determine the overall size of the regulation, the unit costs are more informative for assessing both cost-effectiveness and impacts on individual owners. Table 7 shows unit costs in two ways, by vehicle and by ton of CO₂ reduced. As shown, the average per-vehicle costs of the standards is 16 times higher for combination tractors than for vocational vehicles. Yet the cost per ton of CO₂ reduced (not including fuel savings) by the end of the program in 2050 is actually lower for the combination tractors. The primary reasons for these disparities are the much lower fuel economy (greater carbon density per mile driven) and higher mileage of combination trailers, as shown in Table 1.

Fuel cost savings. These factors also play into the huge difference in fuel cost savings per vehicle across the two vehicle types: \$79,089 over the lifetime of a combination vehicle discounted at 3 percent versus \$5,872 for the vocational vehicle, assuming the diesel price path in the *Annual Energy Outlook* 2010 reference case (EIA 2010). Indeed, fuel savings for all vehicle types are predicted to be so large relative to initial cost that payback periods are under one or two years.¹ Overall, by 2050 when the program evaluation stops, costs per ton of carbon reduced are strongly negative. Note that these costs are negative even before counting all the nonmarket, public benefits associated with fuel economy, such as energy security, health effects related to air pollution, and the like. However, these estimates do incorporate the rebound effect.

Accuracy of cost estimates. An initial source of error in the cost estimates driving the cost-effective valuations is that they are ex ante estimates made by EPA and NHTSA. Previous studies comparing ex ante and ex post cost estimates of regulation have found substantial differences (e.g., Harrington et al. 2000; OMB 2005).

A second source can be found in the great heterogeneity of the industry. There are only a handful of vehicle and engine categories but vastly more types of vehicles, not to mention combinations of vehicle components and engines. However, the regulatory cost estimates used in the RIA are based on the deliberations of the NRC (2010) and engineering studies, such as the TIAX (2009) study commissioned by the NRC committee. They are driven by the estimated costs of particular technologies, and they necessarily have to be the same for each manufacturer. But no doubt the cost estimates will differ—perhaps substantially—between various manufacturers. A likely instance of such variation will be between the integrated manufacturers, such as Volvo and Navistar, and manufacturers that specialize in engines, vehicles, or chassis components. Cost heterogeneity is known to enhance the relative performance of economic incentive approaches relative to direct regulatory approaches. While a credit trading regime could eliminate much of the cost deviation, the proposed HDV rule restricts many trading opportunities in an attempt to prevent class shifting and other unintended consequences of the regulation.

The disparity between the cost and technology imposition on combination vehicles and vocational vehicles suggests that rules on the latter could be eliminated without much effect on the overall cost or effectiveness of the regulation. As noted earlier, one strong motivation for the class 7 vocational vehicle standards is to discourage class shifting. But with cost-effectiveness

¹ With fuel savings so large and immediate, the discount rate used to amortize fuel savings is mostly irrelevant.

determined by cost per ton CO₂ and the incentive for class shifting determined (in part) by cost per vehicle, it is far from obvious that this set of standards, or indeed *any* set of standards, is capable of preventing class shifting at the same time as achieving cost-effectiveness.

Benefits and net benefits. The RIA presents calculations of the benefits of the regulation as well as the costs. Table 8 shows a summary of costs, benefits, and net benefits, expressed as the aggregate averages for model years 2014–2018, in millions of 2009 dollars, using a 3 percent discount rate. The last row of the table shows net benefits using a 7 percent discount rate. These rates follow Office of Management and Budget guidelines. With technology costs of \$1.62 billion per model year and benefits (both public and private) of \$10.48 billion, net benefits are \$9.86 billion, implying that the regulations pass the benefit–cost test. Even at 7 percent, net benefits are still \$6.6 billion.

Let’s look under the hood at the benefits. These include increased energy security from consuming less imported oil (\$0.5 billion), reductions in climate damages from reduced CO₂, emissions (\$1.14 billion²), and two “private” benefits from less frequent refueling of a more fuel-efficient vehicle (\$0.08 billion) and the savings in fuel costs attributable to greater fuel economy (\$10.02 billion). In addition, the agencies adjust these benefits for the external costs of additional driving from the rebound effect (\$0.3 billion, a figure that includes added noise, human health effects from conventional air pollution, more vehicle accidents, and greater congestion). As shown, the net benefits are actually negative (-\$0.24 billion) until one counts the private fuel-savings benefits.

A number issues underlie these estimates. The main issue concerns the “energy-efficiency paradox”: although there appear to be large cost savings available from making energy-efficient investments at prevailing energy prices, few such investments are actually made. This paradox can be resolved by citing market failures, hidden costs, or both. Assumptions about which factors are at play can have a large effect on the accuracy of the cost estimates.

Potential market failures include (i) skepticism, fear of novelty, or a lack of information about the cost-savings; (ii) asymmetric information in the used vehicle market (the “market for lemons”), giving rise to fears that buyers will not be able to recoup their investment in fuel economy if they sell the vehicle; and (iii) split incentives between owners and operators who lease vehicles from them. Those who emphasize market failures tend to see real cost savings that

² This figure is based on EPA’s social-cost-of-carbon estimate, starting at \$22 and ending in 2050 at \$46 per ton, calculated with a 3 percent discount rate.

justify regulations requiring investments that are in the public interest as well as the interest of the companies and individuals undertaking them. The conventional wisdom in the trucking industry is that investments in energy efficiency require a two-to-three year payback in fuel economy savings, and yet the investments will continue to generate fuel savings over the life of the vehicle. These additional energy savings may not figure in the private benefit–cost calculus.

The hidden-cost argument starts with the idea that if such fuel savings were available, the “dollar bills lying on the ground” would be picked up—that is, the market would find a way around any market failures. Thus, if the “paradox” persists, it must be because the market believes the new technologies are oversold or have hidden costs—for instance, in terms of other valued vehicle attributes. In this case, if the regulation forces companies or individuals to make such investments, they will experience real costs, netting out much of the fuel-efficiency benefits or leading to lower benefits than forecast from engineering information.

In their cost–benefit analysis, EPA and NHTSA assumed that market failures explain the energy-efficiency paradox. If, alternatively, they had accepted a hidden-cost argument, the estimated benefits of the regulation would have been smaller. The trouble with the hidden-cost argument is that its proponents cannot point to any specific hidden costs. Nonetheless, to our knowledge, there are no careful empirical studies that shed light on this issue in the commercial-vehicle context.

The concern over these calculations doesn’t end there. The calculations assume a certain amount of new truck sales in each category and penetration into the fleet over time. But these assumptions may be wrong. If the firms balk at making these investments, for whatever reason, they may hold onto their existing trucks longer than usual or shift to less-expensive vehicles. There is precedent: manufacturers shifted to light-duty trucks from light-duty autos when the former were less regulated than the latter.

Calculations for some of the other categories are worth discussing as well because their benefits come close to offsetting technology costs without even counting fuel savings. Of particular note are the estimates of climate change damage avoided from CO₂ reductions, which offset 52 percent of the costs. These calculations use an estimate of \$22/ton in 2010 (rising slowly in later years), which is taken from a study by the Interagency Working Group on the Social Cost of Carbon (2010) based on results from three integrated assessment models. These models are highly aggregative, making many sweeping and controversial assumptions, and changes to them could have huge effects on the estimate, as the agencies admit.

The other controversial estimate is for energy security benefits, which net out about 22 percent of the costs. For such benefits to count, they must be considered externalities and must

be quantifiable. The most widely touted “benefit” to reducing our dependence on foreign oil is to improve our foreign policy flexibility because we would worry less about the impact of our national positions and behavior on Middle Eastern governments. Important as this flexibility might be, it is not an externality as conventionally defined, and how much our flexibility would increase with a relatively small change in our oil imports is unknown. The agencies rely on more conventional metrics of energy: monopsony rents created by changes in world oil market prices given a reduction in U.S. demand and the effect on the U.S. economy of a reduction in oil price volatility (Leiby 2008). As seen in NRC (2010), both of these “externalities” are questionable.

A final issue concerns the externalities associated with the rebound effect. The additional vehicle miles driven in response to the lower price of driving may result in greater emissions of conventional air pollutants. On top of this, if manufacturers believe that emissions standards on diesel vehicles are binding, when faced with the prospect of lower emissions per mile because of the new fuel economy standards, they may relax their controls of these conventional air pollutants, saving on costs to themselves and consumers. In this case, emissions would be unchanged following the imposition of the new fuel economy standards. But because of technical and resource limitations, the EPA and NHTSA did not estimate the model-year effects of the standards on conventional air pollutants (hence this benefit is not in table 8). Instead, they estimated the effects and benefits of the standards on these pollutants in 2030 and extrapolated those to all years of the analysis, for an added benefit of \$25.3 billion (using a 3 percent discount rate). Including this benefit adds more than 50 percent to the overall net benefits of the program from Table 8 over all five model years, of \$49.3 billion. This benefit estimate should be viewed as a possible overestimate, depending on market choices about emissions controls.

6. Some Economic Issues with Fuel Consumption Standards

In this section, we touch briefly on the economic and behavioral aspects of the HDV standards. These consequences either can be an inherent characteristic of regulations that mandate product performance characteristics or the result of a particular design feature. Such features often are added to increase the flexibility of the rule and reduce its cost to the regulated parties. But they often represent missed opportunities or have unintended negative consequences.

6.1. Missed Opportunities

Numerous factors affect fossil fuel use in both light-duty and heavy-duty vehicles:

- fuel consumption rate in new vehicles;
- fuel consumption rate in existing vehicles;

- average vehicle miles (and ton-miles);
- fleet mix and, for HDVs, the match between vehicle and use;
- fleet turnover rates; and
- availability of fuels and engines that use fossil fuels less intensively or use alternative energy sources.

These factors interact with one another, and any fuel-saving policy, even one that directly targets only one of these factors, is likely to affect each of the others indirectly, often in ways that are unexpected or adverse or both. Like CAFE, the HDV fuel economy regulation is a policy that attacks only one margin: the fuel consumption rate in new vehicles. Fuel consumption rate standards only affect some of the factors determining overall fuel use because they regulate the design of new products, rather than their use over the life of the product. In the cost–benefit analysis, the regulators anticipate the energy savings, based on predictions of how rapidly the new engines and vehicles will replace existing products, by how and how much the new vehicles will be used in the future, relative to the vehicles they replace. They also estimate the extent to which the fuel consumption of new vehicles increase with age. However, after the new trucks and engines enter the marketplace, the regulation supplies no further incentives to conserve energy, and indeed, the incentives may run in the opposite direction. Thus, these predictions may prove to be overly optimistic.

It is possible to expand the rules so that they encourage reduced fuel use along other margins than new vehicles and engines. For example, the rules could require retrofits, improvements in existing vehicles. The regulating agencies never seriously considered this option for the light-duty CAFE standards, presumably because most LDVs are built as whole vehicles. With HDVs, there are likely to be more opportunities to improve individual components. For example, the current rule requires the addition of spoilers and fairings to new intercity trailers, and perhaps with little or no modification, they could be just as effective on existing trailers.

Another missed opportunity concerns the treatment of alternative-fueled vehicles. Given the twin goals of reducing oil use and reducing carbon emissions, the agencies settled on an approach that encourages alternate-fueled vehicles with credits to the extent they reduce carbon emissions—but not to the extent they reduce oil use. The agencies are quite aware of this shortcoming and may seek remedies in a future rulemaking.

6.2. Unintended Consequences

Evidence of the unintended consequences of new-product or new-plant regulations is abundant in earlier environmental rulemakings in other contexts. Each of these consequences arises from the fact that the regulations only exert influence over how the vehicles are designed and built, while their fuel use depends to a considerable extent on how they are used, or indeed whether they are purchased at all. While design is also a strong predictor of use, it is not a perfect one. EPA and NHTSA recognize the potential that vehicles will sometimes be used in ways that may not be predicted, but for various reasons tend to minimize the significance of this point. However, the rule also points out that very little empirical work is available that can speak to these issues.

Consider how improving fuel consumption rates in new vehicles might affect other variables that influence fuel use. Other things equal, they will have the following effects:

- They will reduce the cost per mile (or ton-mile) of travel, which in turn will increase total vehicle miles traveled and ton-miles (the “rebound effect”), implying greater demand for transport infrastructure and perhaps an increase in accidents, conventional air pollutants, noise, and congestion.
- They will increase the sales price of new vehicles, which will depress sales of new vehicles, increase the value of existing vehicles, and retard the turnover of the vehicle fleet.
- If regulatory categories vary in stringency such that the incremental costs of compliance are higher in some categories than others, vehicle buyers will have an incentive for “class shifting”: purchasing a vehicle designed for one purpose and using it for another.

The rebound effect. The rebound effect has been extensively discussed for the CAFE standards, with recent studies finding it be very low (e.g., Small and Van Dender 2006). But there has been much less discussion in the case of HDVs. The rebound effect is the product of the demand elasticity of HDV mileage or ton-mileage with respect to the cost per mile and the ratio of the fuel costs per mile to total costs per mile.

EPA and NHTSA admit, on the one hand, that commercial users are likely to be far more conscious of costs than household users, which implies a larger rebound effect for commercial than for household vehicles. On the other hand, commercial users will be just as conscious of other costs, such as the capitalized cost of the vehicle and other fixed costs, labor costs, and vehicle maintenance. But on net, costs per ton-mile arguably will decline because fixed costs per ton-mile will decline with more ton-miles to spread them over and variable costs, like labor, will

remain unchanged. In other words, as fuel costs per mile decrease, this change likely will be reinforced by changes in the other unit costs.

Even so, the changes in other costs are likely to be secondary effects, so that the decline in fuel cost will probably account for the bulk of the change in ton-mile costs. At the same time, the level of fuel costs per mile will be only a fraction of the other costs per mile. The percentage change in overall costs per mile will therefore be much smaller than the percentage change in the fuel costs per mile. These considerations suggest that the commercial rebound effect will be a relatively small.

Incorporating these considerations into their estimate of the effects, costs, and net benefits of the rule, the agencies assumed that the rebound effect will be 15 percent for vocational vehicles, 10 percent for heavy-duty pickups and vans, and 5 percent for combination trailers.

The rebound effect discussed in the RIA is limited to the scope of HDVs. But if the fuel intensity standards are part of a larger effort to protect consumers from the consequences of high energy prices, it is not likely to succeed in the long run. As versatile and useful as petroleum is, keeping it cheap will only encourage its use. Energy savings in regulated sectors of the economy, such as motor vehicles, are at risk of being dissipated in unregulated sectors both at home and abroad.

Fleet turnover effect. The essential trade-off of investments in fuel consumption is that while the price per mile traveled is going down, the initial price of the vehicle is going up. But the effects do not stop with the increase in new vehicle prices. Potential buyers may decide to postpone purchase. This effect could be stronger in HDVs than LDVs, simply because their expected lifetimes are longer. Moreover, this tendency might apply not only to complete vehicles but to components, inasmuch as buyers are accustomed to assembling vehicles from separately manufactured engines, chassis, and body. With most of the improvement in HDV fuel consumption rates in engines, especially for vocational vehicles, it is easy to see how an existing engine could have its life extended significantly by the an increase in the cost of new vehicles and components.

The effect of new vehicle regulations on HDV fleet turnover could be significant. As noted earlier, at least part of the 30 percent decline in sales of new trucks in 2007 could be attributed to the diesel NO_x and particulate standards introduced in that year. The agencies argue that the situations are not comparable. The NO_x rule raised the price of the new vehicles without providing a compensating private good to the would-be buyer. In contrast, the HDV fuel consumption rule does provide a private benefit: the reduced expenditure on fuel. But as we note

earlier, it is unlikely that the private (and social) benefits will be as large as the agencies suggest. Moreover, the agencies have to make a contrary argument elsewhere in the rule, citing the so-called “energy efficiency paradox” to argue against the effectiveness of higher energy prices to encourage the development and diffusion of fuel-saving technology and justify the need for fuel consumption regulations.

Perhaps a better argument, at least for this first set of regulations, is that the low incremental cost of the new fuel consumption standards will not provide a strong incentive to alter purchase decisions. For this argument to remain valid though, future regulations also must have low incremental costs, which is likely to place constraints on the rate at which the HDV standards can be tightened.

Class shifting. In developing the rule, the regulating agencies seemed to be quite concerned about class shifting, pointing to several possible scenarios where it might arise. The most important was a potential shift from class 8 to class 7 combination trailers. Class 7 combination trailers are a bit smaller than Class 8 and are meant to serve short-to-medium-haul transport around metropolitan areas and for short intercity trips. For such vehicles, improving aerodynamics does not have nearly the fuel-saving advantages that it has in long-haul vehicles. Yet a class 7 combination vehicle could serve as a workable substitute for class 8 vehicles. To prevent a shift from the latter to the former, the rule put all combination trailers in the same category and subjected them to the same standard.

Yet by the logic used in the rule to minimize the importance of the fleet-turnover effect, this problem should not exist. Purchasers of class 8 vehicles should be willing to pay for their improvement in fuel consumption. In addition, the solution is an imperfect one at best. By merging class 7 and 8 vehicles, the regulation risks subjecting class 7 vehicles to technologies that fail to improve their fuel consumption rates. The fact that there are so many more class 8 than class 7 vehicles may make the merger a net winner, but it does not achieve the level of efficiency that a policy based on vehicle use rather than vehicle design would achieve, at least in principle.

This solution also ignores incentives that manufacturers may have for designing and building vehicles that do not now exist but that could, with relatively minor alterations, have multiple uses. Looking back at the CAFE standards, the main instance of class shifting arose when manufacturers began to design a variety of vehicles—small pickups, SUVs, and minivans—that were classified as trucks but had appeal as household vehicles. This is not to say that something similar would happen with HDVs, but the incentives for it would be in place if the technology was to become available.

7. Conclusion

The statutory justifications for the first-ever HDV fuel intensity standards are to reduce carbon emissions and address the issue of petroleum dependency. But as is common in regulatory matters, most of the projected benefits of the rule lie in an entirely different area. The regulatory impact analysis predicts that the current regulations have much greater benefits than costs, even at current fuel prices, but the benefits from reductions in carbon emissions and petroleum dependency³ are estimated to be quite small. The real source of benefits are the fuel savings to the purchaser of the vehicle and to future owners. Without these fuel savings, the remaining benefits are less than the costs. In the near term, then, the rule is more an attempt to protect consumers from themselves by requiring manufacturers to adopt warranted energy-saving technologies that consumers are not demanding. It also attempts to protect consumers by achieving its fuel-conserving objectives without policy instruments, such as taxes or rationing, that would raise the price.

We think these two near-term objectives will be achieved absent a stronger-than-expected increase in miles driven as a consequence of the standards. The required technology will be adopted at relatively modest cost, and fuel use and carbon emissions will decline over time as more fuel-efficient trucks enter the fleet. Although an NRC (2010) study finds that fuel consumption in heavy-duty vehicles could be reduced by 50 percent using technology that already exists or could be developed by 2020, these rules only reduce fuel consumption by 7–24 percent in various vehicle categories. Thus, the first regulatory step for this industry was a cautious one, despite the many environmental advocates urging greater reductions.

But what if the regulations does lead to a higher increases in miles driven than expected? This is a real concern, for several reasons. First, little research has been done to back up the agency's assumptions about rebound, turnover, and class shifting effects. Second, the trade-off between power and fuel economy may have unexpected consequences. An anecdotal account notes that reducing power to take loads up hills will induce drivers to go around rather than up the mountains, which can lead to increases in fuel use. How widespread such changing behavioral patterns might be is anyone's guess at the moment. Third, demand will grow for trucking services as a result of economic growth, quite apart from reductions in fuel use per ton-mile. Because the new standards apply only to new vehicle purchases, this demand could easily overwhelm the reach of the standards in reducing diesel fuel use and carbon emissions.

³ Oil imports are projected by EIA (2011) to fall from 50 percent of total petroleum use today to around 42 percent by 2035.

In the longer-term, more stringent fuel economy regulations will be proposed, so it is not guaranteed or even likely that the fuel savings will continue to dominate the other benefit categories. As it is with benefits, so it is with costs: the immediate costs of these rules will be primarily the cost of the fuel-saving technologies needed to meet the regulation. If later versions of the regulations add substantially to the cost of new vehicles, the behaviors described earlier will become common, as owners and buyers attempt to avoid the higher costs, and their actions will very likely increase the costs and compromise the effectiveness of the regulations. Such outcomes will be all the more likely if the price of fuel remains low: the lower the price, the smaller the perceived private benefits of the regulations, and the greater the incentive to take actions to avoid them. Regulation of vehicle design will always be vulnerable to distortions caused by behavioral responses because they target vehicle design characteristics rather than use.

Demand issues are of greater concern in the longer run as well. Both EIA (2011, Table: Liquid Fuels Supply and Disposition) and Exxon-Mobil (2011) are projecting significant increases in diesel fuel use from increased commercial transportation demand and increased road congestion, even accounting for assumed increases in fuel economy.

To help avoid these distortions and perverse outcomes, regulations should target vehicle use either through a carbon tax or a fossil fuel rationing scheme, such as what would be part of an upstream cap-and-trade system. This is not the place to expand on the virtues and design issues of such policies; the interested reader should see such studies as by Parry and Small (2005) and Parry et al. (2007). But these policies have several important advantages over fuel intensity standards: they attack all the margins of fuel use discussed in section 6.1; they are in principle cost-effective, in that they encourage reductions in fuel use up to the point where the marginal cost equals the price of carbon; they can be efficient, if the carbon price is set at the marginal social cost; and they avoid the perverse outcomes that fuel intensity standards are prone to. They can be implemented gradually, beginning with a very low tax rate or an emission cap that barely constrains current use, and then gradually ramps up. This would avoid any sudden and costly disruptions, while still providing plenty of notice of the likely trajectory of future fuel prices. They also can be coupled with cuts in other taxes, especially corporate and personal income taxes, to be revenue neutral and actually reduce distortions in the economy (Goulder and Parry 2008).

Not only can these policies substitute for fuel intensity standards, they also can supplement them, as a way of mitigating the disadvantages of each. This is especially true of a carbon tax. As argued above, the incentives for perverse behavior in response to fuel intensity standards depends on the price of fuel: the lower the price, the greater the incentives. Raising the price of fuel will therefore reduce the likelihood that significant distortions occur. The

combination of fuel intensity standards and a carbon tax to raise the price will be just as effective as fuel intensity standards alone at improving fuel intensity, and it will reduce the rebound effect, stagnant fleet turnover, and class shifting.

Unfortunately, the likelihood is low that such measures will get a fair hearing in Congress for the foreseeable future. Cap and trade is moribund now and few public policy ideas have been less popular with the general public or their legislators than fuel or carbon taxes.⁴ Another possibility is that growing world demand for oil will raise oil prices enough to induce fuel conservation in the U.S. trucking sector. While that is possible, most projections suggest otherwise. For one thing, light-duty vehicle demand is projected to flatten by 2020 or so, with the fleet becoming much more efficient and composed of a high fraction of hybrids and other alternative vehicles. For another, supply is being augmented by new oil discoveries, and new technologies allow access to previously untappable resources (e.g., oil shale, oil sands, and biodiesel) and new areas (e.g., deep water and the Arctic). Both trends will have a depressing effect on oil prices. Thus, policy action to raise prices of trucking fuels will likely be needed to meet the goals of the program in the longer term.

⁴ A nascent interest is budding in carbon taxes; see <http://www.rff.org/Events/Pages/Fiscal-Reform-and-Climate-Protection-Considering-a-US-Carbon-Tax.aspx>.

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Tables

Table 1. Vehicle Weight Classes Defined by U.S. Department of Transportation

Class	Description/examples	Empty weight range	Gross weight range	Typical fuel intensities	
		Tons	Tons	Gallons per thousand miles	Gallons per thousand ton-miles
1c	Passenger cars	1.2–2.5	<3	30–40	67
1t	Small light-duty trucks (including SUVs and minivans)	1.6–2.2	<3	40–50	58
2a	Standard pickups, large SUVs	2.2–3	3–4.25	50	39
2b	Large pickups, utility vans	2.5–3.2	4.25–5	67–100	39
3	Utility vans, minibuses	3.8–4.4	5–7	77–125	33
4	Delivery vans	3.8–4.4	7–8	83–140	24
5	Large delivery vans, bucket trucks	9.2–10.4	8–9.75	83–166	26
6	School buses, large delivery vans	5.8–7.2	9.75–13	83–200	20
7	City bus, Refrigerated truck, fire engine	5.8–7.2	13–16.5	125–250	18
8a	Dump/refuse trucks, city buses, fire engines	10–17	16.5–40	160–400	9
8b	Large tractor trailers, bulk tankers	11.6–17	16.5–40	133–250	7

Table 2. Energy Audit for a Typical Class 8 Combination Vehicle

	Urban	Intercity	Potential energy savings
Engine losses	60%	60%	28%
Heat rejection	26%	26%	
Exhaust heat	24%	24%	
Gas exchange	4%	4%	
Friction	1.5%	1.5%	
Engine accessories	2.5%	2.5%	
Aerodynamic losses	4–10%	21%	11.5%
Drivetrain losses	5–6%	2%	7%
Braking losses	15–20%	0–2%	
Auxiliary loads	7–8%	4%	
Rolling resistance	8–12%	13%	11%

Source: NRC 2010, Figures 2-7 and 4-1 and Table 5-1.

Table 3a. Class 4-7 Truck Sales by Manufacturer, 2004–2008

Manufacturer	2004	2005	2006	2007	2008
Sales					
Ford	60,538	61,358	69,070	70,836	46,454
Freightliner	51,814	51,639	51,357	42,061	30,809
General Motors	34,351	45,144	41,340	34,164	24,828
Navistar	52,278	54,895	61,814	40,268	35,022
Isuzu	10,715	10,620	10,822	9,639	6,157
Other	18,760	20,127	26,170	23,160	21,681
Total	228,456	243,783	260,573	220,128	164,951
% of five-year average	102	109	117	98	74
Market share (%)					
Ford	26.5	25.2	26.5	32.2	28.2
Freightliner	22.7	21.2	19.7	19.1	18.7
General Motors	15.0	18.5	15.9	15.5	15.1
Navistar	22.9	22.5	23.7	18.3	21.2
Isuzu	4.7	4.4	4.2	4.4	3.7
Other	8.3	8.3	10.0	10.5	13.1

Source: NRC 2010, Table 2-7; author's calculations.

Table 3b. Class 8 Truck Sales and Market Share, 2004–2008

Manufacturer	2004	2005	2006	2007	2008
Sales					
Freightliner	73,731	94,900	98,603	51,706	42,639
Kenworth	23,294	27,153	33,091	19,299	15,855
Mack	20,670	27,303	29,524	13,438	11,794
Navistar	38,242	46,093	53,373	29,675	32,399
Peterbilt	26,145	30,274	37,322	19,948	17,613
Volvo	20,323	26,446	30,716	16,064	13,061
Other	792	623	1,379	835	112
Total	203,197	252,792	284,008	150,965	133,473
%. of 5-year average	99	123	139	74	65
Market share (%)					
Freightliner	36.3	37.5	34.7	34.3	31.9
Kenworth	11.5	10.7	11.7	12.8	11.9
Mack	10.2	10.8	10.4	8.9	8.8
Navistar	18.8	18.2	18.8	19.7	24.3
Peterbilt	12.9	12.0	13.1	13.2	13.2
Volvo	10.0	10.5	10.8	10.6	9.8
Other	0.4	0.2	0.5	0.6	0.1

Source: NRC 2010, Table 2-7; author's calculations.

Table 4a. Engine Production and Market Share for Medium-Duty Trucks

Manufacturer	2004	2005	2006	2007	2008
Sales					
Navistar	373,842	382,143	357,470	335,046	264,317
GM	74,328	77,056	83,355	87,749	72,729
Cummins	14,900	15,162	16,400	20,315	27,664
Mercedes Benz	16,075	20,038	27,155	19,330	9,066
Caterpillar	42,535	42,350	45,069	14,693	6,269
Other	671	5,959	7,497	15,550	8,756
Total	522,351	542,708	536,946	492,683	388,801
% of 5-year average	105	109	108	99	78
Market share (%)					
Navistar	71.6	70.4	66.6	68.0	68.0
GM	14.2	14.2	15.5	17.8	18.7
Cummins	2.9	2.8	3.1	4.1	7.1
Mercedes Benz	3.1	3.7	5.1	3.9	2.3
Caterpillar	8.1	7.8	8.4	3.0	1.6
Other	0.1	1.1	1.4	3.2	2.3

Source: NRC 2010, Table 2-8; authors' calculations.

Table 4b. Engine Production and Market Share for Heavy-Duty Trucks

Manufacturer	2004	2005	2006	2007	2008
Sales					
Cummins	64,630	79,100	91,317	65,228	75,307
Detroit Diesel	48,060	61,074	63,809	29,506	35,174
Caterpillar	74,224	86,806	97,544	33,232	20,099
Mack	25,158	36,211	36,198	18,544	16,794
Mercedes Benz	17,178	24,414	24,584	17,048	10,925
Volvo	12,567	19,268	23,455	9,850	8,822
Other	0	0	0	56	947
Total	241,817	306,913	336,907	173,464	168,068
% of 5-yr. avg.	99	125	137	71	68
Market share (%)					
Cummins	26.7	25.8	27.1	37.6	44.8
Detroit Diesel	19.9	19.9	18.9	17.0	20.9
Caterpillar	30.7	28.3	29.0	19.2	12.0
Mack	10.4	11.8	10.7	10.7	10.0
Mercedes Benz	7.1	8.0	7.3	9.8	6.5
Volvo	5.2	6.3	7.0	5.7	5.2
Other	0.0	0.0	0.0	0.0	0.6

Source: NRC 2010, Table 2-8; authors' calculations.

Table 5. Fuel Consumption Standards for Class 7–8 Combination Vehicles

	Engine standards (expressed as percentage emission rate reduction from baseline), by model year (MY)^a					
	Proposed			Final		
	Baseline (gallons per Kbhp-hr) ^a	2014 MY standard ^b	2017 MY standard	Baseline (gallons per Kbhp-hr) ^a	2014 MY standard ^b	2018 MY standard
Medium-heavy duty engines (Class 7)	5.09	4.93 (3%) ^b	4.78 (6%)	5.09	4.93 (3%)	4.78 (6%)
Heavy-heavy duty engines (Class 8)	4.81	4.67 (3%) ^b	4.52 (6%)	4.81	4.67 (3%)	4.52 (6%)
Vehicle standards (expressed as percentage emission rate reduction from baseline)^c						
	Baseline (gallons per Kton-mi)	2014 MY Standard	2017 MY Standard	Baseline (gallons per Kton-mi)	2014 MY Standard	2018 MY Standard
Class 7 day cab						
Low roof	11	10.3 (6.4%)	10.1 (8.2%)	11.4	10.5(7.9%)	10.2 (10.5%)
Mid roof	11	10.3 (6.4%)	10.1 (8.2%)	12.6	11.7 (7.1%)	11.3 (10.3%)
High roof	12.8	11.6 (9.4%)	11.4 (10.9%)	13.6	12.2 (10.3%)	11.8 (13.2%)
Class 8 day cab						
Low roof	8.3	7.8 (6%)	7.7 (7.2%)	8.7	8.0 (8.0%)	7.8 (10.3%)
Mid roof	8.3	7.8 (6%)	7.7 (7.2%)	9.4	8.7 (7.4%)	8.4 (10.6%)
High roof	9.4	8.6 (8.5%)	8.5 (9.6%)	10.1	9.0 (10.9%)	8.7 ((13.9%)
Class 8 sleeper cab						
Low roof	7.4	6.3 (14.9%)	6.3 (14.9%)	7.8	6.7 (14.1%)	6.5 (16.7%)
Mid roof	8.0	6.9 (13.8%)	6.8 (15%)	8.7	7.4 (14.9%)	7.2 (17.2%)
High roof	8.7	7.1 (18.4%)	7.0 (19.5%)	9.3	7.3 (21.5%)	7.1 (23.7%)

Notes:

^aCarbon dioxide (CO₂) emission standards are proportionate and expressed in grams CO₂ per (Kbhp-hr, thousands of brake-horse power hours) or (Kton-mi, thousands of ton-miles). Numerically, the conversion factor from gallons of fuel to grams CO₂ is about 10,000.

^bThe fuel consumption standard for engines is voluntary for 2014. Not so the CO₂ standard.

^cVehicle standards reflect engine improvements.

Table 6. Fuel consumption standards for Class 2b–8 Vocational Vehicles

Engine standards (expressed as percentage emission rate reduction from baseline)						
	Baseline (gallons per Kbhp- hr)	2014 MY standard	2017 MY standard	Baseline (gallons per Kbhp-hr)	2014 MY standard	2017 MY standard
Light heavy-duty engines	6.19	5.89 (5%)	5.57 (9%)	6.19	5.89 (5%)	5.57 (9%)
Medium-heavy duty engines	6.19	5.89 (5%)	5.57 (9%)	6.19	5.89 (5%)	5.57 (9%)
Heavy-heavy duty engines	5.74	5.57 (3%)	5.45 (5%)	5.74	5.57 (3%)	5.45 (5%)
Vehicle standards						
	Baseline (gallons per Kton- mi)	2014 MY standard	2017 MY standard	Baseline (gallons per Kton-mi)	2014 MY Standard	2017 MY Standard
Light heavy-duty class 2b–5	37.6	35.2 (6.3%)	33.8 (10%)	40.0	38.1 (4.8%)	36.7 (8.2%)
Medium heavy-duty class 6–7	22.3	20.8 (6.6%)	20 (10.3%)	24.3	23.0 (5.3%)	22.1 (9%)
Heavy heavy-duty class 8	11.3	10.7 (5.2%)	10.5 (7%)	23.2	22.2 (4.3%)	21.8 (6%)

Notes:

^a Carbon dioxide (CO₂) emission standards are proportionate and expressed in grams CO₂ per (Kbhp-hr, thousands of brake-horse power hours) or (Kton-mi, thousands of ton-miles). Numerically, the conversion factor from gallons of fuel to grams CO₂ is about 10,000.

^bThe fuel consumption standard for engines is voluntary for 2014 and only becomes mandatory in 2016. Not so the CO₂ standard.

^cVehicle standards reflect engine improvements.

Table 7. Costs Reduced in 2050 from Heavy-Duty Vehicle Regulations, 2009 dollars

Cost measure	Class 7–8 combination tractors	Class 2b–8 vocational vehicles
Cost per vehicle (2020)	\$6,004	\$366
Cost per ton CO ₂ reduced (2050, not including fuel savings)	\$20	\$30
Fuel savings per 2018 model year vehicle (lifetime) at 3% and 7% discount rate	\$79,089 \$64,376	\$5,872 \$4,646
Payback period at 3% discount rate	~7 months	~6 months
Cost per ton CO ₂ reduced (2050, including fuel savings)	-\$320	-\$310

Source: U.S. EPA and NHTSA 2011.

Table 8. Estimated Net Benefits of Heavy-Duty Vehicle Regulations

Category	Benefits averaged over 2014–2018 model years, millions of 2009 dollars (3% discount rate)
Technology costs	\$1,620
Public good benefits	
Energy security	\$540
Rebound externalities	-\$300
CO ₂ emission reductions (3% discount)	\$1,140
Net Benefits (before private benefits)	-\$240
Private benefits	
Refueling	\$80
Fuel savings	\$10,020
Net including private benefits	\$9,860
Net including private benefits (7% discount rate)	\$6,600

Source: U.S. EPA and NHTSA 2011.

Table 9. Estimates of Fuel Price Elasticities, 1966–2001

	Short run	Long run
Elasticity of vehicle miles traveled with respect to price per mile		
At sample mean	-0.047	-0.220
1997–2001	-0.026	-0.121
Elasticity of fuel intensity with respect to price per gallon		
At sample mean	-0.044	-0.191
1997–2001	-0.045	-0.220
Elasticity of total fuel use with respect to price per gallon		
At sample mean	-0.091	-0.411
1997–2001	-0.071	-0.342

Source: Small and Van Dender 2005.