The Energy Paradox and the Adoption of Energy-Saving Technologies in the Trucking Industry

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Abstract

Several federal benefit-cost analyses report an energy paradox among firms in competitive markets and conclude that firms would benefit from mandates to increase the use of energy-saving technologies. Such findings appear incompatible with neoclassical views that private firms in competitive markets minimize costs. The Environmental Protection Agency, for example, presumes that owners of trailers pulled by tractors belonging to others underinvest in energy-saving technologies because trailer owners incur the costs while tractor owners get the benefits. We test this hypothesis by collecting data and modeling the use of energy-saving technologies as a function of fleet size, the intensity of truck usage, and proxies for management quality. We find effects consistent with conventional models but no evidence that different ownership of tractors and trailers is associated with reduced use of energy-saving technologies on trailers. Regulators should refrain from making claims that firms underuse energy-saving technologies without first rigorously evaluating evidence for such claims.

JEL codes: D220, K23, R48, Q580

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The Environmental Protection Agency (EPA) and the National Highway Transportation Safety Administration (NHTSA) recently proposed a rule mandating the adoption of energy-efficiency devices on heavy-duty trucks in order to reduce greenhouse gas emissions (Greenhouse Gas Emissions Standards . . . ; Phase II, 2015). The rule is supported by an economic analysis that estimates that trucking firms would enjoy annualized fuel savings of $7.3 to $8.7 billion, which would greatly outweigh the $1.3 billion annualized cost of adopting these technologies (EPA RIA, ES-12). It suggests that for-profit businesses subject to competitive market pressures are in fact failing to adopt technologies that would earn them high returns on their investment.

Federal agencies have issued other estimates, apart from those in the EPA/NHTSA proposal, that their regulations would provide large net benefits to private firms. For three other major regulations that prohibit the sale of energy-intensive equipment, regulators have estimated that the value of the energy savings to private firms greatly exceeds the cost necessary to achieve these savings.[1]

The EPA and the NHTSA's regulatory impact analysis (RIA) estimates large net cost savings for the 2015 proposed rule that appear incompatible with a tenet of neoclassical theory

[1] These rules include (1) the Department of Energy's Energy Conservation Standards for Walk-In Coolers and Freezers (2014), a final rule regulating walk-in coolers and freezers; (2) the Department of Energy's Energy Conservation Program for Certain Industrial Equipment: Energy Conservation Standards for Small, Large, and Very Large Air-Cooled Commercial Package Air Conditioning and Heating Equipment and Commercial Warm Air Furnaces (2016), a direct final rule regulating commercial air conditioning, heating, and warm air furnaces, and (3) the EPA and the NHTSA's Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles, also known as the phase 1 heavy-duty truck rule.

that firms in competitive industries minimize costs. Specifically, neoclassical theory predicts that the private sector could achieve all or most of the projected benefits—i.e., large private cost savings—without regulatory action. We seek to address this issue by collecting, analyzing, and interpreting data to test the more important of the hypotheses put forth suggesting the existence of a market failure: different ownership between tractors and trailers limits incentives to buy energy-saving technologies because the trailer owners incur the costs while the tractor owners enjoy the benefits. Specifically, we collect data on use of energy-saving technologies and characteristics of trucking companies to model the use of these technologies. We do not find that different ownership of trailers and tractors is associated with less use of energy-saving technologies. Our analysis shows that the EPA and the NHTSA could test whether trailers with different ownership are less likely to use energy-saving technologies. More broadly, our analysis demonstrates the possibility of developing the set of empirical studies called for by the National Research Council to assess the in-use effectiveness of these energy-efficiency devices at a relatively low cost (NRC, 2014).

In the rest of the paper we present the background to the recent EPA and NHTSA rulemaking and a review of recent literature, the EPA's description of the regulatory problem behind its rulemaking and the key energy-saving technologies for heavy-duty trailers. We then turn to a discussion of trends and geographic patterns in the use of energy-efficiency devices on trailers. Finally, we present results from econometric models of the use of aerodynamic technologies on trailers.

I. Background

A. Review of Prior Literature

Alcott and Greenstone (2012) report in a comprehensive survey that when one tallies up the available empirical evidence from different contexts, it is difficult to substantiate claims of a pervasive energy-efficiency gap. They add that while "investment inefficiencies do appear in various settings, the actual magnitude of the Energy Efficiency Gap is small relative to the assessments from engineering analyses." In a separate review, Gayer and Viscusi (2013) are more critical of recent federal energy-efficiency regulations based on the unsupported assumption that consumers and firms are irrational. They conclude that the agencies' regulatory analyses do not document these purported failures in consumer choices or firms' energy utilization decisions with any empirical evidence. There articles may be seen as continuing debate about the "Porter Hypothesis" that stringent environmental regulations can induce efficiency and encourage innovations that lead to commercial competitiveness (Porter and van der Linde 1995). In light of the tension between regulators' claims of large private savings from mandates to use energy-efficient technologies and predicted competitive pressures for firms to minimize costs, we focus on evidence for an energy-efficiency gap among for-profit firms.

Heavy-duty trucking is widely seen as a competitive industry. Long before he became a Supreme Court justice, Stephen Breyer (1982) wrote an influential treatise on regulatory reform in which he presumed that interstate trucking was a competitive industry. Engel (1998) concludes, "In the wake of deregulation and the intense competition that followed, the trucking industry has radically changed the quality and types of services it provides its customers; today, the emphasis is on efficiency, and the ultimate beneficiary is the American consumer."

Sutherland and Koepke (2012) also maintain a presumption of competitiveness throughout their more recent analysis.

Several key characteristics of the heavy-duty trucking industry suggest that it is highly competitive. Barriers to entry are low—entrants need only a commercial drivers' license, insurance eligibility, and enough capital to make the down payment on a truck. Average lease or purchase payments on vehicles have ranged from 10 to 12 percent of average marginal costs for the last four years (Torrey & Murray, 2014, table 9). As is consistent with low entry costs, small firms dominate the market. The American Trucking Association reports that a majority of firms are owner-operated and that the very largest firms have market shares well under 5 percent. Capital is quite literally mobile, as trucks are able to move between geographic areas and market segments on very short notice.

Claims that significant market imperfections impede trucking firms' ability to identify and act on opportunities to lower costs through energy-saving innovations appear to be at variance with the paramount importance of fuel costs to firm viability. Fuel is the first or second largest category of costs, so management seems likely to be fully attentive to opportunities to economize in this area.[2] In addition, the Internet has put at the fingertips of owners and managers an abundance of information from a variety of sources regarding the effectiveness and cost of energy-saving technologies.[3] Finally, the market seems capable of a variety of creative contracting solutions. Some shippers now stipulate in contracts that carriers must meet energy-efficiency design or performance requirements linked to the SmartWay program (Sharpe &

[2] Fuel costs exceeded wages and benefits combined during 2008, 2012, and 2013, and fell short of wages and benefits during 2009, 2010, and 2011 (Torrey & Murray, 2014, table 9).
[3] See, for example, "Derive Fleet Efficiency Solutions," Derive Efficiency website by Derive Systems Inc., http://efficiency.derivesystems.com/derive-fleet-efficiency?gclid=COC4-bXf4MkCFQwjHwodX6kK-g.

Roeth, 2014).[4] Trucking seems to be an industry in which significant savings opportunities are likely to be quickly identified and realized.

Boyd and Curtis (2014) link management practices generally to a firm's energy efficiency (the inverse of intensity). Using establishment-level data from the US Census of Manufacturers and results of the World Management Survey, they find that management matters most within energy-intensive industries. Moreover, their results suggest that improvements in management practices would allow firms to be both more productive and more energy efficient. They note, however, that their results "do not necessarily imply the existence of a market failure. Improvement in management practices will be costly to the firm and such costs could outweigh the benefits of improved productivity and input efficiency."

Klemick et al. (2015) use focus groups and interviews to study the energy-efficiency gap in heavy-duty trucking. Their study is based on stated results from interviews (rather than empirical performance data), and the design of their study does not support conventional hypothesis-testing. They report potential market failures related to a lack of information about technology performance and network externalities that contribute to slow adoption of some technologies. They also find that there is some evidence of split incentives between owners and drivers, though companies have invested in a variety of technologies and approaches in an attempt to address these effects.

Regulations that increase fuel efficiency lower the operating cost of trucking and thus tend to increase usage, an effect that partially offsets the mandated increase in fuel efficiency. Leard et al. (2015) use survey data from 1977 to 2002 to estimate such "rebound" effects and the effect of economic activity on truck miles driven. They estimate rebound effects of 29.7 percent

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[4] These contractual requirements might include the use of SmartWay-verified tractors and trailers or a performance standard in terms of fuel efficiency or CO_2 emissions.

for tractor-trailers and 9.3 percent for vocational vehicles. They also estimate the effect of economic activity on truck miles driven and find that tractor-trailers and vocational vehicles respond less than proportionally to economic activity changes. Leard et al. suggest that these estimates point to a likely overestimate by the EPA and the NHTSA in the projections of long-run fuel savings and greenhouse gas emissions reductions resulting from the standards.

The National Research Council (NRC), the operating branch of the National Academy of Sciences, issued a report regarding the fuel efficiency of heavy-duty trucks that addresses opportunities to achieve greater fuel efficiency for trailers (NRC, 2014). The NRC report provides a number of recommendations, including a recommendation that the EPA and the NHTSA adopt a regulation requiring long box dry and refrigerated trailers to reduce their fuel consumption (NRC, 2014). The NRC report also recommends that the NHTSA gather data from private fleets and work with the General Services Administration or US Postal Service to evaluate the performance of energy-saving devices deployed on vehicles used in commercial operations. In the preamble to the 2015 proposed rule, the EPA and the NHTSA report that they have incorporated many of the NRC's recommendations related to the regulation of trailers (Greenhouse Gas Emissions Standards . . . ; Phase II, 2015). With respect to the recommendation to develop data on in-use performance of energy-efficiency devices, the NHTSA responded in the proposed rule's preamble that, due to the length of time necessary to capture useful, relevant data from fleets, it was unable to conduct public or private fleet studies to inform this rulemaking. However, the NHTSA promised that it would consider this recommendation before making future regulatory decisions (Greenhouse Gas Emissions Standards . . . ; Phase II, 2015).

The NRC report also presented the results of a survey conducted by members of the committee on the incidence of aerodynamic devices in-use by dry van trailers at least 53 feet long pulled by tractors with sleeper cabs.[5] The purpose of the NRC survey was to examine whether the use of aerodynamic devices on trailers would be higher in (and near) California—given that only California required such devices—compared to other parts of the United States. The NRC reported that side skirts were by far the most prevalent aerodynamic device in use and that the incidence of side skirts was substantially higher in and near California compared to other parts of the United States. Underbody fairings and tail fairings were observed in only a few instances (NRC, 2014).

B. The EPA's Description of the Regulatory Problem

In their RIA, the EPA and the NHTSA report[6] that

> the vast majority of Heavy-Duty Vehicles (HDVs) are purchased and operated by profit-seeking businesses for which fuel costs represent a substantial operating expense. Nevertheless, on the basis of evidence reviewed below, the agencies believe that a significant number of fuel efficiency improving technologies would remain far less widely adopted in the absence of these proposed standards (EPA & NHTSA, 2015).

The RIA goes on to state,

> economic research offers several possible explanations for why the prospect of these apparent savings might not lead HDV manufacturers and buyers to adopt technologies that would be expected to reduce HDV operating costs. Some of these explanations involve failures of the HDV market for reasons other than the externalities caused by producing and consuming fuel. These include situations where information about the performance of fuel economy technologies is incomplete, costly to obtain, or available only to one party to a transaction (or "asymmetrical"), as well as behavioral rigidities in either the HDV manufacturing or HDV-operating industries, such as standardized or inflexibly administered operating procedures, or requirements of other regulations on HDVs. Other explanations for the limited use of apparently cost-effective technologies that do not involve market failures include HDV operators' concerns about the

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[5] The NRC observations were made from the side of the highway and included two locations on the east coast: Interstate 81 in Pennsylvania, 29 miles south of Harrisburg, Pennsylvania, and Interstate 95 in Maryland, 25 miles north of Washington, DC (NRC, 2014). The survey did not follow a preset sampling plan, and the accuracy of the observations was not verified (NRC, 2014).

[6] The EPA conducted an economic analysis to support its proposed rule (EPA, 2015) to comply with Exec. Order No. 12866 (1993), Exec. Order No. 13563 (2011), and § 202(a)(2) of the Unfunded Mandates Reform Act of 1995 (2012).

> performance, reliability, or maintenance requirements of new technology under the demands of everyday use, uncertainty about the fuel savings they will actually realize, and questions about possible effects on carrying capacity or other aspects of HDVs' utility. (EPA & NHTSA, 2015, p. 653)

The RIA identifies several sources for the "energy efficiency paradox" (EPA & NHTSA, 2015, p. 653):

- imperfect information in the new vehicle market,
- imperfect information in the resale market,
- principal-agent problems causing split incentives,
- uncertainty about future fuel cost savings, and
- adjustment and transactions costs.

The EPA and NHTSA summarize these explanations as follows:

> Some of these explanations imply failures in the private market for fuel-saving technology beyond the externalities caused by producing and consuming fuel, while others suggest that complications in valuing or adapting to technologies that reduce fuel consumption may partly explain buyers' hesitance to purchase more fuel-efficient vehicles. (EPA & NHTSA, 2015, p. 654)

Basically, the agencies argue that the failure of the trucking sector to adopt these technologies is an indication of the need for national regulations.

However, these supporting rationales are based largely on conjecture; there is little empirical research supporting these hypotheses. A notice of data availability issued by the EPA and the NHTSA in March 2016 does not provide additional evidence in support of these hypotheses (EPA & NHTSA, 2016).

C. Key Energy-Saving Technologies for Trailers

The proposed phase 2 rule establishes performance standards for the several categories of box van trailers based on the use of aerodynamic devices and tire technologies. The EPA and the

NHTSA identified the use of several aerodynamic devices (side skirts, underbody devices, and tail fairings) and low rolling resistance tires as key components in developing a technological basis for the proposed standards.

Aerodynamic devices. Aerodynamic drag on the sides and underbody of the trailer and at the rear end of the trailer accounts for a significant portion of energy losses at higher truck speeds.[7] Aerodynamic devices reduce drag around and behind the trailer. At sufficiently low speeds, these devices may increase fuel consumption by adding weight without appreciable reductions in drag.

- Side skirts reduce the open area between the floor of the trailer and the road. They represent the most widely adopted aerodynamic device for trailers. Estimates of fuel savings with the adoption of side skirts range from 3 to 7 percent at highway speed. The price of side skirts ranges from $700 to $1,100 (Sharpe & Roeth, 2014).
- Underbody devices provide a cupped surface in front of the rear axles of the trailer to smooth airflow underneath the trailer and are used instead of side skirts to reduce drag. Fuel savings estimates range from 2 to 5 percent at highway speed. The cost of these devices falls in the range of $1,500 to $2,200 (Sharpe & Roeth, 2014). These devices are less susceptible to damage and less restrictive in terms of maneuverability (Sharpe & Roeth, 2014).
- Fairings installed at the rear of the trailer reduce turbulence in the wake of the trailer. Fuel savings estimates from such rear fairings or tails are in the range of 3 to 5 percent at highway speed, with purchase and installation costs ranging from $1,000 to $1,600.

[7] The EPA and NHTSA proposed to exclude from their rule a set of specialty trailers designed for specific dedicated uses—for example, trailers for logging and mining, trailers using pintle hooks or hitches, trailers designed to haul livestock and perform other agricultural functions, trailers with three or more axles, and trailers designed to perform their primary function while stationary (Greenhouse Gas Emissions Standards . . . ; Phase II, 2015).

Current designs may increase the difficulty of backing a trailer up to the loading dock (with the attendant vulnerability to damage) and interfere with unloading the trailer. Drivers must deploy most current designs, although there are some models that deploy automatically at higher speeds (Sharpe & Roeth, 2014).

Low rolling resistance tires. The rolling resistance of a tire is measured as the energy lost per unit of distance traveled under load: the friction within the tire dissipates energy into heat as the tire rolls. Low rolling resistance tires are designed to reduce the internal friction of the tire to minimize rolling resistance and improve the fuel efficiency of tractor-trailers. The EPA and the NHTSA report that more than 40 percent of the total energy loss from tires for combination tractor-trailers arises from the rolling resistance of trailer tires. The California Air Resources Board (CARB) reports that current SmartWay-verified trailer tires—the first level of improved performance in the phase 2 proposal—will achieve a 15 percent reduction in the coefficient of rolling resistance (CRR); a reduction consistent with at least a 1 percent reduction in fuel consumption (CARB, 2012).[8] The agencies estimate that the use of low rolling resistance (LRR) tires on both the trailer and tractor will yield a 1–3 percent reduction in fuel consumption and CO_2 emissions at 65 miles per hour (Greenhouse Gas Emissions Standards . . . ; Phase II, 2015). There is little cost difference between LRR tires and conventional tires, with the average incremental cost of low rolling resistance tires ranging from $0 to $50 per tire.[9]

Reports from some fleet operators indicate less confidence in the EPA and NHTSA estimates of the fuel efficiency gains and lifetime cost savings associated with LRR tires

[8] The agencies report that the average CRR for trailer tires is 6.0 kg/ton; SmartWay-verified tires must meet a CRR of 5.1 kg/ton (CARB, 2012).
[9] However, a recent NACFE survey found that some SmartWay-verified tires are less expensive than their non-LRR tire counterparts (CARB, 2012; NACFE, 2015).

compared to a standard dual-tire (NACFE, 2015). There are a number of other variables that can affect such comparisons (e.g., tire inflation and alignment). In addition, questions have been raised about other attributes of LRR tires (e.g., tire life and safety) vis-à-vis standard tires. LRR tires have a thinner tread depth, so tire wear results in a shorter interval before the tires need to be retreaded (NACFE, 2015). In addition, industry sources claim that overall LRR tire life is shorter than the life of standard dual-tires—LRR tires take fewer retreads than conventional tires (Sharpe & Roeth, 2014).[10]

While there are questions as well about LRR tire traction in wet or icy conditions, a study by the Oak Ridge National Laboratory reports that LRR tires meet federal stopping distance requirements in wet conditions (Greenhouse Gas Emissions Standards . . . ; Phase II, 2015).[11] However, some fleet operators in Canada have reported weather was a significant barrier to adopting LRR tires because they do not offer enough traction in heavy snow and ice conditions (Sharpe, 2015).

D. Programs to Reduce Energy Use for Heavy-Duty Trucks

The EPA adopted the SmartWay program to facilitate the adoption of technologies to reduce energy use by heavy duty trucks. The EPA's SmartWay Transport Partnership program was launched in 2004 to promote the adoption of energy-efficiency measures within the nation's trucking fleet. Among other activities, it verifies the performance of vehicles, technologies, and equipment that have the potential to reduce greenhouse gases and other air pollutants from freight transport ("SmartWay Aerodynamic Technologies," n.d.). The program develops

[10] This claim is also from interviews with industry sources and other industry reports.
[11] While the test results showed a slight trend to longer stopping distance with lower rolling resistance, this was not statistically significant (Greenhouse Gas Emissions Standards . . . ; Phase II, 2015).

performance criteria—using test data—to ensure that trailer equipment and devices will help fleets improve their efficiency and reduce emissions. In terms of aerodynamic devices and LRR tires, SmartWay has four designated categories based on expected fuel savings: 1 percent (1 up to 3.9 percent), 4 percent (4 to 4.9 percent), 5 percent (5 to 8.9 percent), and 9 percent (9 percent or greater) fuel savings.[12] Fleet managers can combine aerodynamic components to meet the total fuel savings threshold required to qualify as an EPA-designated SmartWay trailer. For example, the SmartWay trailer threshold of at least 6 percent fuel savings could be achieved by combining LRR tires with a 1 percent fuel saving and a 5 percent aerodynamic device.

In 2008, California adopted regulations requiring improvements in the energy efficiency of heavy-duty tractors and trailers (CARB, 2011). The rule required by January 1, 2010, that new MY 2011 and later 53-foot or longer box-type dry van and refrigerated trailers must be SmartWay certified or retrofitted with LRR tires and SmartWay verified devices yielding a 5 percent fuel efficiency improvement for a dry van and a 4 percent improvement for a refrigerated van. MY 2010 and older 53-foot box-type trailers are required to meet the aerodynamic device requirements established for 2011 MY and later trailers by January 1, 2013, and must have SmartWay LRR tires by January 1, 2017. California provided a delayed compliance schedule for refrigerated vans (which varies by model year) and optional phase-in plans for dry vans (with different schedules for small and large fleets).[13]

In 2011, the EPA and the NHTSA issued the phase 1 rule to limit greenhouse gas emissions and fuel consumption for combination tractors, heavy-duty pickups and vans, and vocational vehicles. (Class 7 and 8 trucks account for roughly two-thirds of the greenhouse

[12] Verification is based on the use of several alternative testing-verification pathways: enhanced track testing, wind tunnel testing, coastdown testing, and computational fluid dynamics.
[13] The California rule also provided a local haul exemption for aero devices for trailers operated entirely within 100 miles of their local base.

gas emissions and fuel consumption from the heavy-duty vehicle transportation sector.) The EPA's phase 1 rule adopted separate engine and tractor mandatory standards for class 7 and 8 vehicles beginning with MY 2014; the NHTSA fuel consumption standards are voluntary for MY 2014 and 2015 and are mandatory in 2016 and thereafter. The phase 1 rule adopted engine standards based on technologically available improvements in engine efficiency. The phase 1 rule also adopted separate tractor standards based on the use of a combination of aerodynamic devices, low rolling resistance tires, weight reduction, and automatic engine shutdown and speed limiter devices. The tractor standards are implemented using the EPA's Greenhouse Gas Emission Model to translate the use of these various fuel efficiency devices for a specific tractor into an overall performance standard for the vehicle based on the model. The agencies did not establish standards for trailers because of "outstanding policy and technical issues," including the absence of an adequate test procedure (Greenhouse Gas Emissions Standards . . . ; Phase II, 2015).

In 2015, the EPA and the NHTSA proposed greenhouse gas and fuel economy standards for 10 different subcategories of trailers varying in stringency and in phase-in schedules over the 2018 to 2027 period (Greenhouse Gas Emissions Standards . . . ; Phase II, 2015). The agencies' proposal would require eight subcategories—these subcategories include long and short box vans and long and short box refrigerated vans (and similar "partial aero" vans)—to achieve CO_2 emission reductions and fuel savings based on the use of aerodynamic devices and LRR tires.[14] The agencies project that these proposed standards would yield fuel consumption and CO_2 emission reductions of 3 to 8 percent (EPA & NHTSA, 2015).

[14] "Partial aero" classification applies to box vans that cannot use aero devices at one location on the van because of specialized features such as pull-out platforms for side doors, end lift gates, belly boxes, and drop-deck designs.

For the other two subcategories (non-aero box vans and non-box trailers), the EPA and the NHTSA have proposed design standards requiring LRR tires and automatic tire inflation equipment.[15]

II. Empirical Analysis

We collect, assemble, and analyze data on the use of energy-saving devices for heavy-duty tractor-trailers. These data allow us to evaluate some of the explanations and hypotheses advanced by the EPA and the NHTSA for the energy efficiency paradox in this sector.

One of the key explanations offered by the EPA and the NHTSA for the energy efficiency paradox involves split incentives—differences in ownership and incentives between the tractor owners (trucking firms) and the trailer owners (shippers) (Greenhouse Gas Emissions Standards . . . ; Phase II, 2015). In these cases, the trucking firm typically pays for the fuel, and the shipper has no incentives to incur the cost of installing energy-efficiency devices for the trailer. While this problem might be resolved through contracts, Vernon & Meier (2012) report that their review of contracts "revealed no allowances (or even mention) of fuel efficiency."[16] We test whether the incidence of use of aerodynamic devices for trailers is lower on trailers owned by a shipper separate from the trucking firm.

The conventional view of new technology is that it is typically adopted over a period of time, reflecting the distribution of the benefits and costs of the technology to the entities faced with decisions on whether to adopt it (e.g., Griliches, 1957). Thus, adoption of these devices

[15] The non-aero box trailers category applies to box trailers with work performing devices in two locations that inhibit the use of aerodynamic devices. The EPA also has proposed to exclude from its rule a set of specialty trailers designed for specific dedicated uses—for example, trailers used for logging and mining, trailers using pintle hooks or hitches, trailers designed to haul livestock and perform other agricultural functions, trailers with three or more axles, and trailers designed to perform their primary function while stationary (Greenhouse Gas Emissions Standards . . . ; Phase II, 2015).

[16] Vernon & Meier (2012), p. 271.

should be greater among trucks using long-distance routes (and higher average operating speeds). Similarly, trucking companies with a higher rate of Department of Transportation safety violations may be poorly managed or, in any event, operating on a narrow margin and thus less likely to adopt these energy-saving devices.

Our research departs from previous work in several respects. We compare patterns in the use of aerodynamic devices in 2015 with the incidence reported by the 2013 NRC survey. We also compare use of these devices in 2015 on major interstates with their use on a major regional highway. The patterns in the use of these devices appear to be consistent with what one would expect according to neoclassical theory.

We believe that our study is the first to link use of specific, identifiable energy-efficient technologies to characteristics of firms and firm management, at least for heavy-duty trucks. Further, this study is consistent with Alcott and Greenstone's (2012) plea for more detailed empirical studies, though it does not use the quasi-experimental methods that they would recommend. Our work can also be seen as an exploration of the connection between management practices and energy efficiency that is more specific and detailed than the work of Boyd and Curtis (2014). Finally, this study represents a step beyond Klemick et al. (2015) because it uses objective measures of the frequency of energy-efficient technologies and a dataset that supports quantitative hypothesis-testing.

A. Data

We collected both detailed and summary data from heavy-duty trucks. We collected the summary data to compare the use of aerodynamic technologies on trailers observed during the summer of 2015 with the incidence of use reported by the NRC in August 2013 (NRC, 2014).

The purpose of the NRC survey was to examine whether the use of aerodynamic devices on trailers would be higher in (and near) California compared to other parts of the United States because only California required such devices. The NRC reported that side skirts were by far the most prevalent aerodynamic device in use and that the incidence of side skirts was substantially higher in and near California compared to other parts of the country. Underbody fairings and tail fairings were observed in only a few instances (NRC, 2014).

The NRC observations were made from the side of the interstate and included two locations on the east coast: Interstate 81 (I-81) in Pennsylvania, 29 miles south of Harrisburg, Pennsylvania, and Interstate 95 (I-95) in Maryland, 25 miles north of Washington, DC (NRC, 2014). The survey focused on dry and refrigerator van trailers at least 53 feet long, pulled by sleeper tractors. The survey did not follow a preset sampling plan, and the accuracy of the observations was not verified (NRC, 2014). (The NRC survey results for I-81 and I-95 are presented in table 1.)

We used a method similar to that of the NRC report—roadside observations of trucks operating on the highway—to collect three-quarters of our observations. We collected the remaining, more detailed observations using a variety of approaches, ranging from photographs and notes at interstate rest stops—focused on three routes—to on-road observations on a road trip from Washington, DC, to South Bend, Indiana. (See the Data Appendix.)

- East-bound US 50/US 301 just west of the Bay Bridge over the Chesapeake Bay. This is a major regional four-lane divided highway with traffic headed to the DelMarVa peninsula, Pennsylvania, New Jersey, and the Norfolk area.

- I-95 near Ladysmith, Virginia. This is the major interstate connecting the major Northeast cities from Boston and New York to points south all the way to Florida. I-95 likely handles both regional and long-haul truck traffic.
- I-81 at several locations from southern Pennsylvania to Harrisonburg, Virginia. This is a major interstate artery linking the urbanized Northeast with the South and West. I-81 is likely to comprise the highest proportion of long-haul truck traffic, since it is far from major urban areas for extended distances.

The result is a convenience sample reflecting the truck traffic on these routes on several weekdays from late June to early August 2015. We recorded information on whether the tractors had sleeper cabs for only a subset of our observations.

B. Trends and Geographic Patterns of Use of Aerodynamic Technologies on Trailers

Although our sample is restricted to several eastern locations and as a result is much smaller than the 2013 NRC sample, we can make some interesting comparisons both over time and across locations. We find that the incidence of trailer skirts on the predominantly long-distance route, I-81, has increased in the two years since the NRC sample was taken. Table 1 presents the NRC data for I-81 and I-95 along with our data on whether the trucks on those routes had sleeper cabs. The increase, from 25.7 percent to 40 percent, is statistically significant at the 99 percent level. For the route that is both long- and middle-distance, I-95, the increase from 22.7 percent to 34 percent is not statistically significant at the usual confidence levels. The increase in the use of skirts is highest on the route where the benefits are likely to be largest, as would be expected for cost-minimizing behavior.

Table 1. Trends in the Use of Skirts on Heavy-Duty Truck Trailers with Sleeper Cabs

	No. of trailers in sample	Side skirts	Incidence	t-tests for trends
2013 NRC Survey				
I-81, PA	662	170	.257	NA
I-95, MD	300	68	.227	NA
Detailed 2015 Survey				
I-81, PA,WV,VA	125	50	.400	3.05
I-95, VA	50	17	.340	1.59

Note: NRC = National Research Council.

Our survey across the three locations—US 50/US 301, I-81, and I-95—showed a higher incidence in the use of trailer skirts on I-95 than on a regional artery (US 50/US 301) and, correspondingly, a greater use of trailer skirts on I-81 compared to I-95. This pattern, evident in table 2, suggests economic effects within the industry. Long-haul, interstate trucking companies seem more likely to purchase trailer skirts than regional companies—and trucking firms are more likely to dispatch trailers with skirts on long-haul routes. We interpret this pattern as consistent with cost-minimizing industry behavior, although these results do not conclusively show that trucking firms have optimized skirt use.

Table 2. Incidence of Skirts by Route: Heavy-Duty Truck Trailers (Sleeper and Non-Sleeper Cabs)

Distance	Route	Count (and incidence)	t-tests	
Long distance	I-81	179/455 (0.393)	I-81 vs. I-95	3.20
Long and middle distance	I-95	86/304 (0.283)		
Middle and short distance	US 50/US 301	26/162 (0.161)	US 50/US 301 vs. I-95	2.97

C. Use of Low Rolling Resistance Tires

We also collected data on the use of LRR tires. Because this task was time consuming, we collected data for tires for only 71 heavy-duty trailers. Although these trailers all had eight tires, we observed only the two outboard tires visible from one side of the vehicle. As shown in table 3, many of the trailers used SmartWay LRR tires certified for the tractor but not for the trailer. Of the trailers we observed, 10 percent (7 out of 71) had two LRR tires certified for the tractor (but not the trailer) and 40 percent (28 out of 71) had one LRR tire certified for the tractor and also either a conventional tire or an LRR tire certified for the trailer. Finally, 8 percent (6 out of 71) of the trailers used conventional tires.

Table 3. Tires Observed on Trailers

Tires observed	Count	Frequency
2 LRR tractor tires	7	0.10
1 LRR tractor tire, 1 conventional trailer tire	10	0.14
2 conventional trailer tires	6	0.08
1 LRR tractor tire, 1 LRR trailer tire	11	0.15
1 conventional trailer tire, 1 LRR trailer tire	7	0.10
2 LRR trailer tires	30	0.42

Note: LRR = low rolling resistance.

One might wonder why any trailers would have LRR tractor tires, since these have a higher rolling resistance than a conventional bias ply trailer tire. We offer several potential explanations for these unexpected results. Worn tires have a lower rolling resistance than new tires, so trucking companies may be eking out the last miles from their tractor tires (after they are too badly worn to use on the drive or steer axles) by moving them to the trailer. Alternatively, there may be cost advantages from bulk acquisition of a more limited set of tires or from reducing the inventory of all three types of LRR tires. Furthermore, there may be other management costs that outweigh the energy-saving potential of ensuring that LRR trailer tires are properly placed on the trailer axles. Finally, the management of the trucking firms may believe that the EPA's savings estimates from the LRR SmartWay certifications overstate the benefits of placing the tires on the specified axles.

In any event, these results raise an issue with respect to the EPA's proposal, because the proposed rule would generally prohibit removing any pollution control device or otherwise rendering it inoperable. Arguably, this provision would require the exclusive use of LRR trailer tires on the trailer axles. The observed pattern of mismatches in table 5 would represent a violation of the proposed rule, where LRR trailer tires were original equipment included in the certification for the trailer (EPA, 2015, pp. 316–17).

D. Modeling Use of Energy-Saving Technologies on Trailers

We now turn to an analysis of the use of aerodynamic devices on trailers. We think of the use of devices as a relatively short-run decision by firms, a decision made to economize on fuel costs, in the context of the more permanent characteristics of the firm, which are affected by its management and the niche it occupies in the market. Specifically, we collect data on fleet size and usage (trucks and miles per year), ownership, proximity of the location of firm headquarters to California, and regulatory infractions relating to hours of service and vehicle maintenance. We use a dummy variable for firms located on the West Coast, defined to include California, Arizona, and Oregon as well as Utah, since the CARB has mandated use of aerodynamic devices since January 2010 for MY 2011 and later trucks. We hypothesize that a firm's demand for devices and thus their use increases with the average miles per truck, since this is a proxy for speed or intensity of use (hours driven per year), or both. Faster speeds or more intense usage would be expected to yield improved annual fuel savings and thus increase returns to investments in aerodynamic devices. Boyd and Curtis (2014) suggest that poor management affects the energy efficiency of the firm.

We have two proxies for management quality. First, we measure more sophisticated (or effective) management using fleet size. We presume that a large fleet is associated with more sophisticated or more effective management because the fleet has grown large in the face of competitive pressures. In addition, we expect larger fleets to generate more information, facilitating evaluation by managers of the in-use effectiveness of aerodynamic devices. We also anticipate that the effect of fleet size on adoption of devices will not be linear but will instead diminish as fleet size grows. In addition to fleet size, we use data from the Federal Motor Carrier Safety Administration (FMCSA) of the Department of Transportation (USDOT) about noncompliance with federal requirements on hours of service and vehicle maintenance. The FMCSA database provides a measure of each registered trucking firm's compliance with these federal requirements, a measure of the median firm's compliance, and the threshold measure that prompts additional inspections and scrutiny from FMCSA. We focus on an index of noncompliance defined as the arithmetic mean of the violation measures for hours of service and vehicle maintenance infractions, after we standardize these by dividing by the relevant threshold for additional inspections and scrutiny. We interpret this index of noncompliance to reflect the severity of management challenges facing the firm—either stemming from poor management per se or from other challenges such as inadequate access to capital markets.

Although our data collection focused on semi-tractor-trailer trucks with standard 53-foot trailers, we collected some data on vehicles with nonconventional trailers, including doubles and box trailers that appeared shorter or longer than the standard length, or otherwise deviated from the standard models. Less than 15 percent of all the vehicles for which we have data were such nonconventional box trailers.[17] In some regressions, we introduce a dummy for these nonstandard trailers, but we find that it has no predictive power. As a result, we generally ignore these distinctions among trailers in our analyses.

A threshold question is the unit of analysis in our data. We have relatively few instances of multiple trucks per firm. Specifically, for the variables in question, we have observations on 205 trucks owned by 152 different firms (i.e., we observe 152 distinct USDOT registration numbers on the tractors in our sample). Since our key variables are all firm-specific and not vehicle-specific, with the exception of the presence of an aerodynamic device and different owners for the trailer and tractor, we consolidate our observations and concentrate our analysis on firms. While we present some regressions using vehicles as the unit of observation, our preferred regressions use 152 independent observations (of firms). For these models we use as a dependent variable the probability of the presence of aerodynamic devices. We focused on an independent variable, differences in ownership, which has values in the interval [0, 1]. One implication of this approach is that we cannot control for the location where we collected the data, because averaging locations among two or more interstates is not meaningful.

We present summary statistics of key variables used here in table A in the appendix. The basic model that we estimate is

$$S = \beta_0 + \beta_1 \text{ MPT} + \beta_2 \ln(\text{trucks in the fleet}) + \beta_3 \text{ compliance variables} + \beta_4 \text{ different ownership} + e,$$

where S denotes the percentage of vehicles observed with skirts in that company's fleet, MPT is the total reported annual mileage driven relative to the fleet size reported to USDOT, and

[17] We did not collect data on trailers for which skirts were infeasible, such as those with lower storage space below the height of the wheels and between the drive wheels on the tractor and the trailer wheels.

the other variables are self-explanatory. The following tables also present modifications of this model.

EPA (2015), Alcott and Greenstone (2012), and Klemick et al. (2015) suggest that incentives for the adoption of energy-efficient devices will be lower where there is a difference in the ownership of the tractor and trailer. We interpret this difference in ownership as one of the more important of the several possible sources of market failures identified by the EPA (2015). To test this hypothesis, we construct a variable reflecting whether the owner of a trailer differs from the owner of the tractor pulling it, based on markings visible on the vehicles. Averaged across the fleets that we analyze, the variable indicating different ownership is about 33 percent.

We present in table 4 regressions in which the unit of observation is the fleet and the dependent variable is the probability that a truck we observed in the fleet has a skirt. This probability includes fractional values if we observed that some but not all tractor-trailers in a fleet used skirts. The independent variable of special interest is the probability that a truck we observed in the fleet had an owner different from the owner of the accompanying trailer. The model explains variation in firms' use of skirts with relatively simple determinants of returns on usage (average miles per truck—i.e., total miles traveled by the fleet divided by the number of trucks in the fleet), and proxies for marginal firms, as well as location of headquarters. Specifically, in model 1 we present a simple ordinary least squares (OLS) model and find that miles per truck and the natural log of fleet size are both statistically significant at better than the 99 percent confidence level. In the same model, an index of noncompliance with federal hours of service and vehicle maintenance requirements is not statistically significant at the 90 percent level, while a dummy variable for headquarters locations on or near the West Coast is statistically significant. Also included in the model is a dummy variable for different ownership for the trailer and tractors. This variable is not statistically significant in this model.

Other models give similar results. Dropping the variable for noncompliance with FCMSA requirements gives similar results, as shown in model 2 in table 4. One company, UPS, operates a fleet of 108,197 trucks, more than double the size of the next largest fleet in our sample. In addition, the number of miles traveled for the UPS fleet is more than double the number for all but two other firms in the sample. Thus, UPS is an outlier, and we dropped data for UPS trucks in a sensitivity analysis presented in model 3 of table 4. Dropping the dummy for different ownership described above and instead using a dummy for different ownership only if fleet size is less than 20 trucks also shows no effect of different ownership on adoption of skirts, as shown in model 4. We experimented with alternative cutoffs for such "small" fleets but did not find a cutoff where such effects were negative and statistically significant. Finally, in model 5 of table 4, we switch to a logit model for *any* use of skirts by trucks that we observe within a fleet, but we again find that different ownership is not associated with reduced skirt use. We note that the effect of different ownership (although not statistically significant) is positive in these models, although the literature mentioned above suggests a negative association. We are thus unable to show that different ownership reduces skirt use.

As a sensitivity analysis we also model the occurrence on individual trailers of side skirts, the most common aerodynamic device that we observed. As shown in table 5, we are able to explain a substantial portion of the variance in skirt use by using relatively simple determinants of returns on usage (miles per truck) and management quality, as well as location of headquarters. In model 1 we present an OLS model with fixed effects for routes and find that miles per truck and the natural log of fleet size are both statistically significant at better than the

99 percent confidence level. In that same model, an index of noncompliance with federal hours of service and vehicle maintenance requirements is not statistically significant at the 90 percent level, while a dummy variable for headquarters locations on or near the West Coast is statistically significant. Also included in the model is a dummy variable for different ownership for the trailer and tractors. The effect of this variable in the model is positive but not statistically significant. Model 2 presents the same model without the route dummy variables; the coefficients of primary interest and their statistical significance change very little. Models 3 and 4 delete the data for UPS, the outlier firm. The results are little changed. The last two columns of table 5 present logit regressions. In these models the effect of different ownership on skirt use is again positive but not statistically significant.

Table 4. Firm-Level Models of Skirt Use

Firm level analyses	OLS estimation				Logit estimation
	Model 1	Model 2	Model 3	Model 4	Model 5
Miles per truck	.00323*** (.000932)	.00334*** (.000937)	.00314*** (.000938)	.00297*** (.000950)	.0155** (.00611)
Natural log of trucks in the fleet	.0640*** (.0144)	.0694*** (.0133)	.0672*** (.0147)	.0519*** (.0188)	.451*** (.102)
Noncompliance with FMCSA requirements	−.000186 (.000172)		−.000177 (.000171)	−.000163 (.000180)	−.00133 (.00161)
Dummy for West Coast location of firm headquarters	.476*** (.179)	.463*** (.176)	.472*** (.179)	.494*** (.171)	3.41* (1.80)
Different ownership	.107 (.0820)	.0975 (.0816)	.107 (.0824)		.560 (.473)
Dummy for firms with small fleets of less than 20 trucks				−.157 (.128)	
Different ownership on small fleets of less than 20 trucks				.159 (.120)	
Intercept	−.271** (.126)	−.332*** (.117)	−.273** (.126)	−.144 (.152)	−4.29*** (1.07)
R^2 (or pseudo R^2 for the logit models)	.217	.215	.221	.216	.216
Number of observations	152	152	151	152	152

Table 5. Vehicle Level Models of Skirt Use

Estimation method	OLS, with route fixed effects	OLS, without route fixed effects	OLS, with route fixed effects	OLS, without route fixed effects	Logit, without dummies for route effects	Logit, with dummies for route effects
Miles per truck	.00386*** (.000926)	.00395*** (.000906)	.00327*** (.000933)	.00325*** (.000921)	.0192*** (.00627)	.0192*** (.00622)
Natural log of trucks in the fleet	.0622*** (.0129)	.0652*** (.0123)	.0743*** (.0138)	.0757*** (.0129)	.415*** (.0893)	.415*** (.0964)
Noncompliance with FMCSA requirements	−.000156 (.000195)	−.000140 (.000187)	−.000103 (.000194)	−.000103 (.000186)	−.000627 (.00157)	−.000564 (.00161)
Dummy for West Coast firm headquarters	.402*** (.139)	.392*** (.138)	.374*** (.137)	.369*** (.138)	3.52* (1.91)	3.53* (1.96)
Different ownership	.0439 (.0791)	.0536 (.0785)	.0356 (.0807)	.0458 (.0806)	.122 (.434)	.0716 (.434)
Interstate 80	−.162 (.170)		−.192 (.170)			−4.00*** (1.23)
Interstate 81	−.308** (.136)		−.314** (.137)			−4.63*** (1.15)
Interstate 95	−.282** (.142)		−.236 (.147)			−4.22*** (1.11)
Intercept	NA	−.311** (.127)	NA	−.298** (.127)	−4.50*** (1.08)	NA
N	205	205	198	198	198	198
R^2 (or pseudo R^2 for the logit models)	.571	.224	.590	.246	0.215	NA

Note: We group several observations on Interstate 66 near Washington, DC, with the Interstate 95 observations that were collected along Interstate 95 near Washington, DC.

We introduce into these regressions a dummy variable for atypical trailers (e.g., doubles or ones that appeared to be of nonconventional length). There is still no evidence that differences in ownership are statistically associated with skirt use.

Our results indicate that skirt use responds in the expected way to measures of fleet size and intensity of use. Specifically, increases in fleet size, speed and intensity of use, and proximity to California all are associated with increased skirt use. Noncompliance with federal regulations is negatively associated with skirt use, but this effect is not statistically significant in these models. Finally, differences in ownership between tractor and trailer do not appear to be associated with reduced skirt use.

Firms select skirts to promote fuel efficiency, but they also can choose other aerodynamic devices such as rear fairings (ducktails) and underbody devices to deflect air from rear wheels. To evaluate all such decisions, one might construct an index of the energy savings by firm associated with the use of all such devices and model the determinants of such an index. We experiment briefly with such an index of energy-saving technology by constructing one equal to the expected percentage savings in energy use, according to data on the EPA's SmartWay website. As noted above, a typical side skirt recognized by that program gets a savings of about 5 percent, a trailer ducktail gets about the same savings, and the underbody device gets a savings of 4 percent. To measure the efficiency of trailers we first assign a value of 5 to visible skirts, 5 to ducktails, and 4 to underbody devices. We then construct a fleet-wide average measure of trailer efficiency by taking the arithmetic mean of the index values specific to the trucks within a fleet. Thus a fleet of two trucks, which has only one skirt between them, would have a value of 2.5. Since a majority of trucks have no visible energy-saving devices on the trailers they pull, the resulting distribution has mostly zeros and some values up to nine. OLS regressions using this index again indicate that average miles per truck and the log of trucks in the fleet have strongly statistically significant effects. Noncompliance with FCMS regulations, proximity of headquarters to California, and different ownership do not have statistically significant effects. The effect of different ownership on this index for energy-saving technology on the trailer is not statistically significant and is positive, not negative as postulated by the EPA. Our index does not reflect differences in energy efficiency among different side skirts or among underbody devices or ducktails, and thus it should be seen only as a proof of principle. Future research should explore how an index of energy-saving technologies for heavy–duty trucks might be developed in a way that better reflects actual savings.

Conclusions

Our analysis of trucking firms' use of energy-saving technologies on heavy-duty trailers finds that firms' behavior is consistent with neoclassical economic models. Such technologies are more commonly observed on routes where they might offer greater net benefits. Further, their use increases with the intensity of use of trucks in a fleet, and with fleet size, and decreases with measures of noncompliance with federal regulatory requirements, which may be seen as a proxy for relatively weak management or marginal economic performance. We find no evidence that differences in ownership between the trailer and the tractor reduce the use of energy-efficient technologies, even though such effects are an important basis for claims of market failures.

We recommend that the EPA and the NHTSA review much more carefully the empirical bases for claims of market failures in competitive markets and that they conclude their review before using estimates of large net economic gains in rulemakings. Our analysis illustrates that testing claims of market failures may be relatively inexpensive and quick. Specifically, allocating a fraction of the cost of a typical EPA RIA to such a project should enable the collection of a sample many times larger, and with greater power, than the one analyzed here.

More generally, our results suggest that regulatory agencies' claims of large private benefits from requirements to adopt such technology should be subjected to special scrutiny. In particular, we recommend that the EPA and the NHTSA collect data to estimate the actual effectiveness of energy-saving technologies in commercial operations. As noted, publicly available information about the effectiveness of most energy-saving technologies used on heavy-duty trucks exists only for performance based on special track tests, and not during commercial operations. The regulatory agencies could help inform trucking firms about the private benefits of such technologies by funding a study to assess fuel efficiency of trucks randomly assigned to have skirts. Random assignment, coupled with GPS devices that record location, speed, and elevation, might be a cost-effective way to assess the effectiveness of such technologies in use. Trucking firms would benefit from such information, and we believe the agencies have an obligation to assess such in-use information before mandating the adoption of these energy-saving technologies. Collecting data to estimate the effectiveness of these technologies during commercial use may be the most cost-effective way to address the extent of the apparent market failure associated with an energy-efficiency gap, if indeed such a gap exists.

Data Appendix

Data Collection

We limited our data collection efforts to tractor-trailer trucks with conventional "box" trailers, located on or adjacent to major interstates mostly in the mid-Atlantic region but also west-northwest through Pennsylvania and Ohio to the Indiana Turnpike. Our sample collection was limited to daytime hours and focused on business hours during workdays.

To collect data for our empirical analysis, we initially tried to photograph tractors and trailers at public rest areas to develop a complete record for each truck. This photographic record would include the license plates of the tractor and trailer, USDOT numbers, the names of tractor and trailer owners, basic photos of the tractor and trailer (sufficient to determine what, if any, aerodynamic devices were in place), and photos of steer, drive, and trailer tires on one side. If the trucker was present, one member of our team asked permission to photograph his or her truck to capture aerodynamic devices. If the trucker was not present, we generally took the pictures without first securing consent. Because this approach was very time consuming, we later modified our data collection and developed two additional approaches for the collection of data—a hybrid approach using voice memos supplemented with a more limited set of photos and a "fast collection" approach (similar to the approach used by the National Academy of Sciences).

- *Hybrid approach.* Two team members found a location at the exit of a rest area where they could easily observe trucks moving slowly. One member took photos of passing trucks, focusing on the tractor license plate, the company name on the tractor, and the USDOT number on the tractor. The other recorded a voice memorandum that detailed aerodynamic devices on the tractor and trailer (mirrors, fuel covers, type of cab, side skirts, rear fairings). While this approach did not yield as comprehensive a set of data for each truck vis-à-vis a complete photographic record, it provided much of the data that we were seeking, including company ownership of the tractor and trailer and state license info for the tractor. One team member pursued a variant of this approach by making a voice memo from a moving vehicle traveling from Washington, DC, to South Bend, Indiana, along the most direct major interstates. This approach, which focused exclusively on westbound trucks, did not record the tractor license plate but was otherwise as effective at collecting information.

- *Fast database.* The fast database was compiled by individual members either making voice memorandums or, in fewer cases, tabulating information on notepads. The focus on a limited set of devices (skirts, underbody devices, and tail fairings for each truck) made it easier to collect accurate data for fast-moving trucks.

Data Management: Quality Assurance and Quality Control

Two members of the team collaborated closely in coding the data based on the field records. This process ensured accuracy through a joint and simultaneous process in which each member crosschecked the other's data for each entry for each observation (tractor and trailer). If ambiguities appeared in the field notes, then the coding team sought clarification from whoever had taken the field notes. In the event of persistent ambiguity, the coding team chose to disregard the data in question. In addition, we searched for outliers in all recorded data and reexamined original field records in instances where coded entries appeared questionable. Table A provides definitions of variables used in this analysis.

Table A. Summary Statistics

Variable Definitions	Vehicle level			Firm level		
	N	Mean	SD	N	Mean	SD
Difference: Indicates difference in ownership of the trailer and the tractor, based on corporate information visible on the trailer and tractor	205	.263	.442	152	.328	.468
Ducktail: Indicates rear aerodynamic fairing, or “duck tail,” present on back of trailer	204	.069	.253	151	.079	.271
Hours of service: FMCSA rating of carrier’s hours of service compliance according to USDOT database (https://csa.fmcsa.dot.gov/)	205	.649	.951	152	.815	1.05
Mileage: Number of miles driven annually by company vehicles, according to USDOT website (https://csa.fmcsa.dot.gov/), as recorded in July 2015	205	328,381.5	595,213.4	152	137,700.4	344,429.4
Miles per truck annually: Company’s total miles divided by number of vehicles, in thousands	205	87.97	36.14	152	90.71	36.57
Sideskirts: Indicates side skirts of any kind along side of trailer(s)	205	.439	.497	152	.401	.492
Trucks: Identifies the number of trucks, tractors, hazardous material tank trucks, motor coaches, school buses, mini-buses/vans, and limousines owned, term-leased, or trip-leased by the motor carrier, according to USDOT database (https://csa.fmcsa.dot.gov/)	205	7,598.58	20,853.65	152	2,645.60	10,389.76
Underbody device: Indicates underbody aerodynamic device on trailer (underbody devices and side skirts are mutually exclusive)	205	.024	.155	152	.033	.179
USDOT number: A unique identity number for the truck operator, required by the FMCSA and printed on side of truck cab	205	662,056.7	723,513.4	152	826,678.6	756,473.9
VMMeasure: FMCSA rating of carrier’s vehicle maintenance compliance according to USDOT database (https://csa.fmcsa.dot.gov/)	205	2.98	2.14	152	3.25	2.41

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