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# The Energy Paradox in Seemingly Competitive Industries: The Use of Energy-Efficient Equipment on Heavy-Duty Tractor Trailers

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# About RFF

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# Abstract

Several federal agencies claim the existence of an energy paradox in competitive markets in their benefit-cost analyses: firms fail to use energy-saving equipment that on net would reduce their costs. Such findings appear incompatible with neoclassical views that private firms in competitive markets will seek to minimize costs. EPA and NHTSA (2016) justify their findings in part by claiming that owners of trailers pulled by others underinvest in energy-saving equipment because the trailer owners incur the costs of such investments while tractor owners get the benefits. We collected roadside data over three summers and model use of energy-saving equipment on trailers. We find associations consistent with cost-reducing behavior in the use of energy efficiency devices, such as skirts and automatic tire inflation devices, but no evidence that different ownership of tractors and trailers is associated with reduced use of energy-saving equipment on trailers. We recommend that EPA and NHTSA assess the in-use cost-effectiveness of such equipment and rigorously review the empirical basis for claims of market failures in competitive markets before claiming significant private economic gains in rulemakings.

**Keywords:** Energy efficiency; Energy gap; Energy paradox; Environmental regulation; Market failure; Split incentive

# Contents

# 1. Introduction

In 2016, the Environmental Protection Agency (EPA) and the National Highway Transportation Safety Administration (NHTSA) issued a final rule mandating the adoption of energy efficiency devices on heavy-duty trucks to reduce greenhouse gas emissions (81 FR 73478).[1] The rule is supported by an economic analysis that estimates that trucking firms would enjoy annualized fuel savings of $5.8 to $5.9 billion, an amount that greatly outweighs the $1.0 to $1.3 billion annualized cost of adopting this equipment (EPA and NHTSA, 2016). The estimates suggest that for-profit businesses operating in reasonably competitive markets are in fact failing to install equipment that would increase profits by lowering their fuel costs, the largest or second-largest component of their operating costs.

The estimates of large net cost savings for the 2016 final rule in the EPA and NHTSA regulatory impact analysis (RIA) appear incompatible with the neoclassical view that competitive industries would rapidly realize any such large cost savings without government action. We address the inconsistency between the large private cost savings in the EPA and NHTSA RIA and the neoclassical view by collecting and analyzing data on the use of energy-saving technologies and the characteristics of trucking firms.

We collected roadside data on heavy-duty trucks in the mid-Atlantic area, including the use of various energy efficiency devices. We compiled characteristics of the trucking firms, including number of trucks, total annual mileage, characteristics such as sleeper or day cabs, the owners of the tractors and trailers, and business location, as well as compliance with federal highway regulations. We correlate the prevalence of different devices with these explanatory variables using several statistical approaches. We find the prevalence of energy efficiency devices is higher where they would be more efficient—that is, on high-speed interstates, behind tractors with sleeping compartments, in fleets with high average miles per truck, and in years when average fuel prices are high. We do not find evidence that split incentives caused by different ownership of tractors and trailers is associated with reduced use of energy efficiency devices, although our models otherwise perform reasonably well. These findings suggest trucking firms are seeking to reduce and perhaps minimize their costs in making decisions to adopt and use energy efficiency devices.

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[1] In October 2017, the DC Circuit stayed the Phase 2 rule requirements for trailers pending court review of a challenge by the Truck Trailer Manufacturers Association. Columbia University's Sabin Center for Climate Change Law provides a database of related court filings to date (2018).

In Section 2, we present the background to the recent EPA and NHTSA rulemaking and a review of recent literature, EPA's description of the regulatory problem behind its rulemaking, and the key energy-saving technologies for heavy-duty trailers. Section 3 includes a discussion of trends and geographic patterns in the use of energy efficiency devices on trailers, as well as results from econometric models on the use of energy efficient technologies on trailers. Section 4 presents our conclusions and policy implications.

# 2. Background and Literature Review

## 2.1. Prior Literature

There is an extensive literature on the energy paradox, which posits that the private benefits of energy efficiency technologies exceed their costs because of market imperfections. Hausman first identified the possibility of the energy efficiency paradox in a seminal 1979 article. Gerarden et al. (2017) provide a recent summary of this literature and offer the following conclusions with respect to whether product choices are cost-minimizing in present-value terms:

Here the empirical evidence ranges from strong (split incentives/agency issues and inattention/salience phenomena) to moderate (heuristic decision making/bounded rationality, systematic risk, myopia/shortsightedness, and option value) to weak (learning-by-using, loss aversion, and capital-market failures). Importantly, here, as elsewhere in our review, the bulk of previous work has focused on the residential sector and much less attention has been given to the commercial and industrial sectors. (1503)

Boyd and Curtis (2014) link management practices generally to manufacturing firms' energy efficiency. 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." (466) Allcott and Greenstone (2012) and Gayer and Viscusi (2013) take a more skeptical perspective in addressing claims of large or pervasive energy efficiency gaps. In light of the tension between regulators' claims of large private savings from mandates to use energy-efficient technologies and pressures for firms in competitive markets to minimize cost, we focus on evidence for an energy efficiency gap among private firms in a competitive industry.

Heavy-duty trucking is widely seen as a competitive industry (Breyer, 1982; Engel, 1998; Sutherland and Koepke, 2012). Barriers to entry are low—entrants need only a commercial driver's 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 (Torrey and Murray, 2014). Capital is literally mobile, as trucks are able to move among geographic areas and market segments on short notice. Consistent with the low entry costs, the industry is dominated by small firms—90% of trucking firms operate 6 or fewer trucks and 97.3% operate fewer than 20 trucks. (ATA, 2018).

Trucking firms are generally considered to be fully attentive to opportunities to realize fuel cost savings, because fuel is the largest or second-largest category of costs (Torrey and Murray, 2014). Information on such opportunities is readily available. EPA has sponsored its voluntary SmartWay program to improve energy efficiency within the trucking sector and California has adopted energy efficiency standards for heavy duty trucks operating within that state. Appendix A describes the EPA and California heavy-duty truck programs in detail. In addition, the internet revolution 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 equipment. For example, there are several private, non-profit organizations dedicated to improving the environmental performance and energy efficiency of the transportation sector.[2]

Nevertheless, the energy efficiency literature identifies a number of impediments—including potential market failures—that could restrict the trucking industry from identifying and adopting energy-saving innovations that would lower fuel costs. For example, Klemick et al. (2015), used focus groups and interviews to study tractor-related investment decisions and the energy efficiency gap in heavy-duty trucking; however, they did not explore issues associated with trailers.[3] They reported that the lack of information on energy efficiency may slow adoption of new technologies and that participants demanded fast payback on such investments. They also found some evidence of a split incentive problem between owners and drivers in tractor-related operation that affect in-use energy efficiency, although study participants reported the adoption by owners of technologies and procedures in an effort to address the problem (Klemick et al. 2015, p 161). Overall, Klemick et al. find that, "evidence suggests that companies in our sample are sophisticated consumers of information on available fuel-saving technologies but that, due to heterogeneity among fleets, companies must still conduct testing to determine if a new technology will save fuel for their own fleets" (164).

Vernon and Meier (2012) note that approximately 23 percent of trailers are leased or rented, leading to a potential principal agent problem associated with different ownership of combination tractors and trailers. Aarnink et al. (2012) and Roeth et al. (2013) also cite examples of split incentives associated with different ownership of combination tractors and trailers. While the market seems capable of a variety of creative contracting solutions to address split incentives, Vernon and Meier (2012)

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[2] These include the National American Council for Freight Efficiency (https://nacfe.org/) and the International Council on Clean Transportation (https://www.theicct.org/).

[3] In addition, the study is based on stated results from focus groups comprised of managers of small and medium-sized firms (excluding owner/operators) and interviews with large trucking firms, and the design of the study did not support conventional hypothesis testing.

report that their review of many contracts between tractor and trailer owners revealed no allowances (or even mention) of fuel efficiency of trailers. They also interviewed persons in trucking firms and found little knowledge (or interest) in trailer fuel efficiency. Moreover, Vernon and Meier examined the various types of maintenance and service contracts offered by trailer leasing firms, finding that the structure of these contracts varies in the extent to which they may give rise to split-incentive issues and adversely affect fuel efficiency.

On the other hand, Sharpe and Roeth (2014) report that some shippers are adopting contract terms requiring carriers to meet energy efficiency design or performance requirements linked to EPA's SmartWay program. In addition, a review of leasing options offered by major trailer leasing firms show the availability of energy efficient trailers compliant with EPA's SmartWay program and California's trailer requirements.[4]

The National Research Council (NRC, 2014), addressed opportunities to achieve greater fuel efficiency in heavy-duty trucks. The NRC report provides several recommendations, including that EPA and NHTSA adopt a regulation requiring long box dry and refrigerated trailers to reduce their fuel consumption. The report also recommends that NHTSA gather data from private fleets and work with the General Services Administration or the US Postal Service to evaluate the performance of vehicles in use. To our knowledge, EPA and NHTSA have not responded to this recommendation.

The NRC report also presents the results of a survey on the prevalence of aerodynamic devices in use by dry and refrigerated van trailers at least 53 feet long pulled by tractors with sleeper cabs. Side skirts were by far the most prevalent aerodynamic device, and the prevalence of side skirts was substantially higher in and near California, where they were required. Underbody fairings and tail fairings were rare (NRC, 2014).

Our research goes beyond previous work in several respects. Our study is the first to test for a type of market failure believed to cause underinvestment in energy efficiency devices for tractor trailers. Further, this study is consistent with the Allcott and Greenstone (2012) plea for more detailed empirical studies, though it does not use the quasi-experimental methods that they would recommend. It moves beyond the Klemick et al. (2015) paper by examining in-use behavior in adopting energy efficiency technologies for trailers across a broad spectrum of the heavy duty trucking industry. It addresses in a different way from Vernon and Meier (2012) the extent to which split

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[4] For one example, see Premier Trailer Leasing: https://premiertrailerleasing.com/Fuel-savings.html

incentive issues affect the adoption of energy efficiency technologies for trailers. Our work can also be seen as an exploration of the connection between management practices and energy efficiency in the trucking industry, as compared to the work of Boyd and Curtis (2014) in the manufacturing sector, using safety measures as a proxy for better management practices. Finally, our analysis also provides the kind of empirical research called for by the National Research Council regarding the in-use effectiveness of these energy efficiency technologies (NRC, 2014).

## 2.2. EPA and NHTSA Description of the Regulatory Problem

In their final RIA, EPA and NHTSA report 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" (2016, p 8-4).[5] Even so, the RIA identifies several hypotheses supporting an energy efficiency gap in the heavy-duty trucking industry, including principal-agent problems causing split incentives where the tractor and trailer owners differ. The RIA acknowledges that these hypotheses only provide a potential explanation and that "they are not themselves the basis for regulation" (EPA and NHTSA 2016, 8-4).

Nevertheless, the final RIA reports that "the agencies believe that a significant number of fuel efficiency improving technologies would remain far less widely adopted in the absence of these standards" (EPA and NHTSA, 2016, 8-4). Thus, EPA and NHTSA conclude in the final rule that "a program involving no or minimal mandatory requirements would not be appropriate or meet our statutory requirements", and on this basis proceed to establish the Phase 2 heavy duty truck rule (81 FR 73663).

## 2.3. Key Energy-Saving Technologies for Trailers

EPA and NHTSA identify the use of several aerodynamic devices (side skirts, underbody devices, and tail fairings) and tire-based equipment (low rolling resistance tires and tire pressure systems) as key to improving the energy efficiency of trailers.

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[5] EPA and NHTSA conducted an economic analysis to support the proposed rule to comply with Exec. Order No. 12866, 58 Fed. Reg. 190 (September 30, 1993); Exec. Order No. 13563, 76 Fed. Reg. 14 (January 18, 2011); and Section 202(a)(2) of the Unfunded Mandates Reform Act of 1995, 2 USC §§ 1501–1571 (2012).

The Phase 2 rule establishes performance standards for several categories of box van trailers based on the use of aerodynamic devices and tire technologies.[6]

### 2.3.1. Aerodynamic Devices

Aerodynamic drag accounts for a significant portion of energy losses at higher truck speeds. Aerodynamic devices installed on the sides and underbody and at the rear end of the trailer reduce drag around and behind the trailer. However, at slow and variable speeds, such as in urban driving, these devices may increase fuel consumption by adding weight without appreciably reducing drag. Aerodynamic devices include the following:

- *Side skirts*. The most widely adopted aerodynamic device, side skirts reduce the open area between the floor of the trailer and the road. Fuel savings estimates range from 3 to 7 percent at highway speed. Cost ranges from $700 to $1,100 (Sharpe and Roeth, 2014).
- *Underbody devices*. These provide a cupped surface in front of the rear axles of the trailer to smooth airflow underneath the trailer. Although they are less susceptible to damage than side skirts and less restrictive in terms of maneuverability, and they purportedly achieve roughly comparable energy savings, only 5 percent of trailers use underbody devices. Fuel savings estimates range from 2 to 5 percent at highway speed. Cost ranges from $1,500 to $2,200 (Sharpe and Roeth, 2014).
- *Fairings*. Commonly referred to as boat tails, fairings are installed at the rear of the trailer to reduce turbulence in the wake. Fuel savings estimates range from 3 to 5 percent at highway speed, with purchase and installation costs ranging from $1,000 to $1,600 (Sharpe and Roeth, 2014).

### 2.3.2. Low Rolling Resistance Tires

Low rolling resistance (LRR) tires are designed to reduce the internal friction of the tire to minimize rolling resistance and improve fuel efficiency of tractor trailers. The California Air Resources Board reports that current SmartWay-verified trailer tires—the first level of improved performance in the Phase 2 rule—will achieve at least a 1 percent reduction in fuel consumption (CARB, 2012). There is little difference in the initial cost between LRR and conventional tires, with the average incremental cost ranging between $0 and $50 per tire (CARB, 2012).[7]

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[6] An expansive treatment of the various types of energy-efficiency devices discussed here can be found in NACFE (2018a).

[7] NACFE (2015) finds that some SmartWay-verified tires are less expensive than their non-LRR tire counterparts. However, LRR tires have a thinner tread depth, so tires need to be retreaded more often (NACFE, 2015). In addition, industry sources claim that overall LRR tire life is shorter, as LRR tires will take fewer retreads than conventional tires (Sharpe and Roeth, 2014).

Wide base single LRR tires improve energy efficiency through less sidewall flexing, less aerodynamic resistance, and less weight compared with equivalent dual tires (EPA and NHTSA 2016, pp. 2-31–2-33). Wide tires have a purchase price equivalent to that of duals, and if properly inflated, they have a lower maintenance cost, since a trailer with wide tires has half as many tires as one with duals, and there is no need to balance tire pressure as there is across each dual tire mounting. Drawbacks include a shorter lifetime—a shorter tread life and fewer retreads—than with comparable dual tires. At least in some regions, this translates into a lower trade-in value for wide tires. Trailers using wide tires also have a higher adoption rate for tire pressure systems to ensure proper inflation of the tires (NACFE, 2018b).

### 2.3.3. Tire Pressure Systems

Underinflated tires flex more under the load of the trailer, thus increasing rolling resistance and the potential for tire failure. EPA estimates that underinflated tires (10 psi or more) can decrease fuel economy by up to 1 percent (81 FR 73592). Both automatic tire inflation (ATI) systems and tire pressure monitoring systems (TPMS) have been developed to address inadequate inflation. ATI systems are connected directly to the tires to maintain the desired amount of pressure. In addition to fuel savings, ATI systems increase tire life, improve safety, and reduce maintenance costs. TPMS are also connected to the tires and alert the driver to decreases in pressure below the desired level for each tire. However, unlike ATI systems, TPMS require active intervention by the driver to re-pressurize the tire. While EPA and NHTSA provide credit for both systems, ATI systems receive a greater credit because they do not require active intervention by the driver (2016). NACFE (2018c) reports that ATI systems have a substantially higher adoption rate than TPMS. Installation of these tire pressure systems on trailers costs roughly $700 to $1000, and both systems require regular maintenance. The payback period for an ATI system is one to two years through fuel savings and reduced on-road maintenance from tire failure (Sharpe and Roeth, 2014).

# 3. Empirical Analysis

## 3.1. Data

We collected two different sets of data on energy efficiency devices installed on truck trailers using several major highways in the larger Washington, D.C., area. The first—the "fast" dataset—consists of roadside observations of the aerodynamic devices used by the tractor trailers operating on these major arteries. The second—the "slow" dataset—consists of detailed observations of energy efficiency devices on tractor trailers parked at rest stops on these major highways. Our roadside observations of the use of aerodynamic devices on trailers add three more years of data to the results of the NRC (2014) survey discussed earlier.

The NRC (2014) observations were made from the side of the interstate and included two locations on the East Coast: I-81 in Pennsylvania 29 miles south of Harrisburg and I-95 in Maryland 25 miles north of Washington, DC. I-81 is a major interstate artery linking the urbanized Northeast with the South and West and is likely to carry the highest proportion of long-haul truck traffic. I-95 is the major interstate connecting the major Northeast cities from Boston and New York to points along the East Coast south all the way to Florida. It carries both regional and long-haul truck traffic. The survey focused on dry and refrigerator van trailers at least 53 feet long, pulled by sleeper tractors. We used 962 observations reported in the NRC study in our analysis. We made comparable observations from the roadside at similar locations for 2015-2017: several locations on I-81 from southern Pennsylvania to Harrisonburg, Virginia, and on I-95 at rest areas near Ladysmith, Virginia, and Laurel, Maryland. We collected 135 observations on these routes in 2015, 951 in 2016, and 596 in 2017. We also added comparable observations from US 50/301 near the Bay Bridge, a major regional four-lane divided highway with traffic headed to the Delmarva Peninsula, Pennsylvania, New Jersey, and the Norfolk, Virginia, area. We collected 114 observations on US 50 in 2015, 240 in 2016, and 191 in 2017, for a total of 3,189 observations in the fast data. Appendix B.2.3 contains further discussion of the comparability of our data with the NRC data.

We collected our more detailed observations (the slow dataset) using photographs and field notes at several I-81 and I-95 interstate rest stops. Our convenience sample includes detailed observations for 477 vehicles—80 for 2015, 250 for 2016, and 147 for 2017—on these routes on weekdays from late June to early August. We observed trucks belonging to 71 unique firms in 2015, 203 in 2016, and 132 in 2017. Thus, our data include 406 unique firm-year observations.[8]

Table 1. Summary Statistics for Variables for Truck-Level Combined Fast and Slow Data

| v | N | Mean | Std. dev. | Min. | Max. |
|---|---|---|---|---|---|
| Presence of Skirt/Underbody | 3,650 | .332 | .471 | 0 | 1 |
| 3-month diesel price ($) | 3,650 | 2.923 | .710 | 2.280 | 4.060 |
| Interstate (I-95 & I-81) | 3,650 | .851 | .356 | 0 | 1 |
| Day cab | 3,650 | .113 | .317 | 0 | 1 |
| Slow survey dummy | 3,650 | .126 | .332 | 0 | 1 |

Table 1 presents summary statistics on the combined fast and slow data at the truck level (n=3,650).[9] It is important to note that sleeper cabs dominate the sample—day cabs account for only 11.3% percent of all tractors. A third of this sample used either a skirt or underbody device. Average diesel prices dropped from a high of roughly

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[8] Note that we include only 380 firm-year observations in our preferred regressions of skirt usage (comprising 334 unique firms). This smaller sample is due in part to an incomplete photographic record on some trucks and missing firm information from the FMCSA database on measures such as annual fleet mileage. Sample sizes are slightly smaller in other sensitivity analyses because of these issues as well. Additionally, we removed some firm-years from our dataset because of implausibly low or high measures of the number of miles driven per truck in the fleet or per driver employed by the firm. These all had measures of miles per truck or per driver greater than 300,000 or less than 100. We apply this restriction to the number of individual trucks from the slow data combined into the fast data (n=461 instead of the full 477 observations). We do not drop observations in the combined dataset if mileage information is missing entirely, however.

[9] Appendix B.1 contains additional summary statistics tables that compare these estimates across relevant subsamples. Appendix B.2 contains detailed descriptions of all variables. Since the Census Bureau's Vehicle Inventory and Use survey was discontinued in 2002, it was difficult to identify a single data source that could serve as the basis for assessing the representativeness of our slow sample. However, Torrey and Murray (2014) reports that the average truck is driven 118,800 miles per year; the value for our sample is roughly comparable at 90,000. On the other hand, ATA (2018) reports that 90% of firms operate 6 or fewer trucks, but only 20% of the firms in our sample operate fewer than 6 trucks. In this respect, our convenience sample may not be representative of the population of U.S. trucking firms.

$4/gallon in 2013 to just over $2.30/gallon in 2016 before rebounding slightly in 2017 to roughly $2.60/gallon.

Table 2. Summary Statistics for Variables for Firm-Year Level Slow Data

| Category | Variable | N | Mean | Std. dev. | Min. | Max. |
|---|---|---|---|---|---|---|
| Aerodynamic Devices<br>(Firm-year average) | Skirts and Underbodies | 380 | .428 | .486 | 0 | 1 |
| | ATIs | 376 | .325 | .460 | 0 | 1 |
| Firm Characteristics | Miles Per Truck (1,000 miles) | 380 | 89.380 | 40.271 | .101 | 289.485 |
| | Trucks in the fleet | 380 | 1050.195 | 3066.488 | 1 | 28,111 |
| | Noncompliance with FMCSA requirements | 380 | 163.751 | 179.578 | 0 | 1,359.617 |
| | Fleet Size: Large Firms | 380 | .661 | .473 | 0 | 1 |
| | West Coast headquarters | 380 | .053 | .224 | 0 | 1 |
| | Canadian headquarters | 380 | .071 | .257 | 0 | 1 |
| Vehicle Characteristics<br>(Firm-year average) | Day cab | 380 | .068 | .247 | 0 | 1 |
| | Refrigerated trailer | 375 | .330 | .467 | 0 | 1 |
| Ownership<br>(Firm-year average) | Same ownership | 380 | .698 | .455 | 0 | 1 |
| | Unambiguously different ownership | 380 | .067 | .246 | 0 | 1 |
| | Ambiguous ownership | 380 | .235 | .422 | 0 | 1 |

Table 2 presents summary statistics for the slow data set using firm-year level observations (n=380). It is important to note that when considering the slow data only, adoption of skirts and underbody devices is relatively higher at 42.8%. This is consistent with the collection of this data at rest areas on interstate routes that are more likely to carry long-haul traffic. The average fleet had roughly 1,050 total trucks, but the median firm-year had only 73 trucks, indicating a right-skewed distribution that is consistent with the market organization of the entire trucking industry (many small firms with relatively few very large firms). The noncompliance variable indicates that the average firm was above the normalized threshold for compliance with FMCSA safety measures (discussed in Section 3.3), though as with number of trucks the median is lower, indicating relative compliance (89.56% vs. 163.75%). Roughly two-thirds of the sample is from firms we define as “large” (20 or more trucks). Sleeper cabs dominate the sample—day cabs account for only 6.8% percent of all tractors. Finally, note that 5% of the sample come from West Coast states and 7% are headquartered in Canada. West Coast and Canadian trucks are more likely to be carrying long-haul freight given their distance from the areas where we collected our sample and California has had in place fuel efficiency standards requiring skirts for trailers.

## 3.2. Trends and Geographic Patterns of Use of Aerodynamic Technologies on Trailers

Using our fast data and the 2013 NRC data, we find that the prevalence of trailer skirts and underbody devices (from here forward referred to as “skirts”) on the predominantly long-distance routes of I-81 and I-95 has increased since the NRC sample.[10] Figure 1 presents the 2013 NRC data for I-81 and I-95, along with our fast data for trucks with sleeper cabs along these same routes and for trucks on US 50/301.[11] Following NRC’s methods, we present here only information on trucks observed with sleeper cabs from our fast data set. The prevalence of skirts on the two interstates increased over the 2013-2017 period from 26.5 to 42.3 percent (statistically significant at the 99 percent level).

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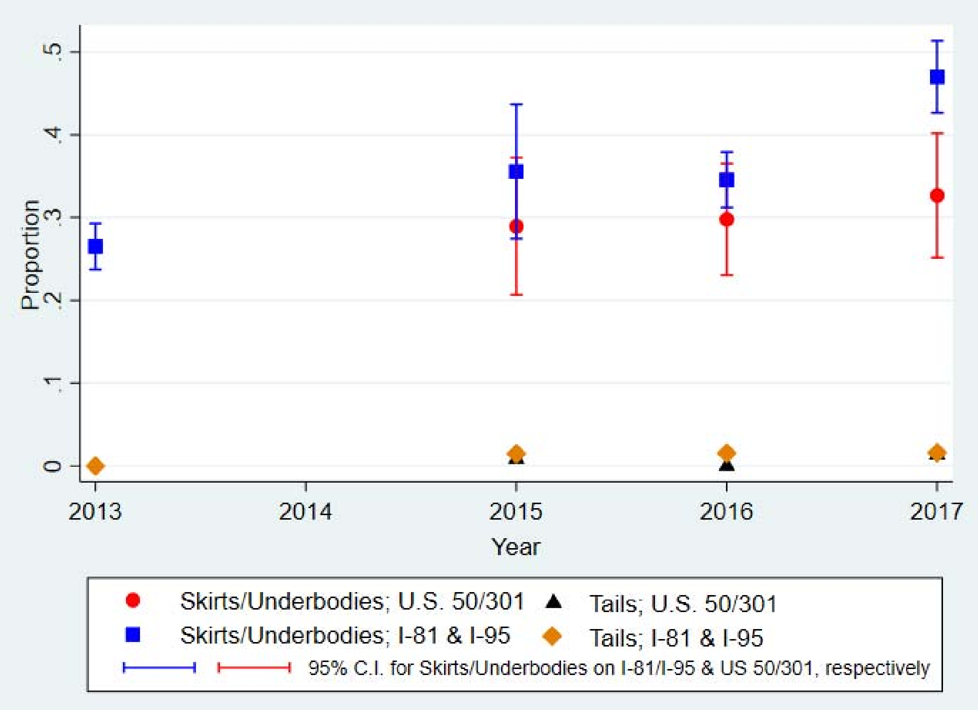
[10] Because skirts and underbody devices are substitutes, we combined the prevalence of both aerodynamic devices for the purposes of analysis, and in the following text, “skirts” denotes the use of either a skirt or an underbody device.

[11] Table B.3 in Appendix B presents numerical proportion estimates and associated confidence intervals from Figure 1 in tabular form.

Figure 1. Prevalence of Aerodynamic Devices on Trucks Observed at Highway Speeds; by Route and Year, Sleeper Cabs Only



Our survey also shows differences in adoption of energy-saving equipment both by route and by type of equipment. Skirts are more common on I-81 and I-95 than on US 50/301. Greater skirt prevalence on the interstate routes, where the benefits are likely to be larger, would be expected with cost-minimizing behavior. In addition, tails are significantly less common than skirts, even though EPA projects that tails provide comparable energy savings.

The patterns of skirt use evident in Figure 1 suggest that firms are responding to economic incentives. Long-haul trucking companies seem more likely to use 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-reducing behavior (although these results do not conclusively show that trucking firms have optimized skirt use).

Table 3 presents a regression using our combined data relating the prevalence of skirts to the three-month average of the real diesel fuel price (July 2017$), a linear time trend, dummy variables reflecting whether the observations were made on I-81 and I-95 or on US 50/301, whether the tractor was a sleeper cab or a day cab, and whether the data are from the fast or slow data.[12] For this model, we combine the NRC data with our fast data and with the detailed set of truck observations from the slow dataset. We specify a linear probability model in which our dependent variable is a binary variable that takes a value of 1 if a skirt was observed and a value of 0 if the trailer did not have a skirt (or underbody device) installed.

## Table 3. Vehicle Level Model of Presence of Skirts/Underbodies, Combined Data (N =3,650, R2=.0476)

| Variable | OLS estimation |
|---|---|
| 3-month fuel price | .08222***<br>(.02773) |
| Linear time trend | .07618***<br>(.01304) |
| Interstate (I-95 & I-81) | .07388***<br>(.02179) |
| Day cab | -.22953***<br>(.02079) |
| Detailed survey (slow) observation | .09872***<br>(.02535) |
| Intercept | -.21521<br>(.12537) |

Note: A * indicates significance at the 0.10 level, ** at the 0.05 level and *** at the 0.01 level.

All the coefficients are statistically significant at the 95 percent level or better. The prevalence of skirts is higher on the two interstates and lower for trucks using day cabs—a result consistent with greater use of skirts when traveling long distances at highway speeds.[13] The interpretation of the linear time trend is that the prevalence of

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[12] We used the East Coast No. 2 diesel retail fuel prices according to EIA (2018) for the month in which the observation was taken, as well as the prior two months. Consistent with EIA's methodology, we used the consumer price index to convert the nominal monthly prices to July 2017$/gal before calculating the three-month average.

[13] We also observe that, in our combined data, the proportion of trailers pulled by day cabs on U.S. 50/301 is roughly double as compared to the proportion for trucks observed on the two interstates (18.89% on U.S. 50/301 vs. 9.98% on I-95 and I-81). This difference is statistically significant (t=6.0889, p < .0001). This is consistent with the intuition that firms are more likely to employ day cabs on shorter, regional routes.

skirts increases by roughly 7 to 8 percent annually. The prevalence of skirts is also higher for our slow data set taken at rest areas on the two interstates—a result that we believe reflects the fact that long haul truckers are more likely to pull into a rest stop. Finally, a $1 increase in real diesel prices is associated with an 8 percent increase in the prevalence of skirts.[14] We conducted several sensitivity analyses, including modeling the time trend as a linear monthly time trend and using forecasts of future diesel prices, but did not identify any alternative specifications that were meaningfully different from the base model presented here.

## 3.3. Modeling Use of Energy-Saving Technologies on Trailers

We now turn to an analysis of the use of energy efficiency devices on trailers using our detailed observations from trucks parked at rest areas on I-81 and I-95. We think of the use of devices as a relatively short-run decision by firms, made to economize on fuel costs, in the context of the more permanent characteristics of the firm (such as whether the firm drives regular long distance routes or commonly carries the same type of freight), 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 firm headquarters to California, and regulatory infractions relating to hours of service and vehicle maintenance. We use a dummy variable for firms on the West Coast, defined to include California, Arizona, and Oregon, as well as Utah, since CARB has mandated the 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). Faster speeds or more intense usage would be expected to yield improved annual fuel savings and thus increase returns to investments in energy efficiency devices. We expect fleet size to reflect the availability of information—larger fleets generate more information, facilitating evaluation by managers of the in-use effectiveness of aerodynamic devices.

Boyd and Curtis (2014) suggest that poor management affects the energy efficiency of a firm. As a proxy for management quality, we use data from the US Department of Transportation (USDOT) FMCSA database about noncompliance with federal

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[14] Conventional theory would suggest that investment in skirts rises with improvements in the expected returns on such investments. We lack data on investments in skirts, either within companies or across the industry. We therefore estimate here the association of the stock of skirts and fuel prices.

requirements for hours of service and vehicle maintenance. This database provides a measure of each registered trucking firm's compliance with these federal requirements, the median firm's compliance measure, 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 thresholds and multiplying by 100.[15] We interpret this index of noncompliance to reflect the severity of management challenges facing the firm, stemming from either poor management per se or other challenges such as the wide range of tasks demanding attention.

A threshold question is the unit of analysis in our data. We have relatively few instances of multiple trucks per firm. Specifically, for our regressions, we have observations on 380 firms, irrespective of whether the same firm was observed across multiple years. In part because we had some firms with more than one truck in our sample, we have a total of 334 unique firms (i.e., we observe 334 distinct USDOT registration numbers on the tractors in our sample). Since many of our key variables are specific to the firm and to the year in which the firm was observed, we chose not to use individual truck observations as the unit of analysis and instead to concentrate on the firm-year level observations. For these models, we use as dependent variables the probability of the presence of energy efficiency devices. We focus on an independent variable, differences in ownership, which has values in the interval [0, 1].[16]

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 the other variables are self-explanatory. Table 4 also presents alternative specifications of the model.

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[15] NAS (2017) reports that FMCSA and other studies showed that hours of service and vehicle maintenance scores—along with the unsafe driving score—were highly correlated with future crash frequency. FMCSA and industry consultants urge that the prospect of future crashes—with possible injuries and fatalities, costs of repair and replacement of equipment, damaged reputation and loss of business, and liability claims in court—deserve careful management attention (FMCSA, 2014).

[16] Only 4% of firm-years in our regression samples did not take on a value of either 0 or 1 in their adoption of skirts (or lack thereof) across all trucks. 3.7% of firm-years in the ATI sample did not take on a value of either 0 or 1.

EPA and NHTSA (2016) and Allcott and Greenstone (2012) suggest that incentives for adoption of energy efficiency devices will be lower where there is a split incentive such as occurs with different ownership between the tractor and the trailer. We interpret this hypothesis as one of the more important of the several possible sources of market failures identified by EPA (81 FR 73860). To test it, we construct a variable reflecting whether the owner of a trailer differs from the owner of the tractor pulling it, averaged at the firm-year level, based on markings visible on the vehicles. Unambiguously different ownership accounted for an average of 6.7 percent of trucks in a fleet in our sample, and tractor-trailer combinations where ownership was ambiguous accounted for an additional 23.5 percent of the sample.

We present in Table 4 regressions where the unit of observation is the fleet in a given year and the dependent variable is the probability that a truck we observed in the fleet has a skirt or underbody device. 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 the owner of a truck we observed in the fleet was 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 number of trucks in the fleet) and a proxy for marginal firms, as well as location of headquarters. Specifically, in model 1, we use a simple ordinary least squares 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. Dummy variables for trucking companies with headquarters in Canada and on the West Coast are also statistically significant. An index of noncompliance with federal hours of service and vehicle maintenance requirements and a dummy variable for trucks using day cabs are statistically significant and operate to reduce the prevalence of skirts. Finally, the model includes dummy variables for unambiguously different ownership and for ambiguous ownership between the tractor and trailer, averaged at the firm-year level. Coefficients for these variables are not statistically significant.

Other models give similar results. As a sensitivity analysis, we considered alternative models (2 and 3). Unambiguously different and ambiguous ownership variables were not statistically significantly associated with the prevalence of skirt use in any of our model specifications. In model 2, we experimented with alternative cutoffs for fleet size, and the dummy variable for large firm size indicated a greater prevalence (statistically significant) of skirt use for large firms.[17] As hypothesized earlier, larger

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[17] Firms with less than 20 trucks were classified as owner-operators or small firms, consistent with the numbers provided by ATA (2018). All firm-years larger than this (with 20 or more trucks) were classified as large firms.

fleet sizes appear to give access to information about effectiveness that helps fleet managers assign vehicles where fuel-efficient technologies would do the most good. In model 3, we use a logit model for the observed presence of a skirt on at least one truck within a fleet but again find that different ownership is not associated with reduced skirt use. We are thus unable to show that different ownership reduces 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, as well as proximity to California, are all associated with the increased prevalence of skirts. Noncompliance with federal regulations is statistically significant and associated with a reduced level of skirt use. Finally, a difference in ownership between tractor and trailer is not associated with reduced skirt use.[18]

We also carried out a similar regression analysis in examining the use of automatic tire inflation systems and present the results in models 4, 5, and 6 in Table 4. We obtained similar results for miles per truck and fleet size and the day cab dummy variable. However, the noncompliance variable and the dummy variable for West Coast location were not statistically significant. The coefficient for the Canada dummy was positive and statistically significant, indicating a lower prevalence of ATI systems used for Canadian trucks. Finally, differences in ownership between tractor and trailer do not appear to affect ATI use.[19]

Our results support the finding of Klemick et al. (2015) that heterogeneity across trucking firms likely results in different rates and levels of adoption of fuel-saving devices. We find a reduced use of skirts on trailers pulled by day cabs that are more likely to be used in short hauls; an increased use of skirts on refrigerated trailers that are more likely used on long hauls, and higher incidence of skirts and ATI used by larger fleets with access to more data on the effectiveness of fuel-saving devices on trailers.

In their Phase 2 rule, EPA and NHTSA (2016) suggest the hypothesis that differences in ownership and incentives between the tractor owners (trucking firms) and the

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[18] In Appendix B.4, we report regression results for a composite energy “inefficiency” index constructed following EPA’s regulatory construct to assess compliance with its 2016 rule. Average miles per truck, fleet size, noncompliance with FMCSA regulations, proximity of headquarters to California, and the dummy variable for day cabs all have strong statistically significant effects similar to the results for skirt use. The effect of different ownership on this index for energy-saving technology is not statistically significant.

[19] While we do not formally model the adoption of wide base tires, we observe a positive and statistically significant correlation between the use of wide base tires and ATI systems in our truck-level data (r=.255, p<.0001).

trailer owners (shippers) represent one of the more important possible sources of market failure leading to inadequate use of energy efficiency devices (81 FR 73860). With different ownership, 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 Vernon and Meier report that their review of contracts "revealed no allowances (or even mention) of fuel efficiency" (2012, 271), we find no evidence that differing ownership matters for adoption or prevalence of energy efficiency devices. However, a different and much larger sample might affect this result.

Finally, Klemick et al. (2015) report that there is some evidence of split incentives between owners and drivers. While we do not have any empirical data to examine this issue in the context of trailers, there are some specific choices in the selection of trailer technologies that may reflect the effect of a split incentive issue between owners and drivers. First, the maintenance of adequate tire pressure is important for both fuel efficiency and safety. The decision of owners to install ATI devices helps to assure the maintenance of adequate tire pressure without requiring intervention by the driver. Second, most current designs of tail fairings require the driver to deploy the tail, although some models deploy automatically at higher speeds (Sharpe and Roeth, 2014). NACFE (2018d) reports that "fleets were uniform in stating that the devices should 'require no driver intervention.'" One fleet owner said, "Any statement that starts with 'All the driver has to do is…' should be questioned." In its 2017 annual report, NACFE (2017) reported that some fleets are no longer buying these trailer tails because of issues with driver use and damage.

Table 4. Firm-Year Level Models of Presence of Aerodynamic Devices, Slow Data

| Variable group | Variable name | Presence of Skirts/Underbodies | | | Presence of Automatic Tire Inflation Systems | | |
|---|---|---|---|---|---|---|---|
| | | Model 1: OLS | Model 2: OLS | Model 3: Logit | Model 4: OLS | Model 5: OLS | Model 6: Logit |
| Firm characteristics | Miles per truck (1,000 miles) | .00144**<br>(.00060) | .00156***<br>(.00059) | .00772**<br>(.00320) | .00152***<br>(.00056) | .00153**<br>(.00060) | .00839***<br>(.00314) |
| | Natural log of the trucks in the fleet | .05736***<br>(.01008) | — | .33196***<br>(.06342) | .03561***<br>(.01049) | — | .21649***<br>(.05753) |
| | Noncompliance with FMCSA requirements | -.00028*<br>(.00015) | -.00040**<br>(.00015) | -.00190<br>(.00134) | -.00013<br>(.00012) | -.00013<br>(.00011) | -.00060<br>(.00077) |
| | Large Firm (More than 20 trucks) | — | .19069***<br>(.06138) | — | — | .22188***<br>(.05588) | — |
| | West Coast | .33895***<br>(.10587) | .35067***<br>(.10936) | 2.20322***<br>(.67975) | -.08989<br>(.096204) | -.05905<br>(.09643) | -.38684<br>(.64094) |
| | Canada | .14307<br>(.09036) | .11916<br>(.09001) | .73983<br>(.45823) | -.22611***<br>(.08449) | -.22894***<br>(.08195) | -1.12891*<br>(.59940) |
| Vehicle characteristics | Day cab | -.43285***<br>(.06939) | -.40432***<br>(.06460) | -2.95793***<br>(.74449) | -.24872***<br>(.07666) | -.25834***<br>(.07461) | -1.56472**<br>(.61113) |
| | Refrigerated trailer | .12718**<br>(.05002) | — | — | .15815***<br>(.05393) | — | — |
| Ownership effects (reference: same ownership) | Unambiguously different ownership | -.00137<br>(.10799) | — | -.01854<br>(.56317) | .13245<br>(.10453) | — | .61093<br>(.46384) |
| | Ambiguous ownership | -.09152<br>(.06344) | — | -.43573<br>(.35669) | -.00459<br>(.05930) | — | .06140<br>(.33611) |
| | Different and Ambiguous Combined | — | -.09742<br>(.06378) | — | — | .05905<br>(.05717) | — |
| Year effects (reference: 2015) | Year: 2016 | .04207<br>(.05797) | .03226<br>(.06155) | .34160<br>(.32403) | .05991<br>(.06168) | .05689<br>(.06238) | .40288<br>(.34379) |
| | Year: 2017 | .13228**<br>(.06278) | .11293*<br>(.06681) | .77325**<br>(.35778) | .12817**<br>(.06339) | .12383*<br>(.06513) | .73172**<br>(.35370) |
| Other | Intercept | .01875<br>(.09775) | .20660**<br>(.09755) | -2.39646***<br>(.62662) | -.03483<br>(.08730) | .01573<br>(.08776) | -2.60777***<br>(.56971) |
| | N | 375 | 380 | 380 | 371 | 376 | 376 |
| | R2 (Pseudo R2 for logit) | .2473 | .2054 | .2204 | .1287 | .1144 | .1029 |

Note: A * indicates significance at the 0.10 level, ** at the 0.05 level and *** at the 0.01 level.

## 3.4. Use of Low Rolling Resistance Tires

We also collected data on the use of low rolling resistance tires for our 477 individual truck observations from the detailed slow data set. On each trailer, we observed only two of eight tires—the outboard tires visible on one side of the vehicle. LRR tires certified for trailers constitute roughly 40 percent of all observations and represent the most commonly observed tire combination.[20] As shown in Table 5, however, many of the trailers were using SmartWay LRR tires certified for the steer position on the tractor, but not for the trailer. When broken down by use of LRR-certified trailer tires, 166 trucks were not using LRR trailer-certified tires, 124 used only one LRR trailer-certified tire out of the two tires observed, and 187 were observed to have both tires as LRR trailer-certified.[21] These results are somewhat surprising because new LRR tractor tires have a higher rolling resistance than a conventional trailer tire. New LRR drive and steer tires have a rolling resistance of 6.6 and 6.5 kg/ton, respectively; the rolling resistance of a conventional bias ply trailer tire is 6.0 kg/ton, and the rolling resistance of an LRR trailer tire is 5.1 kg/ton (EPA, 2012).

The occurrence of LRR tractor tires on trailers has implications for compliance. The EPA and NHTSA final rule requires the maintenance of pollution control devices on trailers where the devices were part of the original certification ensuring trailer compliance with the trailer LRR tire provisions (81 FR 73673). Modifications during the useful life are allowed only where the owner clearly has a reasonable technical basis for knowing the modifications will not cause the vehicle to exceed any applicable standard. This requirement would seem to preclude placement—if the trailer requirements go into effect—of LRR tractor tires on the trailer axles.

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[20] Some tires were certified as low rolling resistance tires for more than one position. For example, Yokohama RY587s are extremely common tires in the dataset but are certified as LRR for all tire positions. Therefore, they were double counted in certain categories. To account for this, we used the following rule: if a tire was certified as LRR for trailer, it was counted as LRR for trailer even if it was also certified as LRR for other positions. In addition, some types of tractor tires are certified for both steer and drive positions; we classified these as steer tires.

[21] Of the 187 trucks with two LRR trailer-certified tires, 26 (~14%) used wide-base tires. Note that 49 observations out of the 477 total are missing LRR information for one or both of the tires.

## Table 5. Tire Combinations Observed on Trailers, Based on Vehicle-Level Observations (N = 477)

| Tires observed | Count | Proportion |
|---|---|---|
| 2 LRR steer tires | 29 | .0608 |
| 1 LRR steer tire, 1 conventional tire | 28 | .0587 |
| 2 conventional trailer tires | 43 | .0901 |
| 1 LRR steer tire, 1 LRR trailer tire | 47 | .0985 |
| 1 LRR trailer tire, 1 conventional tire | 45 | .0944 |
| 2 LRR trailer tires | 187 | .3920 |
| 2 LRR drive tires | 10 | .0210 |
| 1 LRR drive tire, 1 other tire | 39 | .0818 |
| Missing data (either tire) | 49 | .1027 |

Note: Each category is mutually exclusive. Tires that were certified for more than one position were counted as a trailer tire if they were certified for that position.

In the final rule, EPA and NHTSA stated that they "believe that the favorable fuel consumption benefit of continued use of LRR tires would generally result in proper replacements throughout the 10-year useful life" (81 FR 73672). However, trucking companies may be eking out the last miles from their tractor tires by moving them to the trailer axles after they are too badly worn to use as steer or drive tires.[22] In addition, there may also be other operational and management costs that outweigh the energy-saving potential of ensuring that only LRR trailer tires are placed on the trailer axles. As a result, the observed prevalence of LRR tractor tires in Table 5 calls into question the presumption by EPA and NHTSA in the final rule that trailer owners will ensure that tires on the trailer axles will not cause the vehicle to exceed trailer standards.

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[22] The minimum tread depth is 4/32 inch for steer tires and 2/32 inch for any other wheel position (49 CFR 393.75). A senior executive at one trucking company told us that it was routine practice to shift tractor tires to the trailer axles to obtain full use of the tires.

# 4. Conclusions and Policy Implications

Our analysis of the use of energy-saving equipment on heavy-duty truck trailers suggests truckers seek to reduce costs in a manner consistent with the expected behavior of firms in competitive markets. Thus, such equipment is more commonly observed on routes where it is expected to offer greater net benefits. Further, its use increases with fleet size and the intensity of use of trucks in a fleet. In addition, the use of skirts decreases with measures of noncompliance with federal regulatory requirements—a proxy for relatively weak management or marginal economic performance—a finding that suggests that quality of firm management may be an important factor in use of energy-efficient equipment. We find no evidence that differences in ownership between the trailer and the tractor reduce the use of energy-efficient equipment, even though such effects represent one of the sources of market failure hypothesized by EPA and NHTSA.

More generally, our results suggest that regulatory agencies' claims of large private benefits from requirements to adopt such energy-efficient technology should be subjected to special scrutiny. A substantial and growing number of trailers are using skirts and ATI devices, consistent with cost-reducing behavior. On the other hand, our results suggest that only a few trucks are using tails. Further, truckers are using LRR tractor tires on the trailer axles. Such behavior is contrary to projections by the regulatory agencies and suggests that fuel efficiency gains are smaller than projected or that costs are higher than expected for tails and LRR trailer tires, or both. Thus, the cost-effectiveness of these measures deserves further analysis.

We recommend that EPA and NHTSA collect and analyze data regarding the actual effectiveness of energy-saving equipment during commercial operations—echoing a recommendation of the National Academy of Sciences. Publicly available information about the effectiveness of most energy-saving technologies used on heavy-duty trucks comes from performance testing in controlled settings, not during commercial operations. The regulatory agencies could help inform trucking firms about the private benefits of such technologies in commercial use by funding a study using random assignment to assess fuel efficiency of trailers with and without these energy-saving devices. Random assignment, coupled with GPS devices that record location, speed, and elevation, is likely a cost-effective way to assess effectiveness of such equipment in commercial use. Since many medium to large fleets already use GPS and other electronic equipment to monitor their truck operations, EPA and NHTSA should find a way to team up with some of these fleets to study the in-use effectiveness of these technologies. Publication of the resulting study—properly anonymizing the participants—could serve as a public resource on the effectiveness of these technologies. Trucking firms would benefit from such information, and we believe the agencies have an obligation to assess in-use effectiveness before issuing rules mandating adoption of these technologies.

Finally, we recommend that EPA and NHTSA review much more carefully the empirical basis for claims of market failures in competitive markets and that they conclude such review before using estimates of large net economic gains in rulemakings. Our analysis illustrates that testing claims of market failure may be relatively inexpensive.[23] 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 one exists.

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[23] Allocating a fraction of the cost of a typical EPA regulatory impact analysis to such a project should enable collection of a sample many times larger, and with greater power, than the one analyzed here.

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# Appendix A: Programs to Reduce Energy Use for Heavy-Duty Trucks

EPA launched the SmartWay program in 2004 to facilitate the adoption of technologies to reduce energy use by heavy-duty trucks within the nation's trucking fleet. Among other activities, the program verifies the performance of vehicles, technologies, and equipment that have the potential to reduce greenhouse gases and other air pollutants from freight transport (EPA, n.d.). Fleet managers can combine equipment to meet the total fuel savings threshold required to qualify trailers in their fleet as EPA-designated SmartWay trailers. For example, the SmartWay trailer threshold of at least 6 percent fuel savings could be met by combining LRR tires with a 1 percent fuel saving and an aerodynamic device achieving a 5 percent saving.

In 2008, California adopted regulations requiring improvements in the energy efficiency of heavy-duty tractors and trailers (CARB, 2014). By January 1, 2010, The regulations required that new MY 2011 and later 53-foot or longer box-type dry van and refrigerated trailers 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. The California rule also requires that MY 2010 and older 53-foot box-type trailers meet the aerodynamic device requirements established for MY 2011 and later trailers by January 1, 2013, and that they have SmartWay LRR tires by January 1, 2017. California provided a delayed compliance schedule for refrigerated vans (varying by model year), optional phase-in plans for dry vans (with different schedules for small and large fleets), and a local haul exemption for aero devices for trailers operated within 100 miles of their local base.

In 2011, EPA and NHTSA issued the Phase 1 rule to limit GHG emissions and fuel consumption for heavy-duty vehicles—combination tractors, heavy-duty pickups and vans, and vocational vehicles (76 FR 57106). 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 beginning in 2016 and thereafter.[24] The agencies did not establish

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[24] Class 7 and 8 trucks account for roughly two-thirds of the GHG emissions and fuel consumption from the heavy-duty vehicle transportation sector. The Phase 1 rule adopted engine standards based on technologically available improvements in engine efficiency and separate tractor standards based on a combination of aerodynamic devices, LRR tires, weight reduction, and automatic engine shutdown and speed limiter devices.

standards for trailers because of the lack of a suitable test procedure as well as other outstanding policy and technical issues (80 FR 40253).

In 2016, EPA and NHTSA established more stringent standards for tractors in their Phase 2 rule and for the first time also set standards for trailers. The Phase 2 rule identifies several different subcategories of box van trailers with standards varying in stringency and differing phase-in schedules over 2018-2027 (81 FR 73478). The final rule requires eight subcategories—long and short box dry and refrigerated vans (and similar "partial aero" vans that cannot use aero devices at one location because of specialized features)—to achieve $CO_2$ emissions reductions and fuel savings based on the use of aerodynamic devices, LRR tires, and tire pressure systems.[25] The agencies projected that these final standards for box and refrigerator vans would yield fuel consumption and $CO_2$ emissions reductions of 2 to 9 percent (81 FR 73648). For other on-road trailers, including tank, flatbed, and container chassis trailers, EPA and NHTSA set final design standards requiring LRR tires and tire pressure systems (81 FR 73646). On August 17, 2017, EPA announced its decision to revisit the provisions in the Phase 2 rule that relate to trailers (EPA, 2017). On October 27, 2017, the DC Circuit court stayed the emissions reduction requirements for truck trailers, stating that the trailer manufacturers in their brief had "satisfied the stringent requirements for a stay pending court review" (Cama, 2017).

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[25] "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.

# Appendix B: Data

## B.1. Summary Statistics by Interstate Subsamples

Table B.1. Summary Statistics for Variables for Truck-Level Combined Fast and Slow Data, By Route

| Variable | Route | N | Mean | Std. dev. | Min. | Max. |
|---|---|---|---|---|---|---|
| Presence of Skirt/ Underbody | I-81 & I-95 | 3,105 | .342 | .474 | 0 | 1 |
| | US 50/301 | 545 | .272 | .445 | 0 | 1 |
| 3-month diesel price ($) | I-81 & I-95 | 3,105 | 2.978 | .750 | 2.280 | 4.060 |
| | US 50/301 | 545 | 2.611 | .240 | 2.380 | 3.060 |
| Day cab | I-81 & I-95 | 3,105 | .100 | .300 | 0 | 1 |
| | US 50/301 | 545 | .189 | .392 | 0 | 1 |
| Slow survey dummy | I-81 & I-95 | 3,105 | .148 | .355 | 0 | 1 |
| | US 50/301 | 545 | 0 | 0 | 0 | 0 |

## Table B.2. Summary Statistics for Variables for Firm-Year Level Slow Data, By Route

| Category | Variable | Route | N | Mean | Std. dev. | Min. | Max. |
|---|---|---|---|---|---|---|---|
| Aerodynamic Devices (Firm-year average) | Skirts and Underbodies | I-81 | 206 | .417 | .489 | 0 | 1 |
| | | I-95 | 149 | .417 | .492 | 0 | 1 |
| | ATIs | I-81 | 202 | .312 | .459 | 0 | 1 |
| | | I-95 | 149 | .343 | .473 | 0 | 1 |
| Firm Characteristics | Miles Per Truck (1,000 miles) | I-81 | 206 | 91.226 | 39.67 | .101 | 289.485 |
| | | I-95 | 149 | 85.441 | 42.850 | .405 | 222.407 |
| | Trucks in the fleet | I-81 | 206 | 707.670 | 1932.637 | 1 | 17989 |
| | | I-95 | 149 | 670.141 | 2233.103 | 1 | 17814 |
| | Noncompliance with FMCSA | I-81 | 206 | 162.236 | 161.751 | 0 | 931.414 |
| | | I-95 | 149 | 184.080 | 209.139 | 0 | 1359.617 |
| | Fleet Size: Large Firms | I-81 | 206 | .684 | .465 | 0 | 1 |
| | | I-95 | 149 | .570 | .495 | 0 | 1 |
| | West Coast headquarters | I-81 | 206 | .034 | .181 | 0 | 1 |
| | | I-95 | 149 | .081 | .273 | 0 | 1 |
| | Canadian headquarters | I-81 | 206 | .097 | .296 | 0 | 1 |
| | | I-95 | 149 | .034 | .181 | 0 | 1 |
| Vehicle Characteristics (Firm-year average) | Day cab | I-81 | 206 | .039 | .187 | 0 | 1 |
| | | I-95 | 149 | .101 | .302 | 0 | 1 |
| | Refrigerated trailer | I-81 | 201 | .264 | .442 | 0 | 1 |
| | | I-95 | 149 | .450 | .499 | 0 | 1 |
| Ownership (Firm-year average) | Same ownership | I-81 | 206 | .752 | .433 | 0 | 1 |
| | | I-95 | 149 | .602 | .490 | 0 | 1 |
| | Unambiguously different ownership | I-81 | 206 | .053 | .225 | 0 | 1 |
| | | I-95 | 149 | .083 | .274 | 0 | 1 |
| | Ambiguous ownership | I-81 | 206 | .194 | .397 | 0 | 1 |
| | | I-95 | 149 | .315 | .466 | 0 | 1 |

Note: For firm-years where all trucks were observed either on I-81 or I-95, but not both

### Table B.3. Proportion of Trucks with Skirts and Underbodies by Route and Year: Fast Data, Sleeper Cabs Only

| Year | Route | Proportion estimate | 95% C.I. lower bound | 95% C.I. upper bound |
|---|---|---|---|---|
| 2013 | I-81 & I-95 (n = 962) | .2651 | .2372 | .2930 |
|  | US 50/301 (n = 0) | — | — | — |
| 2015 | I-81 & I-95 (n = 135) | .3556 | .2745 | .4367 |
|  | US 50/301 (n = 114) | .2807 | .1976 | .3638 |
| 2016 | I-81 & I-95 (n = 770) | .3455 | .3118 | .3791 |
|  | US 50/301 (n = 178) | .2978 | .2302 | .3653 |
| 2017 | I-81 & I-95 (n = 500) | .47 | .4262 | .5138 |
|  | US 50/301 (n = 150) | .3267 | .2512 | .4022 |

Note: 2013 data from NRC (2014). Data also presented in Figure 1.

## B.2. Variable Descriptions

### B.2.1. Fast Data

We used the following variables in the models of the truck-level, combined fast and slow data. (*Variable names are italicized.*)

*Skirt or Underbody* is the dependent variable. It is a dummy variable that takes the value 1 if an individual tractor trailer in the sample was observed not to have a skirt or underbody device.

*Time Trend* is a linear time trend variable that takes the value of 1 in 2013 and increases by 1 unit for each subsequent year.

*3-Month Diesel Price* is the East Coast No. 2 diesel retail fuel price according to EIA (2018) for the month in which the observation was taken, as well as the prior two months. Consistent with EIA's methodology, we used the consumer price index to convert the nominal monthly prices to July 2017$/gal before calculating the three-month average.

*Interstate* is a dummy for whether a truck was observed on an interstate (I-81 or I-95), as opposed to US 50.

*Day Cab* is a dummy variable that takes the value 1 if an individual tractor trailer was observed to be pulled by a day cab.

*Slow Survey Dummy* is a dummy variable that takes the value 1 if the individual truck was a part of our detailed survey (slow data), as opposed to the fast survey.

### B.2.2. Slow Data

We used the following variables in our models of the firm-year level, slow observations. (Variable names are italicized.)

**Dependent Variables**

*Presence of Skirt/Underbody* is the first dependent variable that we tested. At the vehicle level, it is a binary variable that takes the value 1 if an individual tractor trailer was observed as having either a skirt or underbody device installed. At the firm-year level, this variable is the arithmetic mean of the vehicle level values for all trucks for a firm in a given year.

*Presence of Automatic Tire Inflation System* is the second dependent variable that we tested. At the vehicle level, it is a binary variable that takes the value 1 if an individual tractor trailer was observed as having an automatic tire inflation system installed on its trailer tires. At the firm-year level, this variable is the arithmetic mean of the vehicle level values for all trucks for a firm in a given year.

**Ownership Effects**

Each individual truck in our dataset was sorted into one of 12 ownership categories that we identified. Following this process, we condensed those 12 categories into 3 distinct categories: cases where the tractor and trailer were clearly owned by the same company, cases where the tractor and trailer were clearly owned by separate companies, and cases where the ownership scheme was ambiguous or unclear. Firm-year level averages were then calculated. We also include in Models 2 and 5 an aggregation of the different and ambiguous ownership firm-year level average variables.

**Covariates**

*Miles per Truck* is a continuous measure of the average number of miles driven by the vehicles in a firm-year's fleet. It is calculated by dividing the total mileage driven by the total fleet size as reported by a firm-year on the MCS-150 registration form, which must be filed every two years with the FMCSA.

*Noncompliance Index* is a constructed continuous measure of the degree to which a firm in a given year complies with two FMCSA regulations: the Hours of Service Compliance Measure and the Vehicle Maintenance Measure. We normalize the two variables by dividing them by their threshold for intervention as established by the FMCSA, and then average the two and multiply by 100. Therefore, values greater than 100 indicate relative noncompliance with the two regulations.

*Natural Log of Trucks* is a continuous measure of the natural log of the fleet size for a given firm-year as reported to the FMCSA.

*Firm Size Fixed Effects* are an alternative way of accounting for fleet size. Rather than use a continuous measure such as the natural log of trucks, we broke up the firms into two groups. Firm-years with less than 20 trucks were classified as owner-operators or small firms, consistent with the numbers provided by ATA (2018). All firm-years larger than this (with 20 or more trucks) were classified as large firms.

*Year Fixed Effects* are dummies for each of the three years in which fast data were collected: 2015, 2016, and 2017.

*Day Cab* is a binary variable that takes the value 1 if an individual tractor trailer was observed to be pulled by a day cab. Firm-year level averages of this variable are used as well.

*Refrigerated Trailer* is a dummy variable that takes the value 1 if an individual trailer was observed as a refrigerated trailer. Firm-year level averages of this variable were then calculated.

*West Coast* is a binary variable that takes the value 1 if the home state of the tractor company's headquarters observed is one of four states: California, Oregon, Arizona, or Utah.

*Canada* is a binary variable that takes the value 1 if the tractor company's headquarters are located in a Canadian province.

### B.2.3. Data Sources

All data used in the analysis came from one of five sources:

- our own photographs and notes of observed trucks
- the websites of individual trucking companies

- FMCSA's Safety Measurement System (SMS) online database (https://ai.fmcsa.dot.gov/SMS/)
- EPA's online database of certified low rolling resistance tires (EPA, 2018).
- The 2013 NRC data that we present in Figure 1 is sourced from Annex 6B of the NRC (2014) report. The NRC survey did not follow a preset sampling plan and the accuracy of observations was not verified. Our fast data were collected in a similar fashion (making roadside observations of passing trailers). While NRC observed trailers at ten points across the contiguous United States, we only directly compare our data to the data they collected on I-81 in Pennsylvania and on I-95 in Maryland. We limit our comparison to observations from our fast data that were made on 53 feet dry and refrigerated vans that were pulled by sleeper cabs, as that was the extent of the data collected by NRC.

## B.3. Derivation of EPA's Trailer Inefficiency Index

We also construct an index of trailer energy inefficiency that mimics the measure of trailer energy efficiency used to assess compliance by trailer manufacturers to the 2016 final rule. Specifically, the final rule (81 FR 73666) states,

$$e_{CO_2} = [C_1 + C_2 \cdot (TRRL) + C_3 \cdot (\Delta C_d A) + C_4 \cdot (WR)] \cdot C_5 \qquad \text{(IV-1)}$$

EPA's Equation IV-1 is for carbon dioxide emissions per ton-mile, but these are proportional to fuel consumption and fuel costs per ton-mile under conventional assumptions. EPA describes this equation for carbon dioxide emissions in grams per ton-mile as follows:

Equation IV-1 is a single linear regression curve that can be used for all box vans in these rules to calculate $CO_2$ emissions, $eCO_2$. Unique constant values, C1 through C4, are applied for each of the van types as shown in Table IV-24. Constant C5 is equal to 0.988 for any trailer that installs an ATIS (accounting for the 1.2 percent reduction given for use of ATI), 0.990 for any trailer that installs a TPMS, or 1.0 for trailers without tire pressure systems. We found that this equation accurately reproduces the results of [EPA's emissions model] GEM for each of the box van subcategories, and the program requires these trailer manufacturers use Equation IV-1 to calculate $CO_2$ for compliance. Manufacturers insert their tire rolling resistance level (TRRL), wind-averaged change in drag area ($\Delta C_d A$), weight reduction value (WR) (if applicable), and the appropriate C5 value if a tire pressure system is installed into the equation and submit the result to EPA. (81 FR 73666)

The units of EPA’s Equation IV-1 are kg/ton for TRRL, meters squared for $\Delta C_d A$, and pounds for WR. Our approach neglects any technologies specifically intended to reduce weight (WR), since the use of such technologies on trailers is not observable. We note that EPA credits only one-third of any weight reduction to fuel efficiency gains; the rest is presumed absorbed by increased cargo (EPA and NHTSA 2016, 2-242). For long dry trailers and long refrigerated trailers, which are both included in our sample, we present EPA’s values in Table B.4.

## Table B.4. EPA’s Values for Estimating CO2 Emissions from Trailers (81 FR 73666)

| Trailer type | EPA’s values for constants for trailer compliance equation | | | | | | |
|---|---|---|---|---|---|---|---|
| | C1 | C2 | C3 | C4 | C5 (tire pressure) | | |
| | | | | | None | Monitoring | Inflation |
| Long dry van | 76.1 | 1.67 | –5.82 | –.00103 | 1.00 | 0.990 | 0.988 |
| Long refrigerated van | 77.4 | 1.75 | –5.78 | –.00103 | | | |

There is substantial uncertainty in these estimates, although EPA has not characterized it. In the modeling presented in the regulatory impact analysis (RIA), EPA does not present standard errors associated with the constants $C_2$, $C_3$, and $C_4$. There is additional uncertainty regarding the baseline. For example, regarding tire monitoring and inflation systems, EPA writes, “Tire inflation systems could provide a $CO_2$ and fuel consumption savings of 0.5–2.0 percent, depending on the degree of under-inflation in the trailer system” (EPA and NHTSA 2016, 2-239). Finally, for reductions in trailer weight, there is uncertainty about how much of this increases paid cargo versus fuel efficiency. EPA provides little empirical basis for how much increased payload lighter trailers may carry. Using Equation IV-1 in our study requires values for the relevant variables for trailers we observed. Table B.5 summarizes the values we used.

## Table B.5. Parameter Values Used to Construct an Index of Trailer Energy Inefficiency

| Energy-saving device | Parameter | Value without (baseline) | Value with (baseline) | Source/comment |
|---|---|---|---|---|
| Low rolling resistant tires | TRRL | 6.0 | 5.1 | RIA (2-238). EPA's SmartWay program certifies that wide tires are also 5.1 kg/ton. |
| Skirt | ΔCdA | 0.0 | 0.57 | The RIA (2-228–2-229) gives a range from 0.54 to 0.6. |
| Underbody device | | | 0.57 | Pending |
| Ducktail (deployed) | | | 0.5 | The RIA, pp. 2-228–2-229, gives values between 0.45 and 0.56. |
| Skirts and ducktails | | | 1.2 | The RIA (2-228–2-229) gives values of 1.13 to 1.28. |
| Automatic tire inflation system | ATIS | 1.0 | 0.988 | RIA (2-264). Note that unobservable tire monitoring systems would have values of 0.990. |
| Not applicable | Weight reduction (WR) | Not applicable | | We could not observe weight reduction technologies from the exterior of trailers. |

In Table B.6, we take the parameter values used by EPA in Tables B.4 and B.5 and construct the implied values of $e_{CO2}$ given these assumptions for selected trailers in our data set. Our approach credits the most fuel-efficient trailers with carbon emissions (and implicitly, fuel consumption) that are 5.6 percent less than those of a conventional trailer. Additional savings would come from weight reduction technologies, which are unobservable in our data.

### Table B.6. Projected Energy Efficiencies (g $CO_2$/ton-mile) for Selected Dry Van Trailers

| Energy-saving device | Trailer 1 | Trailer 2 | Trailer 3 | Trailer 4 | Trailer 5 |
|---|---|---|---|---|---|
| Tires | Conventional (6.0) | LRR (5.1) | Conventional (6.0) | LRR (5.1) | LRR (5.1) |
| Skirt | None (0.0) | None (0.0) | Skirts (0.57) | None (0.0) | Both skirts and ducktail (1.2) |
| Underbody device | | | | | |
| Ducktail (deployed) | | | | | |
| Both skirts and ducktails | | | | | |
| Automatic tire inflation system | None (1.0) | None (1.0) | None (1.0) | ATIS (0.988) | ATIS (0.988) |
| Estimated CO2 emissions (eCO2) | 86.12 | 84.62 | 82.80 | 83.60 | 76.70 |

## B.4. Regression Results for the Inefficiency Index

Firms select skirts to promote fuel efficiency, but they also can choose other aerodynamic devices such as ducktails, LRR tires, and ATI systems to improve energy efficiency. To evaluate this group of decisions, we reconstructed the regression models used to evaluate the use of skirts and ATI systems in Table 4 and altered the response variable to the firm-year level average of the values we calculated for our inefficiency index. Our constructed index has a mean value of 83.962 g $CO_2$/ton-mile (sd = 2.474), with a minimum of 76.7 and maximum of 87.9. Using these regression models to examine the effect of different ownership on the energy inefficiency index, we obtain results that are similar to the results for skirt use (shown in Table B.7). Average miles per truck, the log of trucks in the fleet, noncompliance with FMCSA regulations, proximity of headquarters to California, and the dummy variable for day cabs all have strongly statistically significant effects.[26] The effect of different ownership on this index for energy-saving technology on the trailer is not statistically significant.

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[26] Note that the signs for these regressions are opposite to the signs of the analogous variables in Table 4. This is because the inefficiency index rises for firms that use fewer energy efficiency devices. However, the coefficient on the refrigerated trailer variable is positive in both tables. Refrigerated trailers weigh more than dry van trailers, so this variable has a positive effect on the inefficiency index, where higher levels indicate greater carbon dioxide emissions per ton-mile. The greater weight overwhelms the positive effect of the use of skirts and ATI devices.

## Table B.7. Firm-Year Level Models of EPA's Trailer Inefficiency Index, Slow Data

| Variable group | Variable Name | | Model 2 (OLS) |
|---|---|---|---|
| Firm characteristics | Miles per truck (1,000 miles) | –.00992***<br>(.00279) | –.00958***<br>(.00296) |
| | Natural log of the trucks in the fleet | –.25223***<br>(.04984) | — |
| | Noncompliance with FMCSA requirements | .00196***<br>(.00064) | .00278***<br>(.00063) |
| | Large Firm (More than 20 trucks) | — | –1.26879***<br>(.30570) |
| | West Coast | –.97842**<br>(.47267) | –1.01175**<br>(.48320) |
| | Canada | –.13404<br>(.49381) | .00631<br>(.48536) |
| Vehicle characteristics | Day cab | 2.25003***<br>(.34678) | 1.90458***<br>(.34985) |
| | Refrigerated trailer | .95332***<br>(.25991) | — |
| Ownership effects (reference: same ownership) | Unambiguously different ownership | .05389<br>(.48642) | — |
| | Ambiguous ownership | .38369<br>(.31812) | — |
| | Different and Ambiguous Combined | — | .33874<br>(.31068) |
| Year effects (reference: 2015) | Year: 2016 | –.15123<br>(.31118) | .03363<br>(.32105) |
| | Year: 2017 | –.50146<br>(.34596) | –.31638<br>(.35224) |
| Other | Intercept | 85.33085***<br>(.48436) | 85.09533***<br>(.46888) |
| | N | 370 | 370 |
| | R2 | .2839 | .2423 |

Note: A * indicates significance at the 0.10 level, ** at the 0.05 level and *** at the 0.01 level.