# Trucks without Bailouts: Equilibrium Product Characteristics for Commercial Vehicles[†]

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*The entry and exit of products, rather than firms, serve as the main equilibrating force in many markets, so accurately predicting changes from a merger or bankruptcy should incorporate this behavior. This paper estimates a structural model of the US commercial vehicle market and demonstrates the importance of allowing for endogenous product offerings in the context of the $85 billion automotive industry bailout in 2009. Under alternate policies that facilitate an acquisition or liquidation of GM and Chrysler, product entry and exit moderate markup increases and output decreases by up to three-quarters. (JEL D22, G33, G34, H81, L13, L62)*

Many economically important industries are characterized by a stable set of firms but a rapidly changing set of product offerings. For example, in the US automotive market, there has been essentially no entry in over three decades.[1] Outside of autos are many other examples, from aircraft to wrist watches.[2] In these cases, the entry and exit of individual product models, not the Schumpeterian (Schumpeter 1942) creation and destruction of firms, are the main forces driving markets into equilibrium. Yet despite rich literature demonstrating the importance of accounting for entry and exit behavior (Borenstein 1989; Bresnahan and Reiss 1991) as well as the heterogeneous nature of products and their buyers (Berry, Levinsohn, and Pakes 1995), there is little work at their intersection.

Since entry and exit tend to work in the *opposite direction* of the price mechanism, failing to account for them can overstate the impact to prices and purchases

of a change in market structure. To illustrate, consider the acquisition or bankruptcy of a firm in oligopoly. Other things equal, this event increases the market power of surviving firms, who raise markups and earn higher profits. However, the prospect of high profits lures entrants. Even if startup costs are large enough to prohibit *firm-level entry*, the cost of introducing new products for incumbents may be small enough to permit *model-level entry*. Product introductions enable consumers to more easily substitute after the merger or bankruptcy, and as a result prices fall. Alternatively, these market structure changes will increase cannibalization amongst the product offerings of surviving firms, which can induce *model-level exit* as well.[3] Thus, counterfactuals assessing what would happen following a market structure change depend on accurately determining where and to what extent model-level entry and exit will occur.[4]

I study the impact of accounting for model-level entry and exit decisions on policy choice, with an emphasis on subsidization and antitrust. This requires developing a tractable model of equilibrium product offerings that allows me to recover the sunk cost of product entry and exit decisions and to compute counterfactuals. Using these methods, I illustrate the importance of accounting for this behavior in the context of the $85 billion government bailout of the US automotive industry in late 2008 and early 2009.[5] This was a contentious decision that even became a presidential campaign issue.[6] For tractability, I narrow the scope of my assessment to the commercial vehicle segment of the auto industry. Using an original dataset of all product offerings between 1987 and 2012, I can ask, "What would have happened to output and prices had the government not rescued the automakers?" The alternative policies to explore include liquidation, i.e., an effective removal of the GM and Chrysler brands and products from the marketplace, as well as an acquisition by one of the existing rival firms in the market. Thus, the results are applicable not just to "bailouts" but to antitrust policy as well.

The commercial vehicle market is an ideal place to study this phenomenon. No firms have entered or exited in three decades but product offerings have changed frequently.[7] Ownership is concentrated among about ten firms, and it is especially so in subsegments of the market, even though most firms have produced most product types at some point in recent history. Furthermore, the highly modular production of commercial vehicles allows manufacturers to quickly swap parts and introduce new

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[3]For example, consider an acquisition where the pre-merger entities competed in various segments of the market. Directly following the acquisition, the post-merger entity will have offerings whose product characteristics are very similar, or even identical, to one another. Since these offerings cannibalize each other, individually they contribute little to profits. If that contribution is now less than the value of selling off the capital associated with their production, the post-merger entity will find it profitable to retire them (even when the pre-merger entities did not). In the paragraph citing this footnote, I emphasize product entry over exit because the former dominates in this paper. See Fan and Yang (2016) for recent evidence of a case where the latter dominates.

[4]This point extends beyond merger policy (Nevo 2000) to, for example, trade (Goldberg 1995), environmental (Newell, Jaffe, and Stavins 1999), and many other regulatory areas.

[5]Chris Isidore, "Bush Announces Auto Rescue," *CNNMoney,* December 19, 2008.

[6]See, e.g., Mitt Romney, "Let Detroit Go Bankrupt," *New York Times,* November 18, 2008; and Jedd Rosche, "Obama Quotes Romney's Auto Bailout Op-Ed in UAW Speech," *Politico,* February 28, 2012.

[7]In the passenger segment, the most recent entrants are Hyundai and Kia, who began selling in 1986 (Kia began by rebadging its exports and did not legally incorporate a standalone US brand until 1992). As noted above, this ignores Tesla, which as of this paper's writing is very small. In the commercial segment, the most recent were Hino and UD in 1984 and 1985, respectively, although Hyundai exported a small number of vehicles between 2000 and 2001 under the Bering badge before being absorbed into Daimler.

models, often within months of changing demand or competitive conditions. This creates a tight link between the incentives to adjust products and the actual adjustment decisions. Finally, their physical weight, tariff structure, and legal standing isolate commercial vehicles from the passenger vehicle market and foreign automotive markets.

The model of the industry features buyers with heterogeneous preferences over characteristics. For example, urban buyers travel on congested roads and thus prefer short and maneuverable vehicles while long-distance freight carriers prefer large and rugged ones. Each year, sellers play a two-stage game: first, they choose what products to offer, and second, conditional on those offerings, choose what prices to charge. They face marginal costs of production as well as sunk costs (or scrap values) for introducing (or retiring) products. Thus, product entry and exit decisions weigh changes in sunk costs against changes in second-stage profits. Although a large literature in industrial organization addresses the estimation of the "second-stage" problem, there is only sparse work on estimating sunk costs in differentiated product markets, especially over a panel. In this paper, I use exogenous demand shifts (macroeconomic variation across industries as well as law changes that affect buyer preferences in an observable way) to vary the profits that firms expect to receive from offering different product types at different times in the panel. Intuitively, a macroeconomic shock that increases the number of prospective buyers in one industry, holding other industries fixed, shifts out the demand for only the subset of products preferred by that industry. The magnitude of the response, i.e., the number of new offerings, is determined by the size of the sunk costs. Conditional on the size of the shock, for example, systematically seeing two new products offered in the data implies lower and higher sunk costs than seeing one or three, respectively. Since multiplicity is the rule rather than the exception in positioning games, I rely only on the necessary conditions for Nash equilibrium, and these provide inequalities which identify *bounds* on the sunk cost parameters (Tamer 2003; Pakes et al. 2015).

I find that product entry and exit have a dramatic impact on prices and purchases. Under an alternative policy that facilitated an acquisition, the effects depend on the identity of the acquiring firm. When the acquiring firm is Ford, whose products closely overlapped with GM's and Chrysler's offerings, markups on the most affected products rise by nearly 65 percent when entry and exit are ignored but only 17 percent when they are accounted for, a decrease of roughly three-quarters. With or without entry and exit, though, these markup increases are concentrated in subsegments of the market, leaving the majority of buyers and product types unaffected. Total output is also affected. When the acquiring firm's products do not resemble GM's and Chrysler's offerings, entry and exit have much less of an effect. In the event of a liquidation, i.e., that GM and Chrysler brands and products are eliminated from the market, markups rise by as much as 27 percent when product entry and exit are ignored but only 6 percent when they are accounted for. The impact on output is even more severe. Ignoring product entry and exit, it falls over 11 percent for the market as a whole, but accounting for them, it falls by less than 2 percent. While the main goal of this paper is not to assess implications for labor, if long-run employment is approximately linear in the number of vehicles produced, then these results suggest that product entry and exit are equally important for workers. Ignoring the

endogenous nature of product offerings can overstate lost wages for commercial segment autoworkers by over $480 million annually.

Accounting for product entry and exit can be pivotal to the bailout decision, at least within the confines of the commercial vehicle segment. Comparing, for example, liquidation to the bailout, compensating variation is over $253 million without entry and exit but only $28 million with them. If the planner puts zero social weight on bailout funds and profit changes, and the planner has a discount rate between 0.5 percent and 4.7 percent, then the bailout is approved if product entry and exit are ignored and rejected if they are accounted for. If the planner also values lost wages and expects these to persist, then the region of discount rates for which product entry and exit are pivotal expands to between 2.0 percent and 15.3 percent.

This paper contributes to a fast-growing literature on entry, exit, and positioning. Early empirical work relied primarily on cross-sectional geographic variation to illustrate the trade-offs from differentiation (Mazzeo 2002; Seim 2006). More recently, Ho (2009) demonstrates that insurers' hospital network choices impact pricing and investment incentives, Fan (2013) shows that ignoring repositioning by newspapers following a merger substantially changes ex post outcomes, and Crawford, Shcherbakov, and Shum (2015) provide evidence that welfare losses due to the effect of market power on quality meet, or even exceed, those due to the effect of market power on price. For most large differentiated product markets, however, there are only one or two R&D/manufacturing locations nationwide, or even worldwide, which rules out the use of cross-sectional techniques. Eizenberg (2014) studies this problem in the context of personal computer manufacturers' decisions over which processors to include in which laptops. The paper exploits outward shifts in the technological frontier of computing power, determined by Moore's Law, to help identify the fixed costs of offering each processor configurations, and provides a solution to the selection problem (discussed in more detail in Section III). Nosko (2010) studies the problem from the prospective of Intel and AMD (although here fixed cost disturbances are assumed orthogonal to positioning decisions).[8] My approach, however, rests on observable heterogeneity in buyer preferences, which research has shown to be an important determinant of pricing and purchasing behavior in a wide range of differentiated product markets (Petrin 2002; Berry, Levinsohn, and Pakes 2004), and rich enough variation in the composition of these (prospective) buyers. It also allows for multidimensional product characteristics and introduces the notion of hurdle rates, which reflect institutional details but simplify the dynamic problem that sunk costs present.

This paper also closely relates to the literature studying entry, exit, and investment in games where firms employ Markov perfect strategies. For example, Ryan (2012) measures how much the Clean Air Act affected cement producers' costs, Collard-Wexler (2013) shows how fiscal policy that smooths demand affects ready-mix concrete plants, and Sweeting (2013) studies the switching of radio station formats. In addition to multiple geographic markets, the estimation of dynamic

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[8] See Crawford (2012) for a more comprehensive review of the literature on "endogenous" product offerings. That paper makes a helpful distinction between papers that study "whether" or "where" to offer particular products. In that sense, I study the former, e.g., whether Ford would like to offer a conventional cab commercial vehicle rated for 26,000 lbs. gross weight and, in particular, how this decision varies with the policy decision contemplated at the time of the "bailout."

games also requires a more restricted action space than I require here. Again, in many differentiated product markets, the number of potential product types is large while the number of geographic markets rarely exceeds one. Morales, Sheu, and Zahler (2011) provide an alternative procedure that is robust to large choice sets, but uses the assumption of monopolistic competition so that firms face only a single agent problem.

Finally, this paper is among the first to assess the merits of government rescue from the perspective of industrial organization. Goolsbee and Krueger (2015) argue in favor of the 2009 automotive bailout with respect to lightweight vehicles, i.e., the noncommercial segment. The authors, who played key roles in the decision, argue mainly on the basis of negative macro feedback effects due to layoffs, the interdependency among US producers created by the supply chain, the hardships (e.g., relocation costs) to workers, and the resulting public expenditures on unemployment and healthcare. These are valid concerns, especially in the short run, although many will not apply to this paper.[9] Roberts and Sweeting (2016), on the other hand, show negative effects of the 1984 bailout of timber companies facing losses on federal contracts, which they argue dissuaded lower-cost potential rivals from entry. Although this may have bite in the passenger segment, GM and Chrysler commercial divisions did not generally suffer from the high costs of their passenger divisions.

Section I provides background on the commercial vehicle market. Section II provides a model. Section III describes estimation. Section IV provides reduced-form evidence of product entry and exit. Section V reports estimation results while Section VI reports what would have happened under alternate policies. Section VII concludes.

## I. Market Setting and Data

### A. *Overview*

The commercial vehicle segment of the US automotive industry accounts for about 10 percent of total US automotive sales (Wards 1986–2013), which themselves account for 4 percent of gross domestic product.[10] The segment comprises any on-road vehicle rated for over 10,000 lbs. gross vehicle weight (defined below) and sold domestically.[11] In terms of use and users, their scope is quite broad. For example, the market includes inner-city delivery vans, landscaping flatbeds, dump trucks, and highway tractor-trailers. In terms of capabilities, the high end of the segment has carried loads in excess of 250,000 lbs., such as oil rigs and turbine

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[9]For example, the commercial segment is only 5–10 percent of total automotive sales, and much closer to the median US industry size, so macro feedback effects are second-order. I address these caveats later in the paper.

[10]Department of Commerce *Auto Industry Snapshot,* http://selectusa.commerce.gov/industry-snapshots/automotive-industry-united-states (accessed December 20, 2013).

[11]The "on-road" distinction here, or in US Department of Transportation terms "on-highway," merely excludes irrelevant vehicles like one-seat "terminal tractors" and 50-foot-tall mining trucks. I exclude motorhomes, buses, and "step" vans from the dataset because these are by-and-large manufactured by different firms and bought by different consumers than the vehicles in this dataset. Finally, I do not include low-entry cab-forward models. Although these are made by Mack/Volvo, and Peterbilt, who appear in this dataset, there is no variation in who produces them or their characteristics (with the exception of the short-lived Sterling Condor). Their exclusion should also not affect the demand system, since they are used almost exclusively in urban garbage collection.

engines, and as cumbersome as an Airbus A320 fuselage, which was the case when the "Miracle on the Hudson" was hauled from New York City to the Smithsonian museum in Washington, DC.[12]

## B. *Data Sources*

Three main sources of data are used in this paper. First, I compile a panel of all commercial vehicle models sold in the United States from 1986 to 2012 from annual issues of *The Truck Blue Book*. Each observation includes the brand, model year, model name and number, and a host of product characteristics. These include price as well as detailed specifications related to the load capacity, cab, chassis, and other features. Each guide contains data for the prior ten years, easing compilation. Unfortunately, manufacturer's suggested retail price (MSRP), rather than retail price data, is available, although this is a common limitation in the literature. All prices are converted to 2005 constant US$ using the Consumer Price Index (CPI).

I merge the product characteristic data to unit sales data from the R. L. Polk and Co. *New Vehicle Registration Database*. The Polk data cover US vehicle sales Class 3 and above and are compiled from state motor vehicle registration records. Observations are broken down by brand, model name and/or number, as well as gross vehicle weight rating class, fuel-type, and body description. All sales figures are compiled on a calendar year basis. In some cases, a model was identified in the *Polk* data by a model number and in the characteristics data by a model name, or vice versa, although these conflicts can usually be resolved by consulting the *Official Commercial Truck Guide* published by the American Truck Division of the National Automotive Dealers Association (NADA). In two remaining cases, I called a dealership.

The third main data source is microdata on commercial vehicle purchases available through the US Census. These microdata were collected up to and including 2002 under a program known as the Truck Inventory Use Survey (TIUS) and later the Vehicle Inventory and Use Survey (VIUS). Every five years, the Census mailed approximately 130,000 owners of trucks and vans and asked them various questions about their vehicle, the use of their vehicle, and about the owners themselves (relating to their vehicle use). The response rate was approximately 80 percent and relatively stable over time. I observe the industry and state that the buyer operates in, whether the vehicle was acquired new or used, and the characteristics of the vehicle the buyer owns.

Three additional pieces of information complete the dataset. First, the US Census *County Business Patterns* contributes the number of US firms by industry, state, and year, while the US Department of Transportation (DOT) *Highway Statistics* contributes urban and non-urban road mileage by state and year. Together, these provide an empirical distribution of buyer types that serve as the basis for taking simulation draws in the demand system and that determine changes in size of the total potential market for commercial vehicles. Last, the Bureau of Labor Statistics contributes

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[12] The "Miracle on the Hudson" refers to US Airways commercial flight 1549, which Capt. Chesley Sullenberger emergency landed on the Hudson River following a bird strike.

product worker wages at the state and year level, which I match to product models based on their respective factory locations.

## C. *Product Characteristics*

Commercial vehicles are conveniently summarized by a short list of product characteristics. The first and most important is gross vehicle weight rating (GWR), defined as the maximum load that may legally rest on the axles. GWR is the main means by which both the automotive industry and the Department of Transportation characterize vehicles. The threshold of 10,000 lbs. GWR provides a natural separation between the passenger and commercial segments. Below this threshold are cars, minivans, station wagons, nearly all pickup trucks, SUVs, and cargo vans; above it are what would typically be thought of as work trucks. In terms of use, the Census microdata show a very obvious distinction. More than 95 percent of vehicles below 10,000 lbs are designed for "personal use," while less than 5 percent above this threshold are. In terms of production, the physical design is also distinct. Vehicles below this cutoff usually feature unibody design, meaning the exterior skin provides primary support to the load. Vehicles above this cutoff feature "body-on-frame" design, meaning the load is supported by a ladder frame, onto which assemblers attach the axles, cab, power unit, and controls.[13] That is, the driver sits inside the load-bearing structure in a passenger vehicle but sits on top of it in a commercial one. Body-on-frame design allows vehicle assemblers to quickly modify the characteristics of a vehicle, often in as little as a few months.

GWR determines the possible uses of a vehicle. Since carrying loads in excess of it is illegal and unsafe, and since it increases price, buyers purchase vehicles with the minimum GWR that safely covers their needs.[14] Other characteristics, like the transmission and engine, relate quite closely (even though they may not map exactly).[15] Due to the industry's desire for compatible parts (and to avoid buyer confusion), GWR only takes discrete values, despite the fact that it is technically a continuous choice variable. For example, over 30 vehicles in the data have a GWR of exactly 52,000 lbs. The small group of models that did not match exactly to any group were always close to some larger group, so the GWR of the group was substituted in for these models.

The second characteristic is the style of cab, the portion of the vehicle that encloses the passengers, driver controls, and engine. Cabs come in three distinct varieties. The most popular cab type is the "conventional," which is distinguished by its relatively long hood and placement of engine well ahead of the occupants.

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[13] The technical term is monocoque construction, meaning the exterior skin supports the load. Variants of this term, like semi-monocoque and unitary construction, more precisely describe modern passenger vehicles, but all are distinct from body-on-frame.

[14] For vehicles that are more likely to be "pulling" rather than "carrying" loads, manufacturers also provide a gross combination weight rating (GCWR). This is the maximum combined weight of the vehicle and unit being towed behind. This is the appropriate measure for these vehicles, so I adjust for nonstandard GCWRs, although in practice this only affects ten models.

[15] Engines deserve discussion. Although each model typically carries a large number of engine options, the base option is usually the same across manufacturers for a given GWR and cab type. Product guides even include charts that relate one engine type to another across manufacturers, suggesting close comparability. Additionally, the market for large trucks (where engine quality matters most) is dominated by Cummins and Caterpillar, which are independent of any manufacturers in our data.

TABLE 1—SUMMARY STATISTICS

| | Min. | Max. | Average over each period | | |
|---|---|---|---|---|---|
| | | | 1986–1994 | 1995–2003 | 2004–2012 |
| *Panel A. Count of product offerings by type* | | | | | |
| Light-medium GWR conventional | 20 | 24 | 21.0 | 21.7 | 22.3 |
| Medium GWR conventional | 14 | 27 | 25.0 | 20.8 | 20.4 |
| Heavy GWR conventional | 28 | 36 | 31.6 | 33.0 | 32.9 |
| Light-medium GWR cabover | 8 | 11 | 10.0 | 10.3 | 9.8 |
| Medium GWR cabover | 2 | 12 | 11.0 | 8.1 | 5.1 |
| Heavy GWR cabover | 0 | 8 | 7.4 | 1.8 | 0.0 |
| Compact-front-end (all GWRs) | 3 | 5 | 3.0 | 3.3 | 4.1 |
| Long/extended cab (all GWRs) | 9 | 16 | 15.4 | 11.6 | 9.7 |
| All types | 62 | 85 | 77.6 | 75.4 | 75.7 |

| | Min. | Max. | Average over each period | | |
|---|---|---|---|---|---|
| | | | 1992–1994 | 1995–2003 | 2004–2012 |
| *Panel B. Prices charged and units sold* | | | | | |
| Price (in 2005 $) | $70,324 | $75,588 | $73,075 | $73,448 | $72,104 |
| Quantity (in 000s of units) | 165,678 | 584,057 | 286,246 | 395,879 | 369,985 |

| | Min. | Max. | Average over each period | | |
|---|---|---|---|---|---|
| | | | 1986–1994 | 1995–2003 | 2004–2012 |
| *Panel C. Proportion of potential vehicle buyers by type* (%) | | | | | |
| Freight-related industries | 22.1 | 32.1 | 25.2 | 28.0 | 28.6 |
| Construction-related industries | 36.5 | 50.4 | 43.3 | 45.6 | 44.7 |
| Business- and personal service-related industries | 22.8 | 37.1 | 31.5 | 26.4 | 26.8 |

*Notes:* The first panel counts the number of offerings by year in each category. For example, there were a minimum of 20 vehicles offered in the "light-medium GWR conventional" category. The second panel summarizes average price and total units sold by year, and the third panel summarizes the average buyer attribute by year. For price and quantity variables, the third column is truncated due to data restrictions, i.e., that price and quantity in the panel begin in 1992 (see Section I for more details). The low average quantity for the first period, 1992 to 1994, reflects the recession of the early 1990s. Aggregate sales data from *Ward's Automotive Yearbook* confirm that average unit sales for the (extended) period 1986–1994 would be in line with the periods 1995–2003 and 2004–2012.

The conventional cab places the axle ahead of the driver, making for a smooth ride and spacious interior, but its long hood limits the amount of maneuverability in tight spaces. The cab-over-engine (cabover) type features a flat front and places the occupants directly over the front axle and engine. This makes for exceptional visibility and turning but an uncomfortable and less safe driving experience.[16] Although not particularly popular overall, they are common in congested city environments. A compromise between the two is the compact-front-end (compact), whose steering and controls are moved as far forward as possible, resulting in a short but slanted hood. These provide benefits of both cabover and conventional designs but are limited in engine size. Finally, there is a "long/extended" cab (long) option, which is designed to provide maximal comfort and minimal noise to drivers making long or difficult hauls.

Panel A of Table 1 summarizes the product offerings. The two left columns provide the minimum and maximum number of models, by loosely defined product segments, over the panel. Striking is the wide variation in offerings over the panel,

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[16]Cab-over-engine vehicles place no distance between the driver and the vehicle in front of it, which creates the safety issue.

even among the most popular product types. Of course, many product markets show this level of variation over a long panel due merely to trends, perhaps technologically driven. However, the three right columns show this is not the case with commercial vehicles. When the data are broken up into three equal-length nine-year bins, it is clear secular trends are not driving the variation. The one obvious exception is the heavy cab-over-engine vehicle, which was impacted by a legislative change that reduced demand. This is addressed in more detail later in this section and revisited in the descriptive evidence presented in Section IV.

Panel B of Table 1 reports analogous statistics for prices and quantities. Prices have remained relatively stable while the number of units sold has varied widely but, over long stretches, the data are relatively trendless.[17]

## D. *Buyer Attributes*

Buyers differ by industry, driving environment, and legal climate. Industry matters because it determines the load size and driving distance, which in turn influence preferences over GWR and cab size. According to US Census microdata, most buyers belong to either the for-hire transportation (freight) industry, one of three construction-related industries, or the business and personal service industry.

Panel C of Table 1 summarizes the composition of potential buyers by industry. Two basic facts about the product offerings hold for the buyers as well. First, there is wide variation over time. At their peak, many industries are almost 50 percent larger than at their troughs. Second, this variation is not dominated by secular trends in the potential buyer population. Each of these facts as they pertain to both products and buyers are important to model assumptions below.

Driving environments vary by whether surrounding areas are urban or not, which I measure by dividing urban road mileage by total road mileage. The third buyer attribute relates to a series of vehicle length laws. Initially, states regulated the entire vehicle length, from the front of the power unit to the rear of the load being carried. A series of federal legislative and judicial decisions, beginning with the Surface Transportation Assistance Act, mandated that only the length of the load being carried be regulated. This allowed the power unit, i.e., truck or tractor, to be as long as the driver desired. Rather than analyze each complicated decision, I take a simple count of the regulatory actions. More details are provided in Section IV.

Figure 1 illustrates the relationship between buyer attributes and product characteristics. Panel A reports the average GWR of the vehicle purchased conditional on the buyer industry. Business and personal service firms (for example, cable repair vans and electric utility trucks) are much lower than the average GWR, which is around 30,000 lbs. Vehicles used in construction are in the middle, and vehicles used for hauling freight are toward the top. Specialty freight tractors, the bulk of which is frequently referred to as "heavy haul," average over 54,000 lbs. Panel B reports heterogeneity in preferences for the cabover. Poor ride quality make this an unpopular vehicle overall, but better visibility and agility are benefits to urban drivers. Thus, despite much less than 10 percent of total market share, the cabover accounts for

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[17] Note that the first bin of price and quantity data is truncated to only three years, due to limitations described above, and while reported quantities seem low, these merely reflect the recession of the early 1990s.
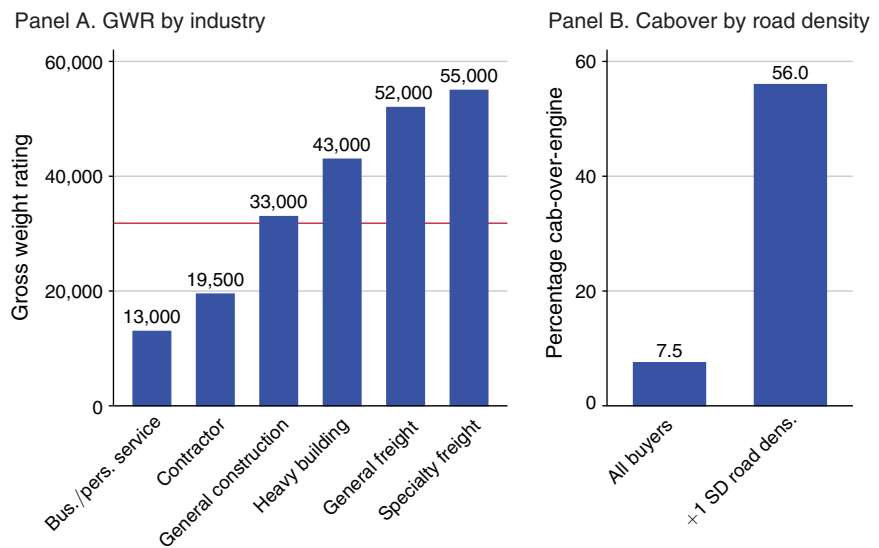
Panel A. GWR by industry  Panel B. Cabover by road density



FIGURE 1. AVERAGE PRODUCT CHARACTERISTICS CONDITIONAL ON PURCHASE AND BUYER TYPE

*Notes:* This figure illustrates demand heterogeneity. Panel A shows expected GWR conditional on purchase across the main US Census-defined industries. Panel B shows cab-over-engine (cabover) sales as a proportion of all sales either overall or for buyers whose USDOT road density measure is one standard deviation above the mean for that measure.

more than one-half of purchases by buyers in areas that are one standard deviation above the mean in terms of road density.

### E. *Firms*

This paper focuses on automotive assembly firms. It treats upstream and downstream operations as either independent or completely determined by assembly operations. There are several reasons for this. First, the assemblers are few in number but large in size and serve as the central party to contracts between the disaggregated parts suppliers and geographically diverse dealerships. Whereas car makers typically build many major components in-house, for example engines and axles, commercial builders rarely do. Cummins and Caterpillar, for example, account for a majority of heavy-duty truck engines but are not active in the market themselves. Also, unlike the passenger vehicle segment, commercial dealers often carry competing brands.[18] One exception is that firms with both commercial and passenger vehicle operations occasionally leverage their passenger vehicle dealerships to sell commercial units (which I account for in estimation).[19] Second, assembly firms map directly to the "brand" that identifies the vehicle. Third, extending the analysis along the value chain is simply beyond the scope of the current data and methods.

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[18] For example, the closest commercial vehicle dealership to Cambridge, MA (as of December 1, 2013) sells both Ford and International vehicles. The second closest sells Mack, Western Star, Isuzu, Volvo, and Peterbilt vehicles, all rivals.

[19] In particular, I allow the sunk costs of offering some characteristics to vary by firm.

US commercial vehicle production is also separate from its foreign market counterparts. The catalyst for this separation is a 25 percent import tariff on trucks imposed in 1963 and in effect today. The duty is part of Proclamation 3654 and ubiquitously referred to in the auto industry as the "Chicken Tax" due to the fact that President Johnson aimed it primarily at stemming poultry imports. It applies to all truck imports to the United States. Although what is meant by "truck" is hotly contested, all vehicles in this paper are covered. Together with the heavy weight and high shipping costs of commercial vehicles, imports and exports are below 3 percent of this market.

There are 9 firms producing 14 brands in the last year of the data. Ford, GM, and Chrysler[20] are based in the United States, have large passenger vehicle operations, and are commonly referred to as the Big Three. Two others are headquartered in the United States: PACCAR, whose brands include Peterbilt and Kenworth; and International. Four are based abroad: Daimler, whose brands include Freightliner, Mitsubishi Fuso (Fuso), and Western Star; Volvo, whose brands also include Mack (in addition to Volvo); Hino; and Isuzu. Due to factors outside the domestic commercial vehicle market, some brands have changed owners. For example, Daimler acquired and later divested of Chrysler in 1998 and 2006, respectively, and in those years less than 2 percent of Chrysler's sales were in the commercial market. Also for example, Volvo acquired Nissan Diesel in 2006, and in that year only 6 percent of the latter firm's sales were in the US market. Details on these transactions are found in online Appendix Section 1.

## F. *The Bailout*

The $85 billion of federal assistance to GM and Chrysler in 2009 constitutes the largest government bailout of a nonfinancial industry in modern history. Its causes are debated but there is mostly consensus on three factors: a global recession beginning in 2008 and prompting a trough in sales, a rise in fuel prices coupled with American manufacturers focus on trucks and SUVs, and legacy costs from pension and retiree healthcare benefits. By late 2008, there was an immediate fear that GM and Chrysler would default, prompting $17.4 billion in assistance.[21] Shortly afterward in 2009, the federal government agreed on more funds, bringing the total to $85 billion.

Whether to provide assistance was hotly contested, split partly along partisan lines, and even became a major US presidential campaign issue. Republican presidential nominee Mitt Romney argued for a market-based solution in a November 2008 op-ed in *The New York Times* titled "Let Detroit Go Bankrupt." Later, in 2012, Barack Obama took credit for its apparent success, saying "I said we're going to bet on American workers and the American auto industry, and it's come surging back."[22] In a 2012 op-ed in the *Wall Street Journal*, Robert Barro pointed out that

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[20] The Chrysler parent produces Dodge brand vehicles. Thus, the bailout discussion will refer to the former and the product market discussion will refer to the latter.

[21] See, for example, Gregory Wilcox, "Big 3 Detail Plans for Bailouts," *Daily News,* December 3, 2008; Chris Isidore, "Bush Announces Auto Rescue," *CNNMoney,* December 19, 2008; and Sharon Carty, "Automakers Ask for Billions in Loans, Credit; Two Say They're Nearly Out of Money," *USA Today,* December 3, 2008.

[22] Jennifer Epstein, "Obama Attacks Romney on '47 Percent,'" *Politico,* October 16, 2012.

rhetoric supporting the bailout ex post ignored counterfactual policy outcomes. He wrote, "If GM had disappeared, its former workers and other inputs would not have sat around doing nothing. Another company—be it Toyota, Honda, or Ford—would likely have taken over its operations."[23]

The response of surviving firms to alternative policies is the focus of the analysis below. The main caveat is that, again, the analysis covers only the commercial vehicle segment of the market. This setting provides tractability for the model and clarity as far as the qualitatively important effects of product entry and exit. Moreover, GM and Chrysler comprise 15–20 percent of commercial vehicle purchases, so the bailout is relevant for the segment.

I consider three alternative policies. The government may have facilitated an acquisition of GM and Chrysler by a competitor, so to illustrate the range of potential outcomes, I consider an acquisition by Ford, whose products overlapped the most with GM and Chrysler, and one by PACCAR, whose products did not overlap at all. I also consider liquidation, effectively the removal of GM and Chrysler parents, brands, and products from the market. This can stem from, for example, a chaotic default subsequent to government inaction. In relation to these alternatives, a final set of caveats is necessary. First, debtor-in-possession financing was scarce at the time of decision, so I rule out other private arrangements, although they were certainly possible. Second, moral hazard is ignored. Firms that expect support in the future may take riskier bets or under-expend effort in unprofitable states of the world. Third, focus on the commercial vehicle segment provides a tractable illustration of the importance of model-level entry and exit in this setting but will not provide a comprehensive answer for the whole auto industry. Fourth, financial distress is rarely random and usually signals underlying problems that might make shutdown efficient. The troubles at GM and Chrysler were largely outside their commercial vehicle operations, so I ignore this issue, but policymakers applying these methods to another context should clearly keep this point in mind.

## II. Model

This section presents a two-stage model that captures how firms endogenously adjust the set of products they offer to changing market conditions. At the beginning of each period, last period's product offerings as well as the demand and marginal cost shifters, e.g., the characteristics of the potential buyers in the market, are public information. Firms realize a set of sunk cost disturbances and choose what products to offer, and then realize a set of demand and marginal cost disturbances and choose what prices to charge. Firms solve the problem by working backward from the second stage, calculate the equilibrium profits that will likely accrue to them under any possible set of product offerings, and then choose the products that maximize those profits. The econometrician solves the problem in the same order.

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[23] Robert J. Barro, "Ryan and the Fundamental Economic Debate," *The Wall Street Journal,* August 14, 2012.

## A. *Stage 2: Demand*

Each buyer, $r$, decides whether to purchase a vehicle $j$ from among $J$ choices or the outside good so as to maximize utility. In the event of purchase, they derive utility from the vehicle based on an interaction between their attributes and the vehicle's characteristics. They also derive disutility from price. The total utility from product $j$ is given by the following:

$$(1) \qquad U_{r,j} \,=\, x_j(\beta_x + \beta_x^o z_r^o + \beta_x^u z_r^u) + p_j \beta_p + \xi_j + \epsilon_{r,j}.$$

Here, $x_j$ denotes the vector of vehicle characteristics excluding price. These include a constant as well as GWR, and dummy variables for cabover, compact-front-end, and long option, which are denoted, respectively, $g$, *cabover*, *compact*, and *long*. Let $z_r^o$ and $z_r^u$ denote these buyer attributes, which can be observed or unobserved by the econometrician. Parameter $\beta_x$ denotes the mean taste for each product characteristic, while $\beta_x^o$ and $\beta_x^u$ are coefficients on the interaction of buyer attributes and product characteristics.[24],[25] Parameter $\beta_p$ denotes the consumer's taste for price, $p_j$. For convenience, let $\beta$ denote the vector of taste parameters, $(\beta_x, \beta_x^o, \beta_x^u, \beta_p)$. Further, $\xi_j$ denotes an i.i.d. product-specific preference shock.[26] Finally, $\epsilon_{r,j}$ denotes an i.i.d. preference shock specific to the choice and buyer. Buyers can also consume the outside good, whose mean utility is normalized to 0 so that buyers receive only $\epsilon_{r,0}$.

This specification yields the familiar logit choice probabilities for each consumer. After integrating out over the total number of simulated consumers, $ns$, I arrive at the market share for any product $j$, denoted $s_j$. Adding a time $t$ subscript, total unit sales are denoted $q_{j,t}$ and equal the product of market share and market size, denoted $M_t s_{j,t}$.[27] This setup assumes that static, unit demand closely approximates the actual purchasing decisions made and that buyers are price takers. In practice, many buyers do *own* multiple vehicles but in most of these cases only *buy* a small number of units at a time.

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[24] The exact specification of equation (1) emphasizes interactions of $x_j$ with $z_r^o$ rather than with $z_r^u$. See Section III for details.

[25] I opted not to interact any buyer attributes with price. The reason was computational. The sunk cost estimation and counterfactual exercises compute Nash prices many times, and if attributes interact with prices, which change with each iteration of the algorithm, then one cannot pre-compute the full array of buyer attributes and product characteristics (as well as the more complicated arrays related to the firms' first-order conditions with respect to prices). Not interacting buyer attributes with price is more palatable here than most settings, e.g., the passenger car market. There, purchases of a meaningful market segment (luxury cars) are explained by high income consumers with convex preferences across vehicle quality and money.

[26] As in most prior work, $\xi$ is i.i.d. over characteristics, firms, and time. If the assumption is violated and $\xi$ has large predictive power, this creates an errors-in-variables problem. That is, it creates measurement error on the right-hand side (vis-à-vis $\Delta\pi$, which is introduced below). This works against me, biasing sunk costs downward and making them more difficult to estimate. For example, if a firm introduces a model and learns of its high $\xi$, it will tend to keep that model in regardless of market conditions. Fortunately, even parsimonious demand systems "fit" well for commercial vehicles, so $\xi$ does not present a large problem.

[27] Model decisions are made annually, so the terms "period" and "year" are used interchangeably.

## B. *Stage 2: Prices*

The second-stage decision from the firm's perspective is to set prices. Firms, $f$, offering a set of products $J_{f,t}$, choose prices to maximize profits, given by

$$(2) \qquad \Pi_{f,t} = \sum_{j \in J_{f,t}} \left[ p_{j,t} - mc_{j,t} \right] s \left( x_{j,t}, x_{-j,t}, p_t, z_t; \beta, \xi_t \right) M_t,$$

where $mc_{j,t}$ denotes the marginal costs of producing $j$ at $t$, and where $x_{-j,t}$ denotes the matrix of characteristics for products other than $j$ at $t$.[28] Firms take the first-order condition with respect to the vector of prices of products that they sell and set it equal to 0. The log of marginal costs is linear in the observable product characteristics, wages, time, and an unobserved factor specific to the product and time, $\omega_{j,t}$, which is i.i.d. over firms, characteristic space, and time.[29] The vector of coefficients on these cost components is denoted $\gamma$.

## C. *Stage 1: Product Offerings*

In the first period, firms simultaneously choose product offerings, i.e., make model-level entry and exit decisions, with the understanding that their actions and their rivals' actions will impact the second stage. They do not know $\xi_{j,t}$ and $\omega_{j,t}$ but do know the distribution of the disturbances, $(F_\xi, F_\omega)$. The expectation over these draws yields the hypothetical expected profits from any set of production offerings. The expected second-stage profits, after a slight change of notation, are

$$(3) \qquad \pi(J_{f,t}, J_{-f,t}, z_t, w_t; \beta, \gamma, F_\xi, F_\omega)$$

$$\equiv \int_{\xi', \omega'} \Pi \left( J_{f,t}, J_{-f,t}, z_t, w_t; \beta, \gamma, \xi', \omega' \right) dF_{\xi'} dF_{\omega'},$$

where $J_{-f,t}$ denotes the products offered at $t$ by firms other than $f$. Henceforth, $\pi(J_{f,t}, J_{-f,t}, z_t, w_t)$ is understood to be evaluated at $(\beta, \gamma, F_\xi, F_\omega)$.

The principal decision firms face in the first stage weighs the added profits of introducing or continuing to offer existing product models against the sunk costs (or scrap values) associated with doing so. Sunk costs are given by

$$(4) \quad SC_{f,j,t,J_{f,t-1}} = x_j' \tilde{\theta}_{f,x_j,t} \times \left[ \left\{ j \in J_{f,t}, j \notin J_{f,t-1} \right\} + \lambda \left\{ j \notin J_{f,t}, j \in J_{f,t-1} \right\} \right],$$

where $\{ \cdot \}$ denotes an indicator function. Since $\tilde{\theta}$ is allowed to vary by firm, time, and product, the only restriction this imposes is that the scrap value recovered from retiring a model is $\lambda$ times the sunk costs of introducing it. For example, if

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[28] Also, $p_t$ denotes the vector of prices over $j$ at $t$; $\xi_t$ denotes the vector of product-specific preference shocks over $j$ at $t$; $z_t$ denotes the matrix of buyer attributes over $r$ at $t$.

[29] Demand is estimable in this paper without the use of supply-side moments, so I can graphically observe what the functional form relationship is between the right-hand variables and the marginal cost estimates.

$\lambda = -0.5$, firms receive \$50 million back for retiring a vehicle with a sunk entry costs of \$100 million.

Sunk costs can induce forward-looking behavior, but in differentiated product markets, the dynamic solution requires storage of and an expectation over billions or more of states. This computational burden is orders of magnitude too hard for firms in practice. A common rebuttal to this concern is that although agents do not appear to explicitly compute optimal strategies, repeated play can nonetheless converge to equilibrium strategies (Fudenberg and Levine 1998; Fershtman and Pakes 2012; Doraszelski, Lewis, and Pakes 2014), although this is ruled out in the present setting. That is, the exceptional number of states paired with less than 50 years of decisions on which to reflect makes reinforcement learning (about the dynamic implications of one's actions) impractical.

This raises an important question as to what managers actually do. Surveys suggest they approximate the solution to complicated budgeting and discounting problems. For example, Graham and Harvey (2001) show that CFOs are two to three times more likely to use contingent-free methods like the payback ratios and hurdle rates while Summers (1987) showed that 94 percent of surveyed Fortune 500 firms use the same discount rate across all projects. Solutions to these problems suggested by practitioners or research staff in private sector firms often suggest the same. For example, Jeff Alden, group manager of Manufacturing Systems Research at General Motors, and Robert Smith, Professor of Engineering, write in *Operations Research* that "by far the most common planning procedure found in practice is to approximate the solution" (Alden and Smith 1992, p. 5183).[30] To figure out as accurately as possible what is done in this setting, I interviewed engineers, designers, and veteran managers. A common thread ran through these interviews, the clearest of which was given by the former head of General Motors Commercial Division, who said:

> *Each year we look at demand, what we offer, and what the competition is going to offer. We consider changing the lineup like adding a vehicle … We know who the customers would be, what we can charge, and the production costs—so we have the added margin. The margin over the investment gives a return on capital, and **we'll build it when it crosses some threshold** (emphasis added).*

I interpret a capital budgeting rule that uses hurdle rates as providing the following.

ASSUMPTION 1: *For all firms f at time t with information set $\mathcal{I}_{f,t}$, equilibrium product offerings $J_{f,t}$ satisfy*

$$(5) \qquad \frac{\Delta \pi (J_{f,t}, J'_{f,t}, J_{-f,t}, z_t, w_t)}{\mathcal{E}\left[\Delta SC_f(J_{f,t}, J'_{f,t}, J_{f,t-1}) \,|\, \mathcal{I}_{f,t}\right]} \geq HurdleRate \quad \forall\, J'_{f,t} \in \mathcal{J}.$$

$\Delta \pi (J_{f,t}, J'_{f,t}, J_{-f,t}, z_t, w_t)$ denotes the difference between $\pi(J_{f,t}, J_{-f,t}, z_t, w_t)$ and $\pi(J'_{f,t}, J_{-f,t}, z_t, w_t)$, and firms compute this difference without error.

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[30] This article provides a simplified single-agent problem and shows how "rolling horizon procedures" approximate the solution.

$\Delta SC_f(J_{f,t}, J'_{f,t}, J_{f,t-1})$ denotes the difference between $\sum_{j \in J_{f,t}} SC_{f,j,t,J_{f,t-1}}$ and $\sum_{j \in J'_{f,t}} SC_{f,j,t,J_{f,t-1}}$, and $\mathscr{E}[\cdot | \mathscr{I}_{f,t}]$ denotes the firm's expectation operator, conditional on its information set. $\mathscr{J}$ denotes the feasible set of product offerings.[31]

Capital budgeting with hurdle rates uses a straightforward rule-of-thumb. Firms choose to offer a set of products such that for any other set the expected ratio of the added profits to added sunk costs does not exceed the hurdle rate. To illustrate, suppose that firm $f$ does not offer product $j$ at $t - 1$ and that introducing it will cost $\$100$ million. If the firm has a hurdle rate of 20 percent, the firm will add it to their offerings if it yields expected profits of $\$20$ million or more and not add it otherwise. A hurdle rate rule is implied by, for example, strategies that approximate a choice-specific expected value function with static profits. It cannot capture option value derived from waiting for uncertainty to be resolved or deterrence value derived from preempting others, although these should be second-order concerns here. With respect to option value, McDonald (2000) shows that, at least with respect to single-agent settings, hurdle rate rules do well because the penalty to deviating from an optimal strategy falls as the option value rises.[32] With respect to preemption, the incentives of competitive firms to enter (or exit) product segments early in the hopes of forestalling rivals from doing the same is highest when second-stage payoffs are predictably growing (or shrinking), but the summary statistics reported in Table 1 do not indicate any large, secular trends underlying the data.

Assumption 1 allows firms to make expectational errors with respect to sunk costs but holds that they know $\Delta\pi$. Relaxing this requires adding second-stage expectational errors. Since the final estimating inequalities allow for flexible first-stage expectational errors, and because the first- and second-stage errors enter those inequalities in the exact same way, relaxing this assumption would not change the empirical findings: it merely requires adding notation. Assumption 1 also rules out economies of scope within the commercial vehicle industry, which simplifies the problem and helps with tractability.[33]

Using the decision rule presented in inequality (5), firms simultaneously choose product offerings to form a Nash equilibrium in product space.

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[31] The feasible set is all combinations of products, where a "product" is defined as a unique bundle of characteristics in the support of the observed offerings. Some underlying constraints on the support are physical. For example, the reason there are no heavy compact-front-end vehicles is due to a lack of engine space when the controls, steering column, etc. are pushed as forward as possible. The set of all products comprises the following: conventional non-long/extended vehicles with $g \in \{12{,}000, 13{,}500, 15{,}200, 19{,}500, 21{,}500, 24{,}200, 26{,}000, 28{,}000, 33{,}000, 35{,}000, 40{,}000, 43{,}000, 46{,}000, 48{,}000, 50{,}000, 52{,}000, 54{,}000, 56{,}000, 58{,}000\}$, cabover non-long/extended vehicles with $g \in \{12{,}000, 14{,}500, 18{,}000, 19{,}500, 26{,}000, 33{,}000\}$, compact vehicles with $g \in \{12{,}000, 15{,}250\}$, conventional long/extended vehicles with $g \in \{52{,}000, 54{,}000, 56{,}000\}$, and cabover long/extended vehicles $g \in \{50{,}000, 52{,}000\}$.

[32] That paper seeks to explain why "most firms do not make explicit use of real option techniques" and "projects are taken based on whether IRRs exceed arbitrarily high discount rates." It shows hurdle rates will far exceed discount rates, with the additional discounting capturing, in a sense, the option value.

[33] The model does allow for some firm-specific sunk cost heterogeneity. This does not capture scope economies per se, but it can address the propensity of Big Three firms to offer relatively more low-GWR vehicles and the propensity of Japanese firms to offer relatively more cabover vehicles. The form of and motivation for this heterogeneity is described in detail in the following section.

## III. Estimation

### A. *Stage 2: Demand*

The estimation of demand closely resembles Petrin (2002). It minimizes generalized method of moments objective function based on two sets of moments. The first set is constructed as follows. Firms do not know the $\xi_{j,t}$ shocks when they choose product characteristics, so $E[\xi | x, w] = 0$. On the other hand, firms do know the $\xi_{j,t}$ shocks when they choose prices. Approximations to the optimal instruments are constructed from variables that shift either marginal costs or markups. Wages are a valid instrument in the former case. I match vehicle models to the areas in which they were assembled and proxy for the factory wage rate with a Bureau of Labor Statistics estimate of the production wage in that area. Production locations are unlikely to relate to current commercial vehicle market conditions since the decision to launch a new facility precedes production by several years and, once launched, the mix of products are rarely reallocated across factories. The competitive conditions provide a valid instrument in the latter case. The markup on $j$ produced by $f$ is decreasing in the number of competing products that are close in characteristic space but increasing in the proportion of these owned by $f$. The timing of choices, again, guarantees that $E[\xi | x, w] = 0$. Observed shares are calculated by simply dividing the units sold by market size, the calculation of which is given in online Appendix Section 1.

The second set matches moments from the microdata to their model-predicted analogs. Specifically, it matches the mean and variance of the buyer attributes conditional on product attributes of the vehicle purchased as well as the mean buyer attribute conditional on any vehicle being purchased. The micro-moments include the following: each industry type and the GWR; each industry type and a constant; the delivery industry and the compact-front-end cab type; the general freight industry and the cabover; the general freight industry interacted with length laws and the cabover; and the urban measure and the cabover. Online Appendix Section 2 provides a more detailed discussion of these moments and the estimation of demand more generally.

Finally, the empirical distribution of $\xi$ is recovered by plugging $\hat{\beta}$ back into the demand system and recovering the residuals.

### B. *Stage 2: Marginal Costs*

Rearranging the Nash pricing condition yields estimates of marginal costs that are a function of only prices and shares, which are both data, as well as (estimates of) the price coefficient and the individual purchase probabilities, which are recovered from the demand system.

Note that the estimation of demand, described above, does not rely on supply-side moments. These are easily formed from the firms' first-order conditions with respect to prices. These can also aid in identification but require an explicit functional form assumption on marginal costs. Instead, I recover the demand parameters and check that the model's implied profit margins are in line with those reported in audited financial statements of the manufacturers (Nevo 2001). (In practice, rich

microdata and an observable marginal cost shifter, which instruments for price, help with second-stage estimation considerably.) Then, after recovering the marginal costs, I assess the shape of those costs with respect to the right-hand-side variables. Graphically, the log of marginal costs is roughly linear in the continuous characteristic, so that $\ln(mc) = [x, w]\gamma + \omega$. After rearranging terms and solving for the additively separable error term, $\omega$, $\gamma$ is estimated via least squares, since $E[\omega \,|\, x, w] = 0$.

Plugging $\hat{\beta}$ and $\hat{\gamma}$ into the price equation yields an estimate of the distribution of $\omega$. Together, these provide unbiased (but potentially measured with error) estimates of the second-stage payoffs firms would expect from offering any alternate set of products.

## C. *Stage 1: Sunk Costs*

*Setup.*—The necessary conditions for a simultaneous move Nash equilibrium provide that firms take rivals' decisions as fixed and find any unilateral deviation to the chosen product offerings unprofitable in expectation. To ease the computational burden, I use only product-by-product deviations. Any alternatives can be used, and richer deviations yield weakly tighter bounds.[34]

When the capital budgeting process relies on hurdle rates, the decision rule can be rewritten as linearly separable in first-stage (sunk cost) related terms and second-stage (profit) related terms. To see this, multiply both sides of inequality (5) by the firm's expectation of sunk costs, substitute in for these sunk costs with the right-hand side of equation (4), define $\theta_{f,x_j,t}$ as $-HurdleRate \times \tilde{\theta}_{f,x_j,t}$, and rearrange terms. As a result, for any firm $f$ at time $t$ that is observed to offer $J_{f,t}, j \in J_{f,t}$ implies

$$(6) \qquad \Delta\pi\left(J_{f,t}, J_{f,t} \setminus j, J_{-f,t}, z_t, w_t\right)$$

$$+ x_j'\left(\{j \notin J_{f,t-1}\} - \lambda\{j \in J_{f,t-1}\}\right)\mathscr{E}\left[\theta_{f,x_j,t} \,|\, \mathscr{I}_{f,t}\right] \geq 0,$$

and $j \notin J_{f,t}$ implies

$$(7) \qquad \Delta\pi\left(J_{f,t}, J_{f,t} \cup j, J_{-f,t}, z_t, w_t\right)$$

$$- x_j'\left(\{j \notin J_{f,t-1}\} - \lambda\{j \in J_{f,t-1}\}\right)\mathscr{E}\left[\theta_{f,x_j,t} \,|\, \mathscr{I}_{f,t}\right] \geq 0.$$

Inequalities (6) and (7) show that product entry and exit decisions reflect a comparison between second-stage profit changes and first-stage sunk cost changes, with the latter scaled multiplicatively by a constant, the hurdle rate. Thus, for the purposes of policy analysis, hurdle rates do not need to be estimated and can be ignored through the remainder of the analysis, including counterfactual calculations. That is,

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[34] As an explicit example, I use the fact that if firms not offering a 26,000 GWR conventional truck in $t-1$ did not introduce it at $t$, the sunk costs were too high to do so. Suppose, however, that the firm did offer a 22,000 GWR conventional truck at $t-1$. Since the 22,000 GWR and 26,000 GWR likely cannibalize one another, a tighter bound might be derived from the observation that the firm did not want to jointly introduce the 26,000 GWR conventional truck *and* retire the 22,000 GWR conventional truck. Tighter bounds are not, however, likely to be derived from simply increasing the number of introductions or deletions. After checking that a firm did not want to add an $g$-GWR *or* a $g'$-GWR vehicle, there is little informational content in the fact that they did not want to add an $g$-GWR *and* a $g'$-GWR vehicle.

the empirical exercise in this paper, as it pertains to endogenous product offerings, merely estimates scaled sunk costs, adjusts $\Delta\pi$ according to the particular counterfactual policy under consideration, and finally compares the adjusted $\Delta\pi$ to the estimated scaled sunk costs to predict product entry and exit. The unscaled sunk costs parameters are not used.[35] For ease of exposition, then, the scaled sunk cost terms will simply be referred to as "sunk costs" in the remainder of the paper.

After two additional assumptions, inequalities (6) and (7) can be used to bound the sunk cost parameters. The first of these allows sunk costs to vary based on the identity of the firms. In particular, it allows the constant and cabover characteristic terms to vary based on whether the firm is headquartered in Japan, denoted *Jpn*. Since the cabover is ubiquitous in Asia due to strict length regulations on nearly all commercial vehicles, these firms may have a sunk cost advantage for vehicles with these cabs (but potentially a disadvantage for vehicles with other types of cabs). It also allows for the constant and GWR characteristic terms to vary based on whether the firm is part of the Big Three, denoted *Big3*. Since Ford, GM, and Chrysler have large passenger vehicle operations, i.e., "light duty" vehicle design, manufacturing, and marketing, they may have a sunk cost advantage for lighter commercial vehicles (but potentially a disadvantage for heavier commercial vehicles). The assumption also allows for a characteristic-time-specific sunk cost disturbance that is unobserved by the econometrician.

ASSUMPTION 2: *For firm f at time t, the sunk cost parameter $\theta_{f,x_j,t}$ is given by $\theta_f + \nu_{2,t}$,*

$$\theta_f = \left[\theta_0 + \theta_0^{Big3} + \theta_0^{Jpn}, \; \theta_g + \theta_g^{Big3}, \; \theta_{cabover} + \theta_{cabover}^{Jpn}, \; \theta_{compact}, \; \theta_{long}\right],$$

*and $\nu_{2,t}$ is a vector of mean zero disturbances. Its elements are denoted $\nu_{2,k,t}$, where k indexes the product characteristics on which sunk costs depend, including the constant term, so $\nu_{2,t} = \left[\nu_{2,0,t}, \; \nu_{2,g,t}, \; \nu_{2,cabover,t}, \; \nu_{2,compact,t}, \; \nu_{2,long,t}\right]$. These disturbances as well as the expectational errors are mean independent of objects in the firm information sets.*

The presence of $\nu_{2,t}$ allows for a more flexible specification of sunk costs but creates a selection problem. That is, its presence allows for, for example, the sunk costs specific to introducing a cabover truck to be cheaper at $t$ than $t - 1$ in a way that influences behavior. In other words, product characteristics will be overrepresented in the vehicle offerings precisely at those times when offering them was particularly cheap.

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[35] This assumes hurdle rates are unchanged over the panel and by the policy choice. Firms, at least anecdotally, rarely change hurdle rates. For example, *The Economist* reported on May 6, 1999 ("Corporate Finance: High High a Hurdle?") that "Shell [Oil Company] left its hurdle rates unchanged for two decades until it 'nudged them down' in 1997, and now intends to keep them at present levels for years to come." That said, the failure of GM and Chrysler could raise the cost of capital for surviving rivals. Higher hurdle rates decrease the present value of future cash flows, i.e., increase the relative price of investing today, and thus would impact the counterfactuals by making entry less likely and exit more likely. One can test the sensitivity of the counterfactual outcomes to this assumption. That is, since the rewritten sunk cost term is multiplicative in the hurdle rate, one could merely take an "offline" estimate for the factor by which discount rates will increase in the case of liquidation, multiply the current sunk cost estimates by that amount, and rerun the counterfactual simulations. I conduct this test, briefly describe the results in Section V, and provide more detailed findings in the online Appendix.

The assumption holds that if the model predictions and the observed actions differ beyond the flexibility provided by $\theta_f$ and $\nu_{2,\cdot}$, then the differences reflect expectational errors made by the firms, denoted $\nu_{1,f,t,J_{f,t},J'_{f,t},J_{f,t-1}}$. (In other words, the structural error term is characteristic-year specific rather than firm-product-year specific, so while the inequalities vary at the firm-product-year level, the structural error term does not.) Formally, $\nu_{1,\cdot}$ errors denote the differences between the true value of and the firm's expectation of $\theta_{f,x_j,t}$. This is a strong assumption that helps with tractability, though it may be a defensible approximation of the data-generating process given the institutional details. The vector $\theta_f$ captures the important, observable firm-characteristic heterogeneity that is evident in the data as well as trade publications and conversations with management. Moreover, $\nu_{2,t}$ captures industry-wide time-varying shocks including those to installation costs, machine components, etc. These shocks are characteristic-time-specific, so they enable, for example, low GWR and conventional cab vehicles to be introduced relatively cheaply in one period and high GWR and cabover vehicles to be introduced relatively cheaply in the next. If this assumption is violated so that firms observe a portion of this residual disturbance, then the model yields sunk costs that are downward biased in absolute value terms.[36] As discussed below, the assumption be relaxed or modified, but this requires additional computational power and/or different assumptions.

The next assumption holds that second-stage profits are measured without error. This is a common assumption in the literature and, again, helps with tractability but may be reasonable in light of the results presented in Section V. It is supported by, for example, the fact that the demand system yields sensible elasticities and profit markets and tight estimates for most parameters that determine purchases and marginal costs.

ASSUMPTION 3: *Second-stage estimation provides coefficients such that*

$$\Delta\hat{\pi}(J_{f,t}, J'_{f,t}, J_{-f,t}, z_t, w_t) = \Delta\pi(J_{f,t}, J'_{f,t}, J_{-f,t}, z_t, w_t),$$

*where* $\Delta\hat{\pi}$ *denotes* $\Delta\pi$ *evaluated at* $\hat{\beta}, \hat{\gamma}, \hat{F}_\xi$, *and* $\hat{F}_\omega$.

Inequalities (6) and (7) cannot go directly to data, since the firms' actions reflect information known to them but not the econometrician. This selection problem is discussed below.

*Selection.*—Discrepancies between the model's predictions and the firms' observed actions are rationalized by errors. To identify the parameters of interest, Assumptions 1–3 make important restrictions: second-stage profits are known with certainty by the firms and econometrician; error that reflects differences between the model's estimates and true sunk costs and that is observed by the firms can vary only up to the characteristic-year level but no further; and all errors are mean independent of objects in the firm information sets. Note that sunk cost disturbances that are observed by the firms but not the econometrician ($\nu_{2,k,t}$) create an inequality analog

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[36] This follows from the logic of the preceding paragraph. If $\nu_1$-type errors are in fact $\nu_2$-type errors, then the expected value of the unobservable is correlated with whether the product is offered.

of omitted variable bias. Conditional on choices, these disturbances are not mean zero. Nonetheless, they are still unconditionally mean zero, a property I use to deal with the selection problem. Note, though, that conditional on these disturbances, residual errors ($\nu_{1,\cdot}$) are mean zero, even conditional on choices.

Assumptions 1–3 provide that there is selection in terms of *how many firms* but not *which firms* take a given action in a given year for a particular product type. Thus, for actions that at least one firm takes for each product type and year, i.e., "staying in" and "staying out," one can form moments by weighting the observations in such a way that precisely one $\nu_{2,t}$ vector is included per year.[37] The resulting moment includes the sample mean of these disturbances, which converges in probability to the unconditional expectation, which in turn equals 0.

Product entry and exit occur less frequently. For instance, firms rarely introduce a product type for which demand has contracted sharply. However, the reason why this condition is often violated provides the intuition for how to construct expectations that eliminate selection: shifts in demand can isolate periods when adding, not adding, removing, and not removing products will almost surely be observed, but they are plausibly unrelated to the disturbance terms. For example, to isolate periods in which a particular type of vehicle is almost certain to be introduced, one can condition on years with robust growth in the buying segment that most heavily relies on it. For these cases, identification also requires that the disturbance terms are mean independent of the shifters[38] and that the shifters provide sufficient variation in profits relative to the support of the disturbances. In this sense, they are instruments (Pakes et al. 2015). The intuition, borrowing from an earlier example, is that if one uses these shifters to condition on periods that appear most favorable to the entry of a particular product type, then the data-generating process must provide at least one introduction of that product type in each of those periods (but will not provide a selected set of sunk cost disturbances for those periods). One can then form moments, as above, whose $\nu_{2,k,t}$ converge in probability to their unconditional expectation and "drop out."

Alternative approaches to the sample selection problem exist. One approach requires only an assumption on the distribution of the disturbances (see Ciliberto and Tamer 2009). For example, one can assume a standard normal distribution, take draws of the disturbances, and calculate bounds on the probability of observing each set of equilibrium offerings. This, though, requires enumerating every possible set of offerings for each firm in each market: at present, feasible only for a small number of players making simple decisions, like whether to enter or not. It is (far) too computationally burdensome for differentiated product markets. Another approach, which can be used in cases when the number of missing bounds is small, requires only a symmetry assumption to recover the bounds (Pakes et al. 2015). This may address certain entry/exit games but generally will not help answer questions

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[37] In particular, one can weight the observations by the total number of firms divided by the number of firms that take the given action in the given year for the given product type. For example, consider a moment associated with 26,000 GWR conventional cab vehicles that "stay in." If three firms continue to offer this product type in a given year, then these observations are weighted by one-third. The resulting moment is additively separable in $(\nu_{2,t=1} + \nu_{2,t=2} + \cdots + \nu_{2,t=T})/T$ multiplied at some constant.

[38] This is satisfied by Assumption 2, since these shifters are constructed using objects in the agents information set.

related to positioning. In differentiated product markets, the typical firm's portfolio comprises a small fraction of total potential offerings.[39]

A recent, alternative approach that addresses an empirical problem resembling mine relies on assuming that the support of the fixed costs lies within the support of the expected variable profit changes (Eizenberg 2014). It constructs the identified set by substituting missing sunk cost bounds with worst-case bounds provided by the upper and lower bounds of the distribution of variable profits. There are trade-offs. This approach requires a weaker assumption than mine in that the data are fully rationalized by disturbances observable to the firms, yet it requires a stronger assumption than mine in that it assumes the support of the sunk costs relate closely to variable profits.[40]

*Moments and Inference.*—Let $\sum_{x_j} \sum_t \sum_f$ represent summations over the unique $x_j$ vectors, over the years, and over the firms, respectively. Also, let $X$, $T$, and $F$ represent the number of unique $x_j$ vectors, time periods, and firms, respectively. Then, as Appendix A shows, these assumptions provide estimating inequalities that can be used to bound the sunk cost parameters. These inequalities are given by

$$(8) \quad \frac{1}{XTF} \sum_{x_j} \sum_t \sum_f h^i_{f,x_j,t}\{j \in J_{f,t}\}$$
$$\times \left[ \Delta\hat{\pi}(J_{f,t}, J_{f,t}\backslash j, J_{-f,t}, z_t, w_t) + x'_j\theta_f(\{j \notin J_{f,t-1}\} - \lambda\{j \in J_{f,t-1}\}) \right] \geq 0$$

and

$$(9) \quad \frac{1}{XTF} \sum_{x_j} \sum_t \sum_f h^i_{f,x_j,t}\{j \notin J_{f,t}\}$$
$$\times \left[ \Delta\hat{\pi}(J_{f,t}, J_{f,t}\cup j, J_{-f,t}, z_t, w_t) - x'_j\theta_f(\{j \notin J_{f,t-1}\} - \lambda\{j \in J_{f,t-1}\}) \right] \geq 0,$$

where the weights placed on the observations to form the moment inequalities are denoted $h^i_{f,x_j,t}$ and indexed by the $i$th moment they provide, and where $J_{f,t}$ are the observed offerings of firm $f$ at $t$.[41] Inequalities (8) and (9) along with the appropriate choice of $h$ provide upper and lower bounds on $\theta_f$ and $\lambda$.

Weights $h^i_{f,x_j,t}$ will depend on the identity of the firms, characteristics of the product offerings, mean buyer attributes as they vary across $t$, what was offered last period, and what is offered in the current period. Since at least one firm continues

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[39] If single product firms position along a continuous dimension, and if their identities do not matter to the counterfactual outcomes, then yet another approach is to assume a unique equilibrium and estimate positioning costs using first-order conditions. This eliminates the multiplicity issue entirely for the purposes of estimation, and it is supported by the fact that prior work studying these types of games has failed to find multiple equilibria (Fan 2013; Crawford, Shcherbakov, and Shum 2015).

[40] The paper that introduces this approach studies laptop computer manufacturer's choices over microprocessor configurations. First-stage costs are fixed, not sunk. Since the potential configurations are based on observed rather than hypothetical offerings (i.e., configurations that were known to have existed), using bounds derived from the support of variable profits probably results in conservative identification.

[41] To be clear, $j$ indexes the product types, i.e., unique bundles of characteristics itemized in footnote 31, and $x_j$ denotes the vector of characteristics excluding price for $j$.

to offer each product type in each period,[42] one set of $h^i_{f, x_j, t}$ for inequality (8) can condition on these $x_j$ and take an average over the years, weighting appropriately. Similarly, at least one firm continues not to offer each product type in each period, which provides an analogous set of $h^i_{f, x_j, t}$ for inequality (9). The ex ante expectation of an advantage for Big Three firms over low-GWR vehicles suggests refinements. Specifically, among conventional cab vehicles whose GWR is below the median, at least one Big Three firm continues to offer each of these in each period, and at least one non-Big Three firm continues not to offer each product type in each period. Among conventional cab vehicles whose GWR is above the median, the opposite is true. The ex ante expectation of an advantage for Japan-based firms over cabover vehicles suggests analogous refinements. To reduce what would be a very large number of moments, I average within five evenly sized GWR bins; this expedites estimation but still provides meaningful statistical power.

Estimates from the demand system suggest ties between delivery/service industry buyers and low-GWR vehicles, between construction industry buyers and mid-GWR vehicles, between freight industry buyers and high-GWR vehicles, and between cab length laws and heavy cabover vehicles. To exploit these relationships for the purposes of estimating inequality (8), $h$ can condition on $j$ not offered by $f$ at $t - 1$ and further condition on periods when product entry is effectively guaranteed to occur. As an example, for years when the construction industry expanded most rapidly, at least one firm introduced each type of mid-GWR vehicle in each of those years. Similarly, with respect to inequality (9), $h$ can condition on $j$ offered by $f$ at $t - 1$ and further condition on periods when product exit is effectively guaranteed to occur. As an example, for years when legislative or court decisions relaxed cab length laws in the United States, at least one firm removed a high-GWR cabover vehicle in each of those years. (These examples in particular are motivated in more detail in the following section.) All together, these provide 97 moments. Just over one-half provide lower bounds; the remainder provide upper bounds. There are 10 sunk cost parameters, so exactly (partially) identifying $(\theta_f, \lambda)$ requires 20 such linearly independent inequalities.[43]

Note that although my data provide a set of parameter values that satisfy these conditions, this need not be the case for small samples, even when the model is correctly specified. In that event, one would minimize an objective function $Q_n(\theta_f, \lambda)$ equal to $\sum_i ([\overline{m}_i(\theta_f, \lambda)/\hat{\sigma}_i(\theta_f, \lambda)]_-)^2$, where $i$ indexes the moment formed by each $h^i$, $\overline{m}_i$ denotes the moment's sample mean, and $\hat{\sigma}_i$ denotes moment's sample standard error. Since the amount by which $\overline{m}_i(\theta_f, \lambda) \geq 0$ is uninformative, the $[\cdot]_-$ operator indicates that $Q$ penalizes only the negative moment values.

Inference follows Andrews and Soares (2010). They construct confidence intervals using moment inequalities that contain the true parameters with probability 0.95. Inference based on inequalities is not as straightforward as that based on equalities. Inequalities provide only one-sided restrictions, the most informative of which are the *least* upper bound and the *greatest* lower bound. Thus, inequalities

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[42] The one exception is the heavy cabover, whose demand is adversely affected by length laws (discussed below). To address this, I merely additionally condition on periods prior to the passage of the very last law.

[43] One set bound from below while one set bound from above. That is, at least ten must take the form of inequality (8), and at least ten must take the form of inequality (9).

provide minima and maxima over the data, instead of averages, which rules out the use of central limit theorem for convenient standard error computation. One solution is to invert a test of the null at each possible value of the vector of the sunk cost parameters (Chernozhukov, Hong, and Tamer 2007). Online Appendix Section 2 describes the inference procedure in detail.

## IV. Descriptive Evidence

Prior summaries of the data reveal that the empirical distribution of potential buyer types varies over time and that different buyers have strongly heterogeneous preferences. What remains is the question, "Do firms adjust product offerings to changing demand?" This would provide support for the notion that firms are solving a problem close in nature to the one presented in Section II, but would also suggest a set of instruments to identify sunk costs (as described in the prior section).

To illustrate, suppose the construction industry expands rapidly, as it did between 2005 and 2007, and then contracts sharply, as it did in the period subsequent to that. The microdata suggest this group prefers only a small subset of the vehicles produced, so firms adapting to market conditions should expand and contract product offerings tailored to their needs over the same periods. Figure 2 extends this logic across the time series and evidences precisely this relationship. In panel A, the *x*-axis measures the number of potential buyers in construction-related industries. The *y*-axis measures the number of product offerings with a GWR between 18,000 and 46,000. Construction buyers account for approximately 40 percent of purchases overall but more than twice that proportion in this subset of products. The relationship is clear: when the number of construction buyers is high, the number of offerings tailored to their preferences is also high. To rule out the case that construction is driving the total number of product offerings, panel B reports this relationship in proportions. The *x*-axis is the proportion of total buyers in construction-related industries, and the *y*-axis is the proportion of total offerings. The relationship is now somewhat tighter, sweeping away variation common to all products.

The deregulation of cab length provides other evidence. For the early and middle part of the twentieth century, states independently regulated the use of their highways. One restriction states imposed was a limit on the combined length of vehicle and trailer. Strict length laws advantaged the cab-over-engine relative to conventional vehicles since short cabs translated directly into larger loads and higher revenue. Regulations varied considerably and in many cases created blocks to interstate commerce in some regions of the country. Beginning with the Surface Transportation Assistance Act of 1982, the federal government began to standardize the maximum legal load being carried and at the same time deregulated the length of the vehicle pulling it. These laws affected the preferences of industry buyers whose loads were large enough to bind but had no change on others' demand. Heavy cabover sales, once strongly favored by freight industry buyers in some states, were decimated. Since the process unraveled slowly and modeling its idiosyncrasies are beyond the scope of this paper, I measure the right-hand-side variation as a simple cumulative count of the relevant legislative and court decisions. (See the online Appendix for more details.)
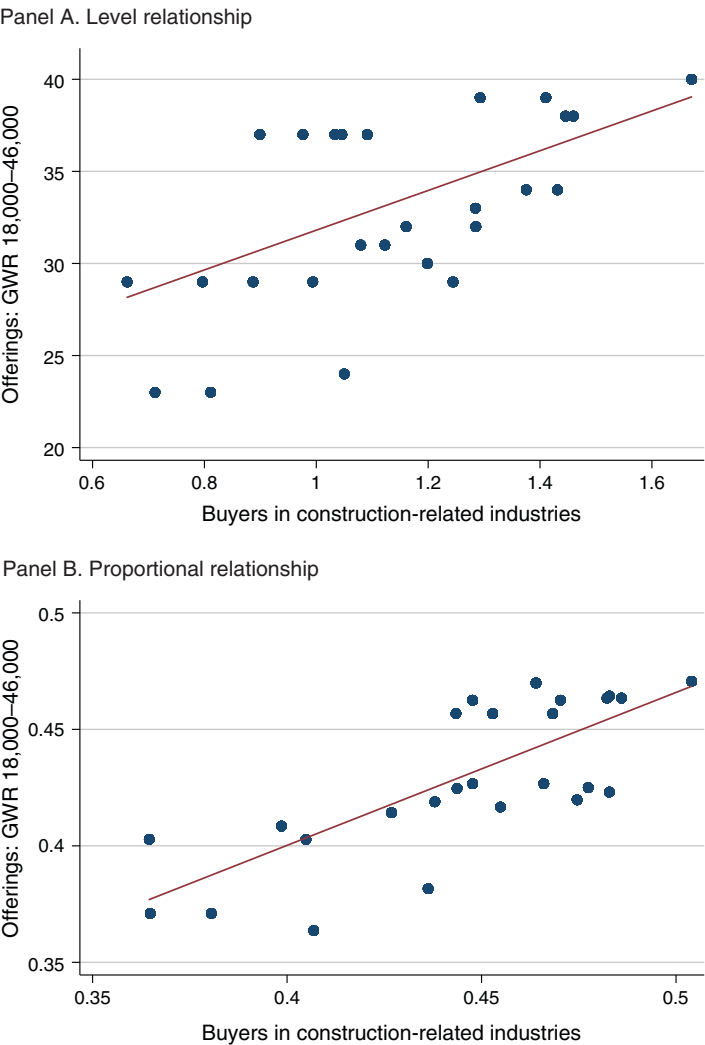
Panel A. Level relationship



Panel B. Proportional relationship



FIGURE 2. REDUCED-FORM EVIDENCE FROM THE CONSTRUCTION INDUSTRY

*Notes:* The figure reports the link between the changing composition of potential buyers and changing product offerings. The *x*-axis measures the total number of potential buyers in millions while the *y*-axis counts product offerings (in panel A) and measures the proportion of total product offerings (panel B). The subset of products with GWR in $[18{,}000, 46{,}000]$ is chosen because this is where demand is concentrated for construction-related buyers.

Figure 3 reports the response to these regulator changes. The year is along the *x*-axis, with vertical lines representing relevant regulatory events. The *y*-axis measures the number of heavy cabover product offerings. Panel A's *y*-axis is in levels and shows a tight relationship between legislative and/or court decisions, which reduce demand for heavy cabover vehicles, and the manufacturers' decisions to reduce their offerings in this segment of the market. Panels B and C rule out that these laws were simply a negative shock to demand for cabovers or to heavy vehicles, respectively. That is, panel B measures the *y*-axis as a *proportion* of all cabover offerings, while panel C measures the *y*-axis as a *proportion* of all heavy offerings. In both panels, this relationship holds equally well, with one slight outlier: that in
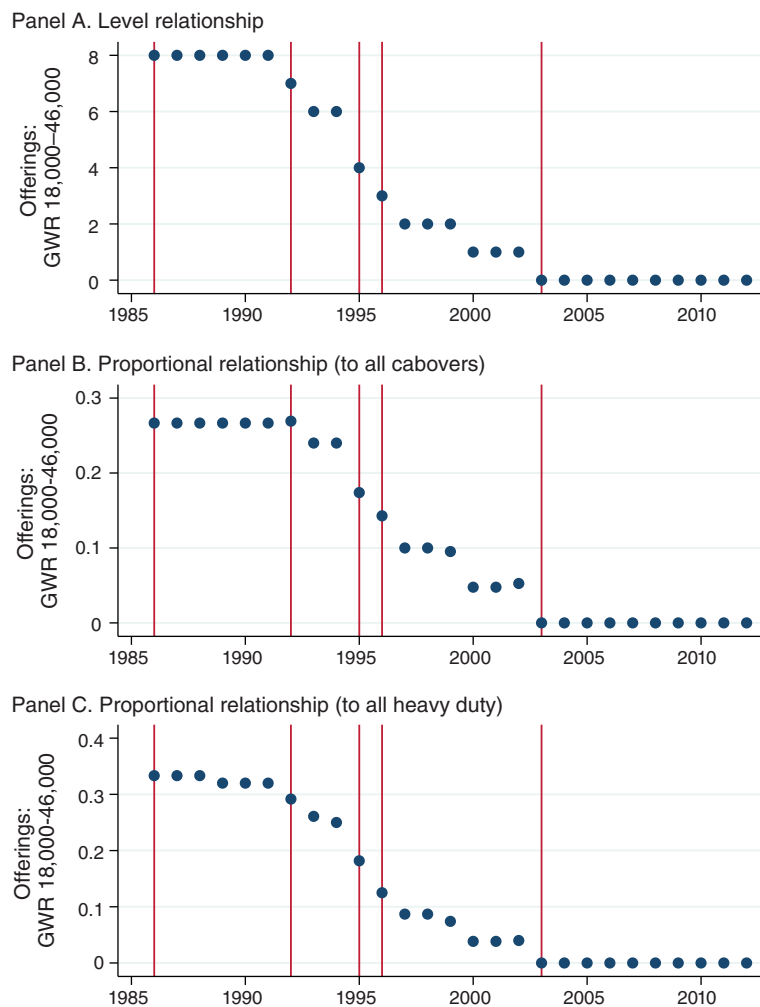
FIGURE 3. REDUCED-FORM EVIDENCE FROM THE FREIGHT INDUSTRY

*Notes:* This figure reports the link between regulatory decisions and changing product offerings. On the *x*-axis is the year, and vertical lines represent regulatory events that relax the cab length laws. Each *y*-axis measures the number of heavy cabover vehicle offerings. In panel A, this measure is in levels. In panels B and C, this measure is as a proportion of all cabover vehicles and all heavy vehicles, respectively.

panel B at 1992, the drop is delayed or reduced, confounded by a general pullback in total offerings that year. Most striking is the eventual complete obsolescence of the heavy cabover in the United States. This contrasts sharply with Europe and Asia (not shown), where length regulation persists and the heavy cabover remains the dominant freight vehicle.

## V. Results

### A. *Demand*

Table 2 reports the results from estimation of the demand system. Note that coefficients referencing the cab-over-engine, compact-front-end, and long-option are

TABLE 2—SECOND-STAGE PARAMETER ESTIMATES

| | Parameter estimate | Standard error |
|---|---|---|
| **Demand** | | |
| Mean parameters | | |
|   GWR (in 0,000s of lbs.) | 2.298 | 0.873 |
|   Indicator for cabover | −24.805 | 2.026 |
|   Indicator for compact-front-end | −1.425 | 0.273 |
|   Indicator for long option | 1.026 | 0.424 |
|   Price (in 000s of 2005$) | −0.44 | 0.037 |
|   Constant | 0.066 | 0.32 |
| Buyer attribute interactions | | |
|   GWR × specialty freight industry | 23.023 | 1.574 |
|   GWR × general freight industry | 16.434 | 0.553 |
|   GWR × heavy building industry | 11.162 | 0.495 |
|   GWR × general construction industry | 7.35 | 0.896 |
|   GWR × contractor industry | 3.693 | 0.915 |
|   Indicator for cabover × general freight industry | 0.906 | 0.261 |
|   Indicator for cabover × general freight industry × length laws | −1.183 | 0.881 |
|   Indicator for cabover × urban | 35.053 | 2.283 |
|   Indicator for compact-front-end × urban | 0.945 | 0.725 |
|   Indicator for long option × freight industry × $z^u_{2,r}$ | 5.842 | 1.754 |
|   Constant × urban | −5.67 | 1.13 |
|   Constant × specialty freight industry | −92.802 | 3.578 |
|   Constant × general freight industry | −57.517 | 2.233 |
|   Constant × heavy building industry | −29.843 | 1.557 |
|   Constant × general construction industry | −15.008 | 0.988 |
|   Constant × contractor industry | −6.993 | 0.87 |
|   Constant × $z^u_{1,r}$ | 6.288 | 0.537 |
| **Marginal costs** | | |
|   GWR | 0.385 | 0.06 |
|   Indicator for cabover | 0.002 | 0.033 |
|   Indicator for compact-front-end | −0.089 | 0.04 |
|   Indicator for long option | 0.073 | 0.012 |
|   Wage ($ per hour) | 0.016 | 0.004 |
|   $t$ (year count) | 0.041 | 0.053 |
|   Constant | 2.132 | 0.215 |
| **Observations** | 1,575 | |

*Notes:* Specialty freight, general freight, heavy building, general construction, and contractor industry denote indicators for the industry in which the buyer operates. Urban denotes the road density measure. Length laws denote the current cummulative number of legislative and court decisions related to regulation of cab length. $z^u_{1,r}$ and $z^u_{2,r}$ are drawn from standard normal distributions, so their coefficients correspond to the standard deviation of their distributions. The marginal cost coefficients for the wage and the year count differ from the prior draft due to inadvertant rescaling in that draft.

relative to the conventional cab, which is the omitted discrete category. The demand parameters are, with very few exceptions, estimated very precisely. This is especially true for the interaction terms, whose precision is aided greatly by the microdata.[44] A few parameters deserve discussion. First, GWR is positive for all buyers. This is an important check of the model, since price is always increasing in GWR and a negative coefficient would imply these buyers should choose an alternate (lighter) means of transportation. Moreover, the industry interactions are ordered in precisely the same way as the microdata would suggest. For example, specialty freight industry

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[44]I began with a large set of potential interactions and dropped those that were consistently neither statistically significant nor impactful. Microdata summary statistics, however, gave a strong indication as to which interactions would ultimately be included.

buyers, often called "heavy haul" firms in industry parlance, value GWR the most, followed by general freight carriers and heavy builders.

The cabover is disliked by the average buyer because of its poor ride quality. Yet, the cabover is strongly preferred by urban buyers, who value its agility and visibility, and this is reflected in the large positive interaction with the road density measure. This squares with a casual observation about cabover presence: that it is an uncommon sight in most of the United States but is practically ubiquitous in areas like downtown Chicago, Manhattan, and San Francisco. The impact of the length regulation, which primarily bound freight carriers, is also evident here. The interaction of the freight industry buyer dummy with the cabover dummy is positive. However, further interaction with the variable capturing cab length deregulation is negative, so two-thirds through the panel the average freight buyer prefers conventional to cabover vehicles. Finally, buyers dislike price. The coefficient is precisely estimated but difficult to interpret on its own, so easily understood implications are provided below.

The demand system implies sensible elasticities and markups. Consistent with profit-maximization in oligopoly, all implied own-price elasticities are greater than 1. They are also in line with but somewhat higher than those computed by Berry, Levinsohn, and Pakes (1995), who consider only passenger cars. For low GWR vehicles, i.e., the closest comparables to the products found in their data, in model year 1992, which is the year for which they provide model-by-model estimates, I find that the own-price elasticities average 10.9. For compact cars, the closest comparables to the products found in my data because their owners purchase them for utility over luxury, own-price elasticities average 6.3.

Implied markups also match public financial disclosures, although caveats are required for this comparison. First, all of these firms operate in either other product markets or other geographic areas or both. For example, PACCAR is active in Australia, Isuzu and Hino are based in Japan, Volvo makes motorboat engines, Ford makes passenger vehicles, and so on. Second, the model provides marginal costs while the firms report average costs, and the financial statements do not state what proportion of the selling, general, and administrative (SG&A) costs are sunk rather than marginal nor what proportion are related to (fixed) headquarters activities. This said, the model predicts profit margins of between 6.1 percent and 6.6 percent, depending on whether one weights by sales, close to but slightly below the reported long-run average operating margin of 7.5 percent.

## B. *Marginal Costs*

Marginal costs are backed out from prices and implied markups, and their log values are regressed on observables. Table 2 reports estimates of $\gamma$. A 10,000 lb. increase in GWR translates to about a 40 percent increase in marginal cost. Longer cabs require more materials, and this adds significantly to cost. The compact-front-end is slightly cheaper, while the cabover is very close to conventional in terms of cost. Costs increase slightly with time (recall this analysis is in terms of CPI-adjusted 2005 constant US$). The coefficient on wages is positive and significant at the 95 percent level, despite relatively limited variation compared with other regressors. Other coefficients are also all significant at the 95 percent level (with the exception of the cabover dummy, although

TABLE 3—SUNK COST PARAMETER ESTIMATES

|  | 95 percent confidence interval |
|---|---|
| Sunk cost parameters (in 000s of 2005$) | |
| Mean parameter | |
| GWR (in 0,000s of lbs.) | [$3,163, $4,664] |
| Indicator for cabover | [5,052, 7,478] |
| Indicator for compact-front-end | [−8,852, 3,411] |
| Indicator for long option | [−6,339, −3,433] |
| Constant | [−27,145, −21,103] |
| Firm identity interactions | |
| Constant × indicator for *Big3* | [−3,066, 7,732] |
| GWR × indicator for *Big3* | [−2,143, 299] |
| Constant × indicator for *Jpn* | [−5,204, −400] |
| Indicator for cabover × indicator for *Jpn* | [9, 5,289] |
| Scrap value scale parameter ($-\lambda$) | [0.531, 0.613] |
| Observations | 11,123 |
| Moments | 97 |

*Notes:* Sunk costs are set identified by moment inequalities, so bounds are reported. Confidence intervals contain the true parameters with probability 0.95. The final parameter, equal to $-\lambda$, is the proportion of the sunk costs of introducing a model that the firm recaptures when it retires the model, i.e., it "scales" sunk costs to scrap values. "*Big3*" denotes indicator for Ford, General Motors, or Chrysler brand. "*Jpn*" denotes indicator for Isuzu, Hino, Bering, Mitsubishi Fuso, or UD/ Nissan Diesel brand. Observations reflect the number of unique comparisons between first-stage and second-stage payoffs on which the moments are based.

this is due to a point estimate near 0 rather than a confidence interval that is much larger than that of the other coefficients, and the exception of the year count).

## C. *Sunk Costs*

Table 3 reports sunk cost estimates of product entry and exit. Since dummy variables are included for the cabover, compact-front-end, and long cabs, the constant term represents the sunk cost for the conventional cab, which is the omitted category, at 0 GWR. It costs firms between approximately $5 million and $25 million to introduce a commercial vehicle to the market (using mid-points of the confidence intervals). This includes design, engineering, the purchasing and installing of machines on the factory floor, and the education of salespeople. The confidence intervals for the mean parameters and the scrap value scaling parameter ($\lambda$) are bounded away from 0 at $\alpha = 5\%$, except for the compact-front-end dummy, which is centered to the left of 0. The confidence intervals for the interaction terms are similarly bounded or very nearly so, except for the Big Three dummy, which is centered to the right of 0.

The sign and magnitude of the estimates are reasonable. Relative to the conventional cab, the compact-front-end is more expensive to introduce. This likely reflects the complexities of fitting the engine, transmission, and steering controls into a tight space while maintaining a safe "crumple zone" to protect the driver

from a front-impact crash. The long cab option is also more expensive, since it requires nonstandard parts, fittings, and amenities. The cabover, on the other hand, is relatively inexpensive. While cabover vehicles may seem to suffer from the compactness problems associated with compact-front-end cabs, they do not. Cabover occupants are conveniently positioned *above* the engine, and when not in use, the cab can easily be unhinged from the chassis and tilted forward, providing unobstructed access to the engine, transmission, and steering controls.[45] Sunk costs are decreasing in GWR, at first, a surprising finding since more rugged vehicles could be more complicated to design. Partially informed by follow-up conversations with industry professionals, I believe this reflects two things. First, GWR affects production through the quality and toughness of the parts, e.g., the strength of the chassis, the weight rating on and the number of axles, and the durability of the transmission. These are marginal costs, and already reflected in prior estimates. Second, sunk costs differences across GWR may load on marketing and selling. Since the primary business of the buyers of low-weight vehicles is not truck transportation, informing them about new models may require a more intensive one-time push.

The final parameter estimate indicates that firms recover about 55–60 percent of the sunk costs when they retire vehicles. On average, firms introduce products when it is relatively profitable to offer them and retire them when it is relatively unprofitable to leave them in. As described in prior sections, the bounds are pinned down by instruments that are constructed from exogenous demand shifts and select out periods where entry and exit in a particular product subsegment is particularly likely and unlikely, respectively. As an example, robust growth for the construction industry in 2005 led to product entry in all "medium-duty" GWR categories. The steep contraction in building in, for example, 1992, led to product exit in these same categories. As another example, statutory changes that relaxed the length of "heavy-duty" vehicle cabs caused product exit in high-GWR cabover categories but precipitated entry in high-GWR conventional cab categories. In periods where demand was relatively flat, firms continued to offer existing products and rarely introduced new ones. The confidence interval around $\lambda$ is tight. It is aided by moments, constructed from the instruments, that provide the inference procedure upper and lower bounds with relatively little variance around them.

The data suggest accounting for firm heterogeneity in sunk costs is important. In line with the fact that the cabover is ubiquitous in Asia due to tight length restrictions, Japanese firms have an advantage in their introduction, perhaps due to borrowing blueprints from existing models or using compatible parts from their home market. This parameter also reflects a small number of light-cabover imports brought in from Japan, which presumably have a very low sunk cost associated with them. However, emphasis on the cabover comes at a cost. Japanese firms introduce non-cabover models at a higher cost than other firms. In line with the fact that the Big Three firms have large passenger vehicle operations, and that part of this expertise can spillover into low-GWR commercial vehicles, Big Three firms introduce light-weight vehicles at a lower cost than rivals. However, as with Japanese firms, this comes at a cost. Big Three firms introduce heavy-weight vehicles at a higher

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[45] For this reason, cabovers are often referred to as "tilt cabs."

TABLE 4—GENERAL MOTORS AND CHRYSLER PRODUCTS IN 2009

| Parent | Brand | GWR | Conv. | Cabover | Compact-front-end | Long/extended |
|--------|-------|-----|-------|---------|-------------------|---------------|
| Chrysler | Dodge | 12,000 | × | | | |
| Chrysler | Dodge | 13,500 | × | | | |
| Chrysler | Dodge | 16,000 | × | | | |
| Chrysler | Dodge | 19,500 | × | | | |
| GM | Chev./GMC | 12,000 | | | × | |
| GM | Chev./GMC | 12,000 | × | | | |
| GM | Chev./GMC | 13,500 | × | | | |
| GM | Chev./GMC | 14,500 | | × | | |
| GM | Chev./GMC | 16,000 | × | | | |
| GM | Chev./GMC | 19,500 | | × | | |
| GM | Chev./GMC | 19,500 | × | | | |
| GM | Chev./GMC | 21,500 | × | | | |
| GM | Chev./GMC | 28,000 | × | | | |
| GM | Chev./GMC | 33,000 | | × | | |
| GM | Chev./GMC | 40,000 | × | | | |

*Notes:* General Motors and Chrysler together offer 15 products approximately at the point the bailout decision is made. As in the rest of the paper, GMC and Chevrolet are treated as one brand, since they are physically identical (except for the brand badge) and indistinguishable in the product characteristic guides and pricing data.

cost than other firms. These parameters reflect basic features of the data such as, for example, the lower profit threshold at which Japanese firms will introduce and continue to offer cabover vehicles (but the higher threshold required to induce them to enter and offer other cab type vehicles).

## VI. Counterfactual Policy Analysis

### A. *Status Quo and Policy Alternatives*

The following section considers what would have happened to the commercial vehicle market in the absence of the $85 billion rescue of GM and Chrysler. Both firms were active in the commercial vehicle market throughout the panel, and by the end of 2009, together produced 15 products. Table 4 describes their offerings in detail. They include conventional, cabover, and compact-front-end vehicles, and tend to populate the lower half of the range of GWRs. These products will be eliminated or transferred to another firm in the event that GM and Chrysler were liquidated or acquired, respectively.

GM and Chrysler product portfolios are most similar to those of Ford, and to a lesser extent those of Freightliner, International, and Isuzu. None of their products are identical to any offered by PACCAR-owned or Volvo-owned brands (not shown).

One policy alternative is to facilitate an acquisition of the troubled firms by a surviving rival commercial vehicle producer. This is a particularly important part of the exercise, given that it seeks answers to a question identical to that of antitrust authorities who are assessing the ex post outcomes following a merger. To illustrate the range of possibilities, I consider an acquisition by Ford, whose products were most similar to those of GM and Chrysler, and by PACCAR, whose products were very dissimilar. Another alternative is to allow liquidation: an absence of acquisition or rescue that results in a default so chaotic as to simply eliminate the trouble firms'

brands and products from the market.[46] In the event of liquidation, one concern is that the policy choice could directly affect discount rates in a way that would limit entry and promote exit. That is, historically investors may have placed weight on the probability of federal assistance in the face of a tail event like the Great Recession, so government inaction may raise required returns for commercial vehicle manufacturers going forward, in turn raising hurdle rates and, by extension, sunk costs. Online Appendix Table A.V shows, though, that the main results below are robust to at least a full "letter grade" drop in the credit ratings of the producers.

For each counterfactual policy, I compare the predictions of an economic model that allows for only prices to adjust against an economic model which allows for prices and product offerings to adjust. Enumerating each of the potentially *many* equilibria is computationally infeasible at present,[47] so I follow Lee and Pakes (2009), who suggest a learning process to reduce this burden. In short, the program assumes an ordering of decisions based on market share in the prior year (or in the present year using observed offerings, since these yield the same order). The first firm chooses what products to enter or exit a best response to all other firms' offerings in the prior year. The second firm similarly best responds, but substitutes the product offerings of the first firm with its best response. The third firm similarly best responds, but it substitutes the product offerings of the first and second firm with their best responses. The program cycles through the firms, continually updating the offerings, until a full cycle is complete and no firm wishes to deviate. The result is a simultaneous move Nash equilibrium, conditional on a single draw of the sunk costs. I take 30 such draws and report the average outcomes across them.[48] The weakness of this approach is that each "run" results in a unique equilibrium, a small fraction of those possible under the model stipulated in Section II. As online Appendix Figure A.III reports, however, the results are robust to completely reversing the order and rerunning the program. Additional implementation details can also be found there.

There are several key findings. An economic model that ignores entry and exit predicts sharp markup increases under a Ford acquisition, much more muted changes under a PACCAR acquisition, and a large output drop under liquidation. Thus, when not accounting for entry and exit, market outcomes strongly depend on the policy decision. Yet it is precisely for policies that increase markups most

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[46] The counterfactual exercises are based on industry conditions as of 2009, in which the market size is 7 percent lower than the average of the prior five years and 19 percent lower than its highest point, which was realized two years earlier. If demand were higher, then the likelihood of product entry is higher, since firms would weigh sunk costs against larger profit increases that result from adding models. By similar reasoning, the likelihood of product exit is lower. To confirm this intuition and demonstrate the robustness of the main findings to changes in the market size, online Appendix Table A.VI replicates Table 5 but sets the market size to its average value over the prior five years.

[47] Eizenberg (2014) accomplishes this, albeit in a less complicated setting. There, four brands decide from among a menu of four product types. Subject to minor additional restrictions, there are $2^9 = 512$ candidates for equilibrium. The number in my setting is many orders of magnitude higher.

[48] In the estimation exercise, the shape of the distribution of sunk cost disturbances is unrestricted. In the counterfactual exercise, I assume that the sunk cost parameters $(\beta, \lambda)$ are equal to the midpoint of their confidence intervals. I add the disturbance-free portion of the sunk costs to a disturbance drawn from a mean-zero normal distribution with a standard deviation equal to 5 percent of the disturbance-free portion. Online Appendix Table A.IV reports that the results are robust to where in the space enclosed by the greatest lower bound and least upper bound the parameters are drawn. Sunk costs are also assumed to have a standard deviation equal to 5 percent of the centered value.

TABLE 5—COUNTERFACTUAL OUTCOMES

|  | Product entry and exit ignored | | | Product entry and exit allowed | | |
|---|---|---|---|---|---|---|
|  | Ford acq. | PACCAR acq. | Liq. | Ford acq. | PACCAR acq. | Liq. |
| Markups (percent) | | | | | | |
| Most affected model | 62.1 | 23.0 | 26.9 | 16.8 | 15.4 | 6.2 |
| Most affected vehicle type | 53.2 | 13.0 | 32.3 | 9.6 | 7.6 | 5.3 |
| Market | 10.9 | 3.0 | 4.0 | 0.8 | 0.5 | −0.0 |
| Output (percent) | | | | | | |
| Most affected model | −34.4 | −18.0 | NR | 6.7 | 16.5 | 8.9 |
| Most affected vehicle type | −30.0 | −8.6 | −100.0 | −63.9 | −54.9 | −64.7 |
| Market | −5.1 | −1.4 | −11.2 | −1.3 | −1.3 | −1.6 |
| Compensating variation | 119.0 | 33.0 | 253.0 | 22.0 | 26.0 | 28.0 |

*Notes:* This table compares market outcomes across counterfactual policy choices. The left three columns report predictions from an economic model that ignores product entry and exit. The right three columns report predictions from one that allows for this behavior. The first three rows report markup changes for the most affected model, the most affected product type (averaged over models of the same type), and the market overall (averaged across models). The next three rows are identical to the first three, except that they report output changes rather than markup changes. The final row reports compensating variation (for the counterfactual policy relative to the bailout). NR denotes not relevant. Compensating variation is expressed in millions of 2005$.

sharply and decrease output most severely that product entry "goes to work," disciplining prices and expanding the choice set. That is, after accounting for product entry and exit, all three alternative policy outcomes much more closely resemble the bailout. Ultimately, accounting for product entry and exit can be pivotal to the bailout decision.

## B. *Findings*

The first alternative to consider is acquisition. In this case, GM and Chrysler products are transferred to another parent company while the GM and Chrysler parent companies are eliminated. Ignoring entry and exit, the worst case from the consumer's, and antitrust authority's, point of view is an acquisition by Ford, so I begin there. Turning over the GM and Chrysler portfolio to it will afford it close to monopoly control over certain subsegments of the market.

Figure 4 reports the impact of this policy choice. The *x*-axis for all panels is GWR. Panel A presents the number of GM and Chrysler offerings in the prior year as a proportion of all offerings, i.e., it summarizes Table 4 across the most salient characteristic, taking into account the competing firms' products. Panel B reports the effects of the market structure change on markups when product offerings are not allowed to adjust to the policy change. Here the *y*-axis measures the percentage change in the dollar markup relative to the case where GM and Chrysler are rescued. The increases are severe: markups for the most affected products rise by nearly two-thirds. The severity is perhaps unsurprising in light of strong preference heterogeneity, evidenced by the microdata, and the high degree of ex ante concentration. This distributional impact is also wide. While several product segments, and by extension, their prospective buyers, see nontrivial markup increases, the majority of products, and buyers, are unaffected. For instance, GM, Chrysler, and Ford did not serve
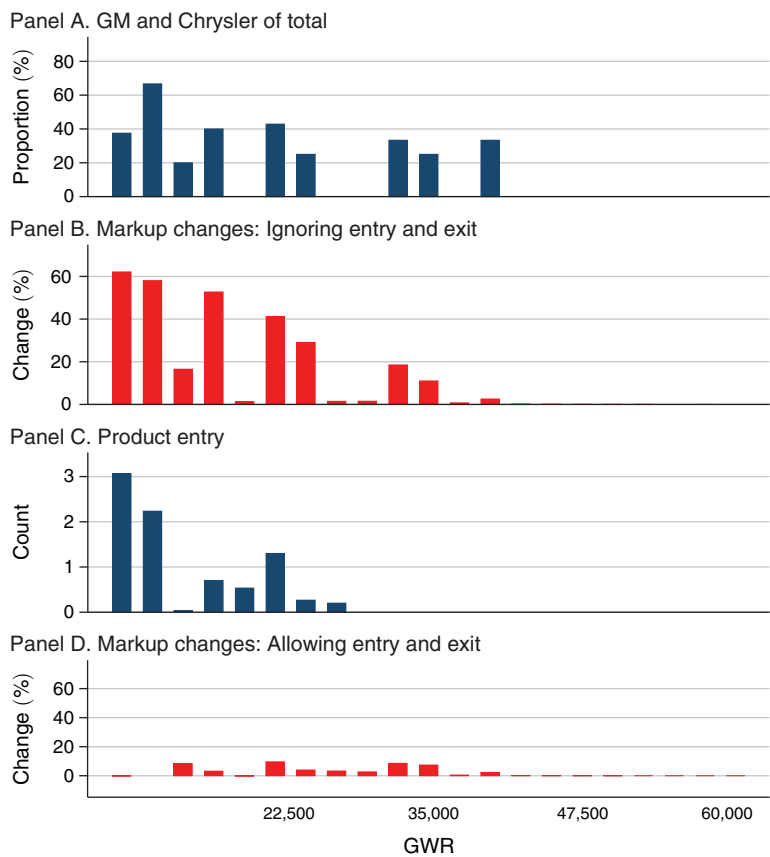
Panel A. GM and Chrysler of total

Panel B. Markup changes: Ignoring entry and exit

Panel C. Product entry

Panel D. Markup changes: Allowing entry and exit

FIGURE 4. COUNTERFACTUAL OUTCOMES UNDER ACQUISITION BY FORD

*Notes:* The *x*-axis is the GWR (likely the single most important characteristic). The *y*-axis in panel A is the proportion of all products that are offered by GM and Chrysler. The *y*-axis in panel B is percentage change in dollar markup, i.e., $(p_{FordAcquisition} - mc)/(p_{Bailout} - mc)$, for the most affected product in each GWR bin (if the economic model does not allow for product repositioning). The *y*-axis in panel C is a combined count of the net number of product entries. The *y*-axis in panel D is analogous to the second (but the economic model allows for product repositioning).

"heavy haul" freight industry buyers, or offer products these buyers might substitute to, so these firms' consolidation has no impact on these buyers' welfare. Comparing these results with panel A, it is clear that markup increases across GWR are tightly linked to the proportion of products that are offered by GM and Chrysler.[49]

High profits, however, lure potential entrants. Panel C of Figure 4 illustrates that it is precisely where markups would otherwise go up the most that surviving rival firms enter new products. The *y*-axis in this panel measures the number of vehicles entered. The acquisition prompts between seven and eight product introductions on average by rivals, all in the vicinity of where markups would otherwise rise sharply. For example, the acquisition incentivizes no entry in the top half of the support of GWR, including in the area around 40,000 GWR vehicles, which see modest

[49] For a comparison of markups to the *count* of GM and Chrysler products and to the total number of offerings, by GWR, please see online Appendix Figure A.I.

markup increases in the absence of entry. Note that although it is not shown, the acquisition results in product exit, too, all by either an acquired or an acquiring brand. In line with economic intuition (Fan and Yang 2016),[50] these exit decisions correspond to products that used to be independently owned brands but are now duplicate offerings of the Ford-GM-Chrysler merged entity. Product characteristics are now *in equilibrium*, i.e., all firm offerings are now consistent with the conditions set forth in the prior section.

How much do product entry and exit affect the markups that would otherwise result from the acquisition? Panel D of Figure 4 shows that the effect is dramatic.[51] As in panel B, the *y*-axis in this panel measures the percentage change in the markup in dollars relative to the case where GM and Chrysler are rescued. In this case, markups for the most affected products only increase 17 percent. Although product entry occurs at only a few distinct GWR values, products (imperfectly) substitute for one another across this characteristic, so all products in the "neighborhood" of the entrants are affected.

The locations of product entry points across GWR show that it is where markups would otherwise go up the most that (net) entry has the biggest impact in driving them back down. For this reason, the distributional effects are strong. The acquisition largely impacts only low- and medium-weight vehicles, so the price changes, or lack thereof, are borne almost entirely by small service, light delivery, agricultural, and utility firms, and to a slightly lesser degree, construction firms.

Table 5 expands on this analysis and compares the Ford acquisition to the other policy choices. The left three columns report predictions from an economic model that ignores product entry and exit. The first two rows report markup changes for the most affected models and vehicle types, respectively, where "type" refers to a unique characteristic bundle, while the third row reports the average markup change in the market. One striking fact from this table is that, ignoring entry and exit, ex post market outcomes depend critically on the policy choice. Markup changes, for example, are much steeper under an acquisition by Ford. This reflects not only increased concentration but also the transfer of overlapping products to Ford's portfolio; buyers substituting away from high Ford prices will face a higher likelihood of switching to a Ford-owned model, which further increases Ford's incentive to price high.

The most affected model in each scenario is Ford's low-GWR conventional truck. Markup increases are only slightly larger under liquidation than a PACCAR acquisition. However, this difference nearly triples when one considers the average markup change for this *type* of vehicle. There are two reasons for this. First, when the choice set does not change (as with an acquisition), markup changes across types are averages across models and thus always more muted than the changes across the models themselves. Second, liquidation eliminates models that, in this setting, happen to have lower margins ex ante than other models with the same characteristics.

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[50] Their recent work shows that allowing for product entry and exit following a merger in the smartphone market may *decrease* predicted ex post product variety and consumer surplus. Their setting and model differ from mine in many ways, e.g., product offering costs are fixed rather than sunk, although the fact that product exit dominates is striking and should compel future work on the horse-race between incentives to enter and exit products.

[51] The scale of the *y*-axis in panel D is fixed to that of panel B to ease the comparison in markups, i.e., not require reinterpreting the height of the bars. However, it makes comparisons over GWR more difficult. For more detail, online Appendix Figure A.II duplicates this figure but with a rescaled *y*-axis for panel D.

Whether model-level or type-level changes are the policy relevant metric is open to debate. Researchers and policymakers may dismiss model-specific preferences, the $\epsilon_{r,j,t}$ terms in the demand system, due to a belief that they reflect, for example, superficial tastes for styling and design. However, unobservables that generate match-specific "error" in the econometric model can reflect real costs like travel time to the dealership just as much as mere cosmetic differences. To make this concrete, consider a buyer who strongly prefers a medium-weight conventional truck. The fact that Mack offers this model at a much lower price than the buyer's local Ford dealership is little help if the nearest Mack dealership is, for example, 200 miles away, and especially little help if servicing necessitates repeat visits.

In either case, distributional effects in the absence of entry and exit are large. Recall that large passenger vehicle operations provided an apparent sunk cost advantage to Big Three producers of low-GWR vehicles, so their product offerings tend to concentrate in the lower half of the support of GWR. The clustering of their products in segments of the market raises the relative concentration from, for example, an acquisition by Ford, but also guarantees that the majority of buyers in this market are unaffected. Despite large predicted markup increases for subsets of products and buyers, the average markup increase, which the third row of Table 5 reports, is just above 10 percent.

The right three columns of table 5 report analogous results to the first three columns but allow for product entry and exit. The result, not to be provocative, is that the policy choice is much less important. Markups for the most affected models increase roughly 6 percent to 17 percent and for the most affected vehicle types about 5 percent to 10 percent.

Although this paper focuses on markups, the main concern of policymakers at the time of the decision was employment. The caveats required for these results to accurately forecast labor use, or stretching further, changes to their welfare, are too numerous to list. Nonetheless, if the number of automotive workers is linear in the number of vehicles produced, at least to first order, then the final three rows of Table 5 are informative in the long run.[52] As with markups, ignoring entry and exit leads to predictions that drastically overstate output drops. The differences are starkest for liquidation due to the combined effect of higher prices *and* fewer choices. In the event of liquidation, total output drops over 11 percent if entry and exit are ignored, but the drop is moderated by nearly 90 percent if entry and exit are accounted for.

To put these quantities in dollar terms requires supplementary data. According to industry reports, Big Three production workers were paid $30 per hour, or $61,200 per year, in wages along with $23 per hour of benefits, including healthcare, life insurance, pension, and other benefits.[53] Commercial vehicle assembly is more labor intensive than passenger cars and truck assembly, with output-to-worker-year ratios of 6.22 at PACCAR, 6.78 at Volvo, 6.33 at Freightliner, 6.89 at Hino, and

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[52] A quantity-driven analysis ignores, at a minimum, relocation costs, and in the extreme case, from the standpoint of US policymakers, the loss of these jobs to Mexico.

[53] Some media sources erroneously add $15 to these benefit costs, which results from dividing the total wage bill by the number of employees, but these reflect "legacy" costs to retired workers afforded more generous packages than exist today and do not reflect current labor costs.

9.32 at International.[54] The latter may reflect a lower-GWR product mix.[55] If the output-to-worker ratio is 8 vehicles per year, then product entry and exit moderates lost wages by over $480 million.[56]

The monetary transfer that potential buyers require to be indifferent between the bailout and the alternate policies reflects both price and product changes. These transfers are reported in the final row of Table 5. Across policy alternatives, compensating variation ranges between $33 million and $253 million if entry and exit are ignored but only $22 million and $28 million if entry and exit are accounted for. In the event of liquidation, entry and exit moderate the required transfer by $225 million: just under a 90 percent drop. Allowing the product offerings to adjust only slightly decreases the required transfer in the event of a PACCAR acquisition, since PACCAR inherits and then retires duplicate product offerings by GM and Chrysler. The same happens in the event of a Ford acquisition, but the drop in markups more than offsets this effect.

The final question is whether accounting for entry and exit could be pivotal to the bailout decision. The answer is "yes," at least within the confines of the commercial vehicle market. The federal government invested a total of $85 billion, of which about $6 billion was required by the commercial vehicle operations of GM and Chrysler (if required funds are proportional to segment sales). At worst, the planner puts zero social weight on the bailout funds[57] and changes in profits.[58]

Without firm-level entry and exit, the changes to markups persist forever. Thus, the return on investment equals the compensating variation divided by the required rescue funds. In the case of liquidation, for example, the break-even discount rate is 4.7 percent when product entry and exit are ignored and 0.5 percent when product entry and exit are allowed. Thus, a planner with a discount rate in that range (between 0.5 percent and 4.7 percent) approves the bailout if product entry and exit are ignored but rejects the bailout if product entry and exit are accounted for. Moreover, the planner may value lost wages and expect these to persist, since worker assembly skills are specialized. In this case, the discount rate for which product entry and exit are pivotal expands to between 2.0 percent and 15.3 percent.[59]

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[54] For the first three producers, these ratios are based on 143,000, 19,000, and 133,000 units, respectively, and 23,000, 2,800, and 21,000 employees respectively. For Hino, this ratio was derived from sales of 1.314 trillion Yen, an exchange rate of 108 Yen per US$1, an average price of $70,000 per vehicle, and 25,000 employees. For International, this ratio is based on $10.775 billion in sales, an average price of $70,000 per vehicle, and 16,500 employees.

[55] This is supported by a press release for GM suggesting that 500 Michigan-area and 544 Ohio-area employees would be fired if the medium duty division of GM were closed down. At the time, the combined GMC and Chevrolet medium duty sales were approximately 10,154 units, resulting in an output-to-worker ratio of 9.7.

[56] This is based on roughly 375,000 units sold per year. The calculation is transparent enough that recalculation under alternate assumptions is left to the reader.

[57] This assumption may not be too far from the truth. As one Treasury official remarked, "Our goal was never to make a profit but to stabilize the auto industry." Of course, some repayment was expected. While early reports of full repayment were misleading, since they referred only to the outstanding debt, which represented a minority of the total Trouble Asset Relief Program (TARP) investment, a 2013 announcement by the Treasury Secretary indicated that the equity stake had generated $39 billion in proceeds.

[58] A weaker condition to arrive at the same result is that the planner values producer surplus, but these gains are substantively canceled out by losses associated with private sector expectations of future bailouts, which encourage risky behavior or under-provision of effort.

[59] These figures are calculated as $253 million/$5,344 million, $28 million/$5,344 million, ($81 million + $28 million)/$5,344 million, and ($569 million + $253 million)/$5,344 million, respectively. The denominators represent $6,015 million in constant 2005 US$.

## VII. Conclusion

Regulatory decisions on subsidies, taxes, and mergers depend on accurate forecasts of how these choices affect ex post market outcomes. The usual antitrust concern is consumer welfare vis-à-vis markup changes, so much of modern empirical industrial organization focused on equilibrium price changes, particularly in differentiated product markets. Much less attention has been paid to entry and exit, perhaps because it is historically infrequent at the *firm level* in most economically important differentiated product markets. Yet, in many of these industries, *model-level* entry and exit are robust and therefore should not be ignored.

This paper provides evidence that endogenous changes in product offerings have a first-order impact on price and output changes. In the context of the $85 billion automotive industry bailout in 2009, at least as it pertains to the commercial vehicle segment of the market, allowing product offerings to adjust, rather than fixing them at pre-policy-decision levels, has a dramatic effect on markups, production, and perhaps even employment. In fact, the effects are large enough that accounting for product entry and exit can easily be pivotal in this policy decision or others like it.

Intuitively, the exit of two large producers, or their merger into a rival that produced similar products, might have led to drastic markup increases reflecting steeply higher market power but for the fact that these potentially high profits would lure rivals to introduce new models. These new models increase variety and make substitution easier, thereby cutting markups and increasing total output. This, in turn, improves consumer welfare and increases the demand for autoworkers. This result depends crucially on sunk costs of product introduction that are low enough relative to perceived profit increases to actually induce this entry. The essential feature of the data that provides these "low-enough" bounds on sunk costs is swift and robust entry (exit) of products following exogenous upward (downward) shifts in demand.

### Appendix

PROOF OF INEQUALITY (8):

To derive this inequality, notice that

$$\frac{1}{XTF} \sum_{x_j} \sum_t \sum_f h^i_{f,x_j,t} \{j \in J_{f,t}\} \, \Delta \hat{\pi} (J_{f,t}, J_{f,t} \backslash j, J_{-f,t}, x_t, w_t)$$

$$+ \frac{1}{XTF} \sum_{x_j} \sum_t \sum_f h^i_{f,x_j,t} \{j \in J_{f,t}\} x'_j (\{j \notin J_{f,t-1}\} - \lambda \{j \in J_{f,t-1}\}) \theta_f$$

$$= \frac{1}{XTF} \sum_{x_j} \sum_t \sum_f h^i_{f,x_j,t} \{j \in J_{f,t}\} \, \Delta \pi (J_{f,t}, J_{f,t} \backslash j, J_{-f,t}, x_t, w_t)$$

$$+ \frac{1}{XTF} \sum_{x_j} \sum_t \sum_f h^i_{f,x_j,t} \{j \in J_{f,t}\} x'_j (\{j \notin J_{f,t-1}\} - \lambda \{j \in J_{f,t-1}\}) \theta_f$$

$$= \frac{1}{XTF} \sum_{x_j} \sum_t \sum_f h^i_{f,x_j,t} \{j \in J_{f,t}\} \, \Delta \pi (J_{f,t}, J_{f,t} \backslash j, J_{-f,t}, x_t, w_t)$$

$$+ \frac{1}{XTF} \sum_{x_j} \sum_t \sum_f h^i_{f,x_j,t}\{j \in J_{f,t}\} x'_j (\{j \notin J_{f,t-1}\} - \lambda\{j \in J_{f,t-1}\})\theta_{f,x_j,t}$$

$$- \frac{1}{XTF} \sum_{x_j} \sum_t \sum_f h^i_{f,x_j,t}\{j \in J_{f,t}\} x'_j (\{j \notin J_{f,t-1}\} - \lambda\{j \in J_{f,t-1}\})\nu_{2,t}$$

$$= \frac{1}{XTF} \sum_{x_j} \sum_t \sum_f h^i_{f,x_j,t}\{j \in J_{f,t}\} \Delta\pi(J_{f,t}, J_{f,t}\backslash j, J_{-f,t}, x_t, w_t)$$

$$+ \frac{1}{XTF} \sum_{x_j} \sum_t \sum_f h^i_{f,x_j,t}\{j \in J_{f,t}\} x'_j (\{j \notin J_{f,t-1}\} - \lambda\{j \in J_{f,t-1}\})\mathscr{E}[\theta_{f,x_j,t}|\mathscr{I}_{f,t}]$$

$$+ \frac{1}{XTF} \sum_{x_j} \sum_t \sum_f h^i_{f,x_j,t}\{j \in J_{f,t}\}(\{j \notin J_{f,t-1}\} - \lambda\{j \in J_{f,t-1}\})\nu_{1,f,t,J_{f,t},J_{f,t}\backslash j,J_{f,t-1}}$$

$$- \frac{1}{XT} \sum_{x_j} x'_j h^i_{x_j} \sum_t h^i_{x_j,t}\nu_{2,t} \left[\sum_f \{j \in J_{f,t}\}\tilde{h}^i_{f,x_j,t} + \{h^i_{x_j,t} = 0\}\right]^{-1}$$

$$\times \sum_f \tilde{h}^i_{f,x_j,t}\{j \in J_{f,t}\}(\{j \notin J_{f,t-1}\} - \lambda\{j \in J_{f,t-1}\})$$

$$= \frac{1}{XTF} \sum_{x_j} \sum_t \sum_f h^i_{f,x_j,t}\{j \in J_{f,t}\} \Delta\pi(J_{f,t}, J_{f,t}\backslash j, J_{-f,t}, x_t, w_t)$$

$$+ \frac{1}{XTF} \sum_{x_j} \sum_t \sum_f h^i_{f,x_j,t}\{j \in J_{f,t}\} x'_j (\{j \notin J_{f,t-1}\} - \lambda\{j \in J_{f,t-1}\})\mathscr{E}[\theta_{f,x_j,t}|\mathscr{I}_{f,t}]$$

$$+ \frac{1}{XTF} \sum_{x_j} \sum_t \sum_f h^i_{f,x_j,t}\{j \in J_{f,t}\}(\{j \notin J_{f,t-1}\} - \lambda\{j \in J_{f,t-1}\})\nu_{1,f,t,J_{f,t},J_{f,t}\backslash j,J_{f,t-1}}$$

$$- \frac{1}{XT} \sum_{x_j} x'_j h^i_{x_j} \sum_t h^i_{x_j,t}\nu_{2,t}C$$

$$\xrightarrow{p} E_{x_j,t,f}\left[h^i_{f,x_j,t}\{j \in J_{f,t}\} \Delta\pi(J_{f,t}, J_{f,t}\backslash j, J_{-f,t}, x_t, w_t)\right]$$

$$+ E_{x_j,t,f}\left[h^i_{f,x_j,t}\{j \in J_{f,t}\}\left[x'_j(\{j \notin J_{f,t-1}\} - \lambda\{j \in J_{f,t-1}\})\mathscr{E}[\theta_{f,x_j,t}|\mathscr{I}_{f,t}]\right]\right]$$

$$+ E_{x_j,t,f}\left[h^i_{f,x_j,t}\{j \in J_{f,t}\}(\{j \notin J_{f,t-1}\} - \lambda\{j \in J_{f,t-1}\})\nu_{1,f,t,J_{f,t},J_{f,t}\backslash j,J_{f,t-1}}\right]$$

$$- CE_{x_j}\left[x'_j h^i_{x_j} E_t\left[h^i_{x_j,t}\nu_{2,t}\right]\right] \geq 0,$$

where $h^i_{f,x_j,t} = F\left[\sum_f \{j \in J_{f,t}\}\tilde{h}^i_{f,x_j,t} + \{h^i_{x_j,t} = 0\}\right]^{-1} h^i_{x_j} h^i_{x_j,t}\tilde{h}^i_{f,x_j,t}$. Here, $i$ indexes the moments; $j$ indexes the product types, i.e., the unique bundles of characteristics itemized in Footnote 31; $x_j$ is the vector of characteristics excluding price for $j$, so $(f, j, t)$-indexing is at the same level of specificity as $(f, x_j, t)$-indexing.

Note that $h^i_{x_j}$ selects observations based on product characteristics. For example, if the $i$th moment considers conventional vehicles only, then $h^i_{x_j} = 1$ when the *cabover*, *compact*, and *long* dummy variables in $x_j$ equal 0, and $h^i_{x_j} = 0$ otherwise. Further, $h^i_{x_j,t}$ depends on the demand shifters specific to the subset of product types and action under consideration. For example, the construction industry accounts for the largest

proportion of medium GWR vehicles. Hence, if the $i$th moment considers the entry of medium GWR vehicle buyers, then $h^i_{x_j,t} = 1$ for $t$ in which the proportion of prospective buyers from the construction industry is particularly high. Finally, $\tilde{h}^i_{f,x_j,t}$ selects observations such that either $j \in J_{f,t-1}$ or $j \notin J_{f,t-1}$. For example, if the $i$th moment considers entry, then $\tilde{h}^i_{f,x_j,t} = 1$ when $j \notin J_{f,t-1}$, and $\tilde{h}^i_{f,x_j,t} = 0$ otherwise. Note that $C$ is a constant equal to 1 if $\tilde{h}^i_{f,x_j,t}$ selects $j \notin J_{f,t-1}$ and equal to $-\lambda$ otherwise, as described below.

The first step replaces $\Delta\hat{\pi}$ with $\Delta\pi$. This follows from Assumption 3, which provides that second-stage payoffs are measured without error. The second step replaces $\theta_f$ with $\theta_{f,x_j,t} - \nu_{2,t}$. This follows from Assumption 2, which restricts the unobservable (to the econometrician) heterogeneity in the sunk cost disturbances. Note that $\nu_{2,t}$ is a vector whose elements are characteristic-specific, as defined in the body of the paper. The third step replaces $x'_j\theta_{f,x_j,t}$ with $x'_j\mathscr{E}[\theta_{f,x_j,t}|\mathscr{I}_{f,t}] + \nu_{1,f,t,J_{f,t},J_{f,t}\setminus j,J_{f,t-1}}$, which follows from the definition of the expectational errors, i.e., the $\nu_1$ terms (see Section III). It also redefines $h^i_{f,x_j,t}$ and then extracts $h^i_{x_j}$, $x_j$, $h^i_{x_j,t}$, and $\nu_{2,t}$ from the inner summations. The fourth step simplifies the product of $\frac{1}{F}\sum_f \{j \in J_{f,t}\}\tilde{h}^i_{f,x_j,t}$ and its reciprocal, given any $x_j$ and $t$, to 1, provided that $h^i_{x_j,t} \neq 0$.[60] The fifth step follows from the law of large numbers.

These manipulations yield three expectations. Regarding the first term, notice that inequality (6) provides that the bracketed term,

$$\Delta\pi(J_{f,t}, J_{f,t}\setminus j, J_{-f,t}, z_t, w_t) + x'_j(\{j \notin J_{f,t-1}\} - \lambda\{j \in J_{f,t-1}\})\mathscr{E}[\theta_{f,x_j,t}|\mathscr{I}_{f,t}],$$

is weakly positive for all $j \in J_{f,t}$. Since $h_i$ is weakly positive, and since the linear combination of weakly positive terms is itself weakly positive, the first term is weakly positive. Regarding the second term, $\nu_{1,\cdot}$ is mean independent of objects in the agent's information set and not known by firms when they make choices. Hence,

$$E_{x_j,t,f}\Big[h^i_{f,x_j,t}\{j \in J_{f,t}\}(\{j \notin J_{f,t-1}\} - \lambda\{j \in J_{f,t-1}\})\nu_{1,f,t,J_{f,t},J_{f,t}\setminus j,J_{f,t-1}}\Big]$$

$$= E_{x_j,t,f}\Big[h^i_{f,x_j,t}\{j \in J_{f,t}\}(\{j \notin J_{f,t-1}\} - \lambda\{j \in J_{f,t-1}\})\Big]$$

$$\times E_{x_j,t,f}\Big[\nu_{1,f,t,J_{f,t},J_{f,t}\setminus j,J_{f,t-1}}\Big] = 0.$$

Regarding the third term, $\nu_{2,t}$ is mean independent objects in the agent's information set[61] and not indexed by $x_j$, so $E_{x_j}\Big[h^i_{x_j}x'_jE_t\big[h^i_{x_j,t}\nu_{2,t}\big]\Big]$ can be written as $E_{x_j}\Big[h^i_{x_j}x'_jE_t\big[\nu_{2,t}|h^i_{x_j,t}\big]E_t\big[h^i_{x_j,t}\big]\Big]$ and as the product of $E_{x_j}\Big[h^i_{x_j}x'_jE_t\big[h^i_{x_j,t}\big]\Big]$ and $\big[E_t\nu_{2,t}\big]$.

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[60] These are the weights described in footnote 37. Note that for some moments, in particular those that pertain to product entry and exit, the data does not guarantee that for every $x_j$ and $t$, at least one firm takes the action in question. For example, consider a moment that pertains to entry. For $x_j$ and $t$ such that the demand shifters provide $h^i_{x_j,t} \neq 0$, the data guarantees there at least one firm enters. However, for $x_j$ and $t$ such that $h^i_{x_j,t} = 0$, there is no such guarantee. If no firm enters, $\sum_f \{j \in J_{f,t}\}\tilde{h}^i_{f,x_j,t} = 0$, and $\big[\sum_f \{j \in J_{f,t}\}\tilde{h}^i_{f,x_j,t}\big]^{-1}$ is undefined. Thus, to avoid division by zero, an indicator for $h^i_{x_j,t} = 0$ is included in the bracketed term in the denominator.

[61] Hence, $\nu_{2,t}$ is mean independent of $h^i_{x_j,t}$, which depends on the demand shifters. For example, one could base $h^i_{x_j,t}$ on a law change or on recent expansion or contraction of the industries in which prospective buyers of commercial vehicles operate. See Section III for more details on the choice of $h^i_{x_j,t}$.

The second term in the product is the unconditional mean of the disturbance, which equals zero. ∎

PROOF OF INEQUALITY (9):

To derive this inequality, proceed analogously to the proof above. Any differences are cataloged here. The second-stage profits are computed for $J$ relative to $J \cup j$ rather than for $J$ relative to $J \setminus j$. The term $\{j \notin J_{f,t}\}$ is substituted for $\{j \in J_{f,t}\}$. The signs on all sunk cost-related terms, $\theta_f$, $\theta_{f,x_j,t}$, $\mathscr{E}[\theta_{f,x_j,t} | \mathscr{I}_{f,t}]$, $\nu_{1,\cdot}$ and $\nu_{2,t}$, are the opposite of the signs on those terms in the proof of inequality (8). Expectational errors are given by $\nu_{1,f,t,J_{f,t},J_{f,t} \cup j, J_{f,t-1}}$ rather than by $\nu_{1,f,t,J_{f,t},J_{f,t} \setminus j, J_{f,t-1}}$.

To summarize the notational differences, the first and last lines are given by

$$\frac{1}{XTF} \sum_{x_j} \sum_t \sum_f h^i_{f,x_j,t} \{j \notin J_{f,t}\} \, \Delta \hat{\pi}(J_{f,t}, J_{f,t} \cup j, J_{-f,t}, x_t, w_t)$$

$$- \frac{1}{XTF} \sum_{x_j} \sum_t \sum_f h^i_{f,x_j,t} \{j \notin J_{f,t}\} \big[ x'_j (\{j \notin J_{f,t-1}\} - \lambda \{j \in J_{f,t-1}\}) \theta_f \big]$$

$$\xrightarrow{p} E_{x_j,t,f} \Big[ h^i_{f,x_j,t} \{j \notin J_{f,t}\} \, \Delta \pi(J_{f,t}, J_{f,t} \cup j, J_{-f,t}, x_t, w_t) \Big]$$

$$- E_{x_j,t,f} \Big[ h^i_{f,x_j,t} \{j \notin J_{f,t}\} \big[ x'_j (\{j \notin J_{f,t-1}\} - \lambda \{j \in J_{f,t-1}\}) \mathscr{E}[\theta_{f,x_j,t} | \mathscr{I}_{f,t}] \big] \Big]$$

$$- E_{x_j,t,f} \Big[ h^i_{f,x_j,t} \{j \notin J_{f,t}\} (\{j \notin J_{f,t-1}\} - \lambda \{j \in J_{f,t-1}\}) \nu_{1,f,t,J_{f,t},J_{f,t} \cup j, J_{f,t-1}} \Big]$$

$$+ CE_{x_j} \Big[ h^i_{x_j} x'_j E_t \big[ h^i_{x_j,t} \nu_{2,t} \big] \Big] \geq 0,$$

where $h^i_{f,x_j,t} = F \Big[ \sum_f \{j \notin J_{f,t}\} \tilde{h}^i_{f,x_j,t} + \{h^i_{x_j,t} = 0\} \Big]^{-1} h^i_{x_j} h^i_{x_j,t} \tilde{h}^i_{f,x_j,t}$. Note that inequality (7) provides that the bracketed portion of the first expectational term is weakly positive (rather than inequality (6), which was used in the prior proof). Note also that $E_{x_j,t,f} \Big[ h^i_{f,x_j,t} \{j \notin J_{f,t}\} (\{j \notin J_{f,t-1}\} - \lambda \{j \in J_{f,t-1}\}) \nu_{1,f,t,J_{f,t},J_{f,t} \cup j, J_{f,t-1}} \Big]$ and $CE_{x_j} \Big[ h^i_{x_j} x'_j E_t \big[ h^i_{x_j,t} \nu_{2,t} \big] \Big]$ both equal 0 by analogous logic to that which is used in the prior above. ∎

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