Contractibility and Asset Ownership:
On-Board Computers and Governance in U.S. Trucking

George P. Baker*
Thomas N. Hubbard**

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We investigate how the contractibility of actions affecting the value of an asset affects asset ownership by examining how truck ownership has changed with the diffusion of on-board computers (OBCs). We develop and test the proposition that driver ownership should decrease with OBC adoption, particularly for hauls where drivers have the greatest incentive to drive in non-optimal ways or engage in rent-seeking behavior. We present evidence consistent with this proposition: driver ownership decreases with OBC adoption, especially for long hauls. In contrast, driver ownership falls less with adoption for hauls that use trailers for which demands are unidirectional than bi-directional, corresponding to differences in the rent-seeking costs of driver ownership. We also find that non-owner drivers with OBCs drive better than those without them. These results suggest that increases in contractibility may lead to less independent contracting and larger firms.

*Harvard Business School and NBER
**University of Chicago Graduate School of Business and NBER

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1. Introduction

What determines who owns assets in the economy? This question, essential to determining the boundary of the firm, goes back at least to Coase (1937), who argued that transactions are mediated within firms rather than through markets when the cost of transacting in markets is higher than the cost of internal coordination. Williamson (1975, 1985) and Klein, Crawford, and Alchian (1978) extended and elaborated on this insight, arguing that contractual incompleteness in the presence of opportunism and asset specificity leads to transaction costs in markets that are mitigated by firms. A natural implication of this line of analysis is that improvements in contracting should reduce transactions costs in markets, and thus lead to less vertical and horizontal integration.[1]

Recent theories of firms' boundaries (e.g., Grossman and Hart (1986), Holmstrom and Milgrom (1994)) have embraced a "level playing field" approach to integration that emphasizes that contractual incompleteness affects the cost of transacting within firms as well as in markets, and in which organizational form does not affect the contractibility of any piece of information. An implication of this view, discussed in Baker and Hubbard (2001), is that contractual improvements can lead either to more or less concentrated asset ownership: how increases in contractibility affect firms' boundaries depends critically on the details of what becomes contractible.

This paper examines relationships between asset ownership and the contracting environment in the United States trucking industry. Trucking is a good empirical context in which to investigate the determinants of asset ownership for several reasons. First, while truck-tractors (the front halves of tractor-trailer combinations; hereafter "trucks") are quite homogeneous, they are operated under different organizational forms. In 1987, about 15% of the approximately one million trucks in the United States were owner-operated; the rest were operated by "company drivers" – individuals who do not own the trucks they operate. Second, there exist detailed micro-level data about the ownership, characteristics, and use of individual trucks. These data exist for multiple years, allowing for time-series as well as cross-sectional analysis. Third, an important new technology became available during our sample period that fundamentally changed contractibility in the industry. Combined, these features allow us to test theoretical propositions about ownership with more

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[1] Malone, Yates, and Benjamin (1987) have applied this logic to argue that contractual improvements enabled by information technology should lead to greater reliance on markets as institutions for mediating economic activity.

precision than most previous empirical studies of organizations. We can examine not only the cross-sectional patterns of asset ownership, but also how ownership patterns change with changes in the contracting environment, and can do so at an unusually high level of detail. A broad finding from our analysis is that driver ownership of trucks has declined with increases in the contractibility of drivers' actions; in this industry, improvements in the contracting environment have been associated with a greater reliance on firms as mechanisms for mediating economic activity.

We first develop a model in which incomplete contracting affects the costs of transacting both within firms and through markets. In this model—the details of which are derived from discussions with truck drivers, dispatchers, and others in the industry—truck ownership is determined by weighing the costs and benefits of allocating two sets of residual decision rights to drivers: control over the use of the truck and control over the care of the truck. The relative importance of these decision rights and their interaction with other non-contractible decision rights determine the optimal ownership of trucks. We argue that allocating control rights over the use of the truck to drivers strengthens their incentives to engage in inefficient rent-seeking behavior. Mitigating these incentives is a benefit of using company drivers rather than owner-operators. On the other side of the balance is the benefit of giving drivers the residual claim on the value of the truck. The value of the truck is determined by how the driver drives, as well as a host of other residual decisions about care and maintenance (generally performed when the truck is in the shop) that are held by the truck's owner.[2] We model the *costs and benefits* of driver ownership, assuming initially that how the driver drives the truck is not contractible.

The model generates two propositions about cross-sectional relationships between haul characteristics and optimal ownership. One is that drivers should own trucks more when trucks are used for long than short hauls; the benefits of giving drivers ownership incentives are highest when driving in ways that do not preserve trucks' value would otherwise be most tempting. The other is that they should own trucks more when hauls require equipment for which demands are unidirectional than bidirectional; as we explain in more detail below, the costs of driver ownership

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[2] In our model, the allocation of the "in shop" maintenance decision rights does not affect the quality of these decisions: either the company or the driver can make these decisions equally well. What matters is that the holder of these decision rights holds the residual claim on the value of the truck.

are lower in the former case because truck ownership encourages rent-seeking only when "backhaul" (return trip) opportunities exist for the truck. Using truck-level data from the 1987 and 1992 Truck Inventory and Use Surveys (TIUS), we find evidence in favor of these propositions.

This cross-sectional analysis is preliminary to our main analysis, which exploits the time-series nature of our dataset as well as the change in contractibility noted above, and subjects the model to increasingly more stringent tests. In the late 1980s, on-board computers (OBCs) expanded the set of variables upon which carriers and drivers could contract. OBCs continuously record various operating parameters of trucks (e.g., their speed), allowing truck owners to construct better performance measures of how drivers operate trucks. Our model shows how this change in the contractibility of key decisions should change the optimal ownership of trucks: it should increase the use of company drivers, especially for hauls where drivers have the greatest incentive to drive in suboptimal ways. Our logic is simple: OBCs lead the benefits of driver ownership (strong incentives to take non-contractible actions that preserve the value of the truck) to decline, but do not affect the costs of driver ownership (incentives to engage in inefficient rent-seeking). Using first-difference specifications, we find evidence in favor: driver ownership decreases with OBC adoption, and this relationship is stronger for longer hauls. This evidence is consistent with the proposition above and is our main empirical result.

It is important to recognize that this empirical result—OBC adoption is associated with reduced driver ownership, especially for long hauls—is consistent with any number of alternative theories that propose a benefit of driver ownership associated with improved driver actions, and a cost of driver ownership that is unaffected by OBC adoption. Consider a model in which drivers are risk averse and own trucks only when the incentive benefits of driver ownership outweigh the risk-bearing costs. Such a model would also predict that a technology that achieves these incentive benefits without allocating the full risk of ownership to the driver should lead to less driver ownership of trucks, especially for long hauls.[3] We therefore provide a more stringent test of our model of the cost of driver ownership by testing an additional prediction: the relationship between

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[3] A similar argument could be made if drivers were wealth constrained. Yet another argument has been offered by Nickerson and Silverman (2002), who argue that asset specificity (in the form of interactions between drive-train configurations and haul characteristics) discourage drivers from owning certain trucks and provide evidence consistent with this.

OBC adoption and changes in driver ownership should be stronger when driver rent seeking is a problem than when it is not. Specifically, we examine whether this relationship is stronger for hauls for which there is typically a “backhaul” than those for which there generally is not. We find evidence that this is the case, suggesting that part of the cost of allocating ownership rights to drivers is that it invites rent-seeking behavior.

These first-difference results relate changes in ownership to changes in OBC use. However, as our theoretical model emphasizes, OBC adoption is endogenous, so they need not reflect that adoption causes ownership changes. While first-differencing controls for unobserved time-invariant haul characteristics that could drive both OBC adoption and ownership, it does not eliminate the possibility that unobserved haul characteristics that change over time drive our results. We provide some additional evidence with respect to causality by exploiting the fact (discussed at length in Section 2) that OBCs are adopted for reasons other than improving drivers' incentives. These non-incentive benefits vary across hauls – for example, because the value of improving coordination with shippers is greater when trucks haul some products than others. We argue that these other classes of benefits are independent of unobserved changes in haul characteristics affecting ownership. We therefore run the first difference specifications, using the products trucks haul as instruments for OBC adoption. Our point estimates change little when we do so, although our results are weaker due to higher standard errors.

Finally, we examine relationships between trucks' fuel economy and OBC use. This provides direct evidence regarding whether increased contractibility affects how drivers drive. We find that controlling for trucks' characteristics, how they are used, and where they are maintained, trucks with OBCs get better fuel economy than trucks without them. This is not surprising: OBCs provide a number of potential maintenance benefits that could improve fuel economy. However, the fuel economy difference between company drivers with and without OBCs is greater than the difference between owner-operators with and without them. Furthermore, this is true only for long-haul drivers. The evidence thus supports our characterization of how OBCs affect drivers' behavior.

Overall, our evidence suggests that contractual improvements have led to more integrated asset ownership in trucking, especially in circumstances where allocating control rights to drivers is costly. Contractual improvements need not lead to more market transacting: how contractual improvements relate to changes in firms' boundaries depends critically on what becomes contractible and on how these newly-contractible decision rights interact with other non-contractibles.

This paper extends several strains of the empirical literature on organizations. Our emphasis on relationships between contractibility and ownership is similar to work that examines how outlet characteristics (which affect how well managerial actions can be monitored) influence contractual form in franchising (Brickley and Dark (1987), Lafontaine (1992), Shepard (1993)). We are able to construct more powerful empirical tests than these earlier papers because we can base them on relationships between informational and organizational *changes* rather than *levels*. Our evidence that monitoring and ownership are substitutes is consistent with findings from this literature; our emphasis on changes in contractibility is new. This paper is also related to a growing empirical literature that examines relationships between IT adoption and organizational form. (See Brynjolffson and Hitt (1997) and its citations.) Our data and context allow us to provide much more detailed evidence regarding why organizational form changes with new IT than most papers in this literature. Finally, the paper is related to recent work that investigates organizational issues in trucking (Hubbard (2001), Lafontaine and Masten (2002), Nickerson and Silverman (2002)), some of which focuses on technological issues (Chakraborty and Kazarosian (1999), Hubbard (2000)). In particular, it is closely related to Baker and Hubbard (2002), which examines relationships between OBC adoption and shippers' make-or-buy decision; i.e., whether shippers use a truck from their private fleet for a haul, or outsource their shipping needs to for-hire carriers.

An outline of the rest of the paper follows. In section 2, we describe contracting problems in trucking, and how asset ownership and OBCs affect them. In section 3, we build a formal model that generates the hypotheses to be tested. In section 4, we describe the data and present cross-sectional patterns with respect to ownership and OBC use. In section 5, we present and interpret our main results, estimates of relationships between OBC adoption and organizational change. In section 6, we present some evidence of OBCs' incentive effects by examining relationships between OBC use and fuel economy. In section 7, we conclude.

2. Production, Contractibility, and Asset Ownership in Trucking

Carriers (for-hire trucking firms and trucking divisions of firms that are not trucking specialists, so-called "private fleets") haul goods for shippers (firms or divisions that want cargo moved from one place to another). When carriers receive orders, their dispatchers assign trucks and drivers to hauls. They may use company trucks and company drivers, or they may use owner-operators; many carriers use each for different hauls.[4] In either case, they face several incentive problems in their agency relationship with their drivers. One is motivating drivers to complete hauls in a timely fashion; another is inducing them to drive in ways that neither cause undue wear and tear on trucks and their engines nor lead to higher than optimal accident rates. Arriving on time and driving in an optimal way are costly for drivers because they require effort and restrict drivers' ability to work at their own pace.

Motivating drivers (whether company drivers or owner-operators) to arrive on time is relatively straightforward. Performance incentives work well. Carriers can obtain verified information regarding arrival times at low cost and reward drivers accordingly. Shippers generally notify carriers when trucks arrive unexpectedly late. Carriers reward drivers who consistently arrive on time with bonuses or good job assignments and punish those who consistently arrive late by firing them (if a company driver) or not hiring them again (if an owner-operator). Although factors outside of drivers' control affect whether drivers arrive on time, carriers often can verify whether traffic or delays in loading or unloading trucks cause trucks to be late. Agency costs associated with late arrivals are thus not large.[5]

Motivating company drivers to drive in an optimal fashion is more difficult because performance incentives are less efficient. Conditional on arriving on time, the cost of a haul is lower when drivers drive at a consistent rate than at a variable rate. Costs are increasing and convex in speed, both because of higher fuel consumption and greater depreciation of trucks' engines. Drivers may prefer to drive quickly then take longer breaks because it allows them to rest longer, visit friends, etc., and still arrive on time. Their ability to do so is particularly high on hauls with

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[4] Owner-operators generally operate as subcontractors within a larger trucking fleet. This helps our analysis of ownership because using owner-operators need not, and generally does not, imply the loss of scale economies in our context.

[5] An exception to this is when contract enforcement issues inhibit carriers from punishing poor-performing drivers. Carriers sometimes allege this to be the case for union drivers. We do not emphasize such issues because the analysis is based primarily on the “truckload” sector, which is mostly not unionized.

infrequent scheduled stops because there is more opportunity to make up time. Although one can base performance incentives on fuel use, trucks' condition, or accident rates, such measures are noisy indicators of how drivers drive. Fuel use and trucks' condition largely reflect how well trucks are maintained and accidents are rare events that are often caused by other drivers. Traditionally, how drivers drive has been non-contractible.

Asset ownership can motivate drivers to drive well. Owner-operators are residual claimants on the value of their truck and are responsible for maintenance and fuel purchases. They therefore internalize most of the costs associated with how they drive.

On the basis of the above description, it would seem that most hauls, especially long hauls, should be completed by owner-operators. However, another contracting problem plagues the agency relationship between carriers and drivers, and leads to high levels of company ownership of trucks, even for long hauls. Drivers must be motivated to accept hauls and owner-operators, because they have control rights over their truck, have incentives to engage in activities that increase their bargaining power with carriers.

Hauls vary in their desirability to drivers. Those that take drivers into congested or dangerous areas are less desirable than those that do not. Hauls that involve layovers or empty ("deadhead") miles can be undesirable to long-haul drivers, whose compensation is generally output-based.[6] Carriers negotiate with drivers to induce them to accept undesirable hauls, particularly when drivers are far from their base and carriers have no other drivers in the area. This negotiation usually involves a combination of moral suasion, promises to assign drivers desirable hauls in the future, and pecuniary compensation. Negotiation is pervasive because the timing of demand and availability of capacity are extremely difficult to forecast precisely outside of very short horizons. Carriers usually are not able to specify the exact hauls they will offer drivers more than a few hours in advance. Although arrangements between carriers and drivers usually extend over multiple periods, they are incomplete with respect to the specific hauls they cover.

Company drivers and owner-operators differ both in their leverage with carriers and in the extent they can improve their bargaining position. Company drivers can quit, but doing so leaves

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[6] Drivers' compensation for intercity hauls is generally based on either miles, loaded miles, or a fraction of the haul's revenues. This is true for both company drivers and owner-operators.

them with no equipment and whatever prospect they have for finding alternative employment. Owner-operators, on the other hand, have their trucks: they can access spot markets for hauls that exist in many regions. These markets, usually mediated by brokers, offer owner-operators and carriers access to hauls and play an important role in helping them fill long "backhauls" when return trips are not prearranged. Spot markets exist for certain types of hauls and capacity, but are almost non-existent for others. When trucks haul cargo in trailers for which demands are unidirectional (for instance logging trailers), there are virtually no backhaul opportunities. There tends to be no spot market in destination cities for such capacity.

Except in situations where there is no opportunity for backhauls, truck ownership gives owner-operators the ability to access, and the incentive to explore, alternative shipments even while they are completing hauls for a particular carrier. Identifying alternative hauls improves their bargaining position with the carrier, and promises better terms for the hauls that they accept.

This description of carriers' relationship with their company drivers and owner-operators is consistent with characterizations in the literature, and those related to us in interviews. Dispatchers often claim that they have more difficulty inducing owner-operators to accept hauls than company drivers. Unlike company drivers, owner-operators are considered to have the right to refuse hauls; owner-operators are more "difficult to control" as a consequence.[7] The model of driver rent-seeking that we develop in the next section attempts to capture—in a stylized way—this frequently cited advantage of company ownership of trucks.

The implication with respect to ownership patterns is the following: using owner-operators is costly in situations where they have incentives to invest in bargaining positions for subsequent hauls—that is, search for alternative hauls. Driver ownership of trucks mitigates incentive problems with how trucks are driven, but can induce drivers to engage in rent-seeking behavior.

Regulatory Issues and Control Rights Over Trucks

Economic regulation of the trucking industry decreased dramatically during the late 1970s

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[7] See Maister (1980), Ouelett (1994), for example. Practitioner opinions about organizational forms are notoriously suspect, since they rarely have extensive experience with multiple forms, and are thus subject to the "grass is always greener on the other side of the fence" syndrome. Our interview data is less subject to this criticism, since the dispatchers with whom we spoke simultaneously work with both company drivers and owner-operators.

and early 1980s. It did not vanish, however. One provision that remains is that firms must obtain operating authority from the Federal government in order to legally haul goods between states. The cost of obtaining operating authority is not prohibitive but is high enough so that not all truck owners obtain it. Many owner-operators do not have operating authority, and therefore must operate under the authority of a carrier that does.[8] Federal law requires owner-operators who operate under another carrier's authority to formally transfer control rights over their truck to the carrier during the period in which they are doing so. This is accomplished by an owner-operator lease. Some of these leases nominally cover long periods; six-month or one-year leases are not uncommon. In practice, most are open-ended.

On their face, long-term owner-operator leases appear to limit owner-operators' incentives for rent-seeking behavior: drivers cannot threaten to serve other customers if carriers have control rights over their truck. But the formal lease terms are misleading. Carriers do not deny owner-operators access to their trucks, even when drivers unilaterally terminate leases prematurely. The control right provisions in owner-operator leases are, for our intents and purposes, a legal fiction. They do not change the depiction of incentive conflicts above.[9]

This discussion gives rise to a more general contractual question: why don't owner-operators contractually forfeit the right to take their truck with them whenever they quit? Contractual arrangements in which owner-operators agree not to use the truck for hauls other than the carrier's would lower drivers' rent-seeking incentives while retaining their incentive to maintain their trucks and drive well. However, such arrangements would create new incentive problems: carriers could appropriate rents associated with the truck. One way they could do so is by offering drivers only hauls that are undesirable for the reasons given above. Not surprisingly, arrangements that give drivers residual claimancy but no control rights over the use of their trucks are not optimal.

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[8] Most owner-operators have continuing relationships with one or more large carriers through whom they obtain hauls. Those without authority are required to formalize such relationships.

[9] Thanks to Francine Lafontaine for useful discussions about owner-operator leases. See CFR 376.11 for the relevant regulations.

On-Board Computers

On-board computers (OBCs) appeared on the market during the mid-to-late 1980s.[10] There are two classes of OBCs: trip recorders and electronic vehicle management systems (EVMS). As of 1992, trip recorders cost about $500. EVMS hardware cost $3,000-$4,000 to buy or about $150/month to lease.

Trip recorders collect information about trucks' operation; one can think of them as trucks' "black boxes." They record when trucks are turned on and off, their speed over time, acceleration and deceleration patterns, fuel use, and variables related to engine performance. Data from trip recorders are collected when drivers return to their base; drivers give dispatchers a chart, floppy disk, or data cartridge with the data. EVMS contain all trip recorders' capabilities, but have several additional features. For example, they can transmit trucks' real-time location to carriers, often via links to global positioning systems. They also allow dispatchers and drivers to send short text messages to each other, making it easier for dispatchers to initiate communication with drivers when they are out of radio range.

Both classes of OBCs provide carriers better measures of how drivers operate trucks; for example, carriers can verify better when drivers speed or take long breaks. While this paper's primary focus is on how this particular contractual improvement affects whether drivers own trucks, OBCs also offer other benefits. They can help verify the cause of accidents to third parties such as insurers (was the truck speeding?), or carriers' customers (did the truck arrive late because of traffic or because it departed late?). They can also provide mechanics with information about trucks' engines that helps them diagnose problems better.[11] EVMS' communication capabilities make them useful for improving resource allocation (scheduling) decisions as well as contracts and maintenance. For example, knowing exactly where trucks are in real time helps dispatchers schedule their next haul more effectively. It also lets carriers provide their customers better forecasts of trucks' arrival time, thereby letting customers better schedule cargo-handlers and others involved in taking

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[10] See Hubbard (2000) for more details.

[11] "On-Board Computers Enhance Driver Performance," *Fleet Equipment*, January 1989, describes in detail how carriers use trip recorders to monitor drivers and improve maintenance.

deliveries. This tends to be valuable when trucks deliver to loading docks, especially when recipients employ "just-in-time" inventory practices.

Hubbard (2000) investigates OBC adoption in detail. Using cross-sectional data from 1992, he finds that OBC use is higher for longer hauls and for trucks operated by company drivers. OBC use thus tends to reflect the magnitude of agency problems between carriers and drivers with respect to operation of the truck. Conditional on who owns the truck and haul length, OBC use is also high when trucks haul hazardous cargo such as petroleum or chemicals, or haul products for which sales/inventory ratios tend to be high. These facts suggest that OBC use goes up when the value of verifying trucks' operation to third parties (such as insurers and customers with lean inventories) is high. Finally, he finds that EVMS adoption is high relative to trip recorder adoption when trucks haul products that are generally delivered to loading docks or are used for hauls with irregular schedules; OBCs' coordination-improving capabilities are particularly valuable in such circumstances.

These previous results shape the empirical framework in this paper in two important ways. First, they confirm that OBC adoption is endogenous. When interpreting relationships between OBC adoption and truck ownership, we must therefore account for the fact that OBCs are not adopted randomly. The fact that we examine relationships between adoption and *changes* in organizational form rather than levels -- does driver ownership diminish more in segments with higher adoption rates? – makes this less of an issue than it otherwise would be, but the issue does not disappear entirely. Second, they provide evidence that OBCs offer benefits other than improving contracts with drivers, and that these other benefits vary systematically with the nature of the cargo. We will exploit this below in exploring whether the empirical relationships we find are causal, as we use cargo characteristics as instruments for adoption in differences-in-differences specifications. We discuss our empirical strategy in more detail below.

The next section presents a model of organizational form that we will then take to the data.

3. Model

We use a multi-tasking approach to model the choice of organizational form in trucking. There are two parties: a driver and a carrier. The driver faces effort choices on two tasks: driving well and rent seeking. The carrier has an order to haul cargo, and wants to induce a driver (who could be an employee or an owner-operator) to drive a truck to fulfill the order. The revenue of the haul is V, and the cost of the haul is M. M includes the wear-and-tear on the truck, and is a function of how well the driver drives. M is not contractible, since the amount of wear-and-tear due to any one haul is not evident. The profitability of the haul is thus:

$$\pi = V - M(e_1), \tag{1}$$

where V is the revenue from the haul, e_1 is the non-contractible effort expended by the driver on good driving, and $M(e_1)$ is the cost of the haul. Assume that $M(e_1) = m - g_1e_1$.

We will refer to g_1, the marginal effect of driver effort on cost, as the "scope for good driving." When g_1 is large (for instance, on long hauls), the driver can do a lot to affect the cost of the haul, conditional on arriving on time; when g_1 is small (for instance, on short hauls) he has little scope to affect the cost of the haul.

Drivers can also search for alternative hauls. The value of an alternative haul lined up by the driver is $P(e_2)$. e_2 is the effort expended by the driver lining up alternatives: $P(e_2) = p + g_2e_2$. We assume that V is always greater than P, so it is always efficient to accept the carrier's haul. But a better alternative haul will give the driver more bargaining power with the carrier when it comes to haggling over the price on the backhaul. We refer to g_2, the marginal product of driver effort on P, as the "scope for rent seeking." g_2 is large when the driver can greatly affect the value of his outside opportunities.

Both types of driver effort are costly. Driving well (e_1) is costly for two reasons: it demands more attention and it forces the driver to forgo opportunities for on-the-job consumption. Searching for outside opportunities (e_2) is costly because it requires time and energy. The driver's cost of effort is:[12]

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12. Our results are, of course, sensitive to our assumption about the additive separability of this function. One can get almost any comparative static out of this simple model by assuming that e_1 and e_2 are either substitutes or complements. However, we have no priors as to whether driving well is either a substitute or a complement to searching for alternative hauls in drivers' effort supply functions. We feel that our assumption that they are independent activities is closest to the truth.

(2) $$C(e_1, e_2) = \frac{e_1^2 + e_2^2}{2}$$

Conditional on an ownership structure, the driver chooses e_1 and e_2 to maximize his utility. We examine driver incentives under each ownership structure separately, then compare the surpluses that result to see which structure is more efficient.

Under company ownership of the truck, the carrier holds the claim on the residual value of the truck. Thus the driver bears none of the (non-contractible) wear-and-tear costs of his driving, and so devotes no effort to good driving: $e_1 = 0$. Furthermore, since the driver cannot capture any more rents from lining up an alternative haul (since he does not have the right to use the truck) he will devote no effort to rent-seeking: $e_2 = 0$.

Under driver ownership, however, the driver both bears the costs of his poor driving and has an incentive to engage in rent seeking. We assume that he bargains with the carrier, receiving half of the difference between what the haul is worth to the carrier and his alternative bid.[13] He thus stands to receive:

(3) $$\frac{V + P(e_2)}{2} - M(e_1)$$

Driver utility is equal to his monetary reward, minus his cost of effort:

$$g_1 e_1 + \frac{g_2 e_2}{2} - \frac{e_1^2 + e_2^2}{2}$$

Maximizing utility with respect to both e_1 and e_2 yields:

$$e_1 = g_1, \; e_2 = g_2/2.$$

Under driver ownership, the driver exerts effort towards both good driving and rent seeking.

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[13] We do not model the bargain between the driver and the carrier under company ownership, because it has no effect on the driver's incentives. We could assume that the driver receives half of the revenue on each haul, or we could assume that he receives a fixed wage.

Optimal Ownership Under Non-Contractible Driver Effort

Under the assumption that it is always efficient to use the truck for the carrier's haul, total surplus is the sum of carrier profit and driver utility. Optimal ownership is that which maximizes total surplus. Surplus under company ownership is:

$$S_c = V - M(0) - C(0,0) = V - m, \tag{4}$$

while surplus under driver ownership is:

$$S_o = V - M(g_1) - C(g_1, \frac{g_2}{2}) = V - m + g_1^2/2 - g_2^2/8. \tag{5}$$

It is easy to show that drivers should own their trucks whenever $2g_1 > g_2$.

This model yields several predictions about when drivers should own trucks. One is that they should do so when the scope for good driving is large—that is, when g_1 is large. As discussed above, this is more likely to be the case for long hauls than short hauls, since drivers can drive trucks very hard for many hours, and then consume the rest of the time it *should* have taken them however they choose.

The model also predicts that drivers should own trucks when the scope for rent-seeking is small—that is, when g_2 is small. There are two possible situations in which incentives to rent-seek are likely to be small. One is when backhaul markets are highly efficient. The other is when there is no market for a backhaul that uses the truck. The latter occurs when hauls require trailers with unidirectional demands. Our data are not sufficiently refined to enable us to discern when backhaul markets are highly efficient, but we can identify circumstances where hauls use trailers for which there is usually no backhaul demand.

This model thus yields the following cross-sectional predictions about truck ownership with non-contractible effort:

P1: Driver ownership should be more common in long-haul trucking than short-haul trucking.

P2: Driver ownership should be more common when hauls use trailers for which demands tend to be unidirectional (such as livestock or logging trailers) than those where they are more likely to be bidirectional (such as vans or platforms).

Partially Contractible Effort

The predictions thus far have been purely cross-sectional: they predict how patterns of asset ownership are related to haul characteristics. However, the model also makes predictions about how OBC adoption should *change* ownership patterns, by changing what is contractible. Exploration of relationships between OBC adoption and ownership changes constitutes the main empirical contribution of the paper.

Suppose that the introduction of OBCs makes it possible to measure driver effort more accurately. This would allow the carrier to write an explicit incentive contract that leads the driver to drive in a value-maximizing way. Such a contract would set e_1 at (or near) first-best, g_1.

With OBCs, company ownership generates surplus equal to:

$$S_c^{OBC} = V - M(g_1) - C(g_1,0) - k = V - m + g_1^2/2 - k, \tag{6}$$

where k is the per-period cost of OBC adoption, net of the benefits OBCs provide that are unrelated to drivers' incentives. k varies with haul characteristics, and might be positive (if costs exceed these other benefits) or negative.

An owner operator with an OBC generates surplus equal to:

$$S_o^{OBC} = V - M(g_1) - C(g_1, \frac{g_2}{2}) - k = V - m + g_1^2/2 - g_2^2/8 - k, \tag{7}$$

Inspection of equations (5) and (7) shows that OBCs should only be observed on owner-operated trucks when k is negative: that is, when OBCs' other benefits exceed their cost. The intuition is clear: since there are no incentive conflicts with respect to how owner-operators drive, OBCs would only be adopted for their other benefits.

The prediction of a link between OBC adoption and ownership change can be seen by comparing the surplus generated by company drivers and owner operators with and without OBCs. This comparison shows that OBC adoption can induce ownership changes by improving driver incentives. Before OBCs, driver ownership of trucks could generate more surplus than carrier ownership because of better driving incentives. But once OBCs are adopted, driver ownership loses this advantage.

P3: Driver ownership of trucks should decrease with OBC adoption.

Further comparison of equations (4)-(7) yields more precise predictions about when OBC adoption will lead to ownership changes. Ownership will only change with adoption if $S_o > S_c$ and $S_c^{OBC} > S_o^{OBC}$. This requires $2g_1 > g_2$, $g_2 > 0$. We thus have two additional predictions about the relationship between OBC adoption and ownership change. First, ownership will only change for hauls in which the scope for good driving (g_1) is sufficiently high.

P4: Driver ownership should decrease with OBC adoption more for longer than shorter hauls.

Second, when g_2 is zero, there should be no change in ownership induced by OBC adoption. In such cases, a company driver with an OBC has exactly the same incentives as an owner-operator, and $S_c^{OBC} = S_o^{OBC}$. Adoption may take place for such hauls, since OBCs do things other than improve drivers' incentives, but it should not be associated with ownership change.

P5: Driver ownership should decrease with OBC adoption less for hauls that use trailers for which demands tend to be unidirectional than bidirectional.

We examine these five propositions empirically in the following sections, focusing most of our attention on P3, P4, and P5.

4. Data and Cross-Sectional Patterns

The data are from the 1987 and 1992 Truck Inventory and Use Surveys (TIUS) (See Bureau of the Census (1989, 1995), Hubbard (2000).) The TIUS is a survey of the nation's trucking fleet that the Census takes every five years. The Census sends forms to the owners of a random sample of trucks. The survey asks owners questions about the characteristics and use of their truck.

Characteristics include trucks' physical characteristics such as make and model year. They also include whether certain aftermarket equipment is installed—including whether and what class of OBCs are installed. Questions about use yield information on how far from home the truck was generally operated, the class of trailer to which it was generally attached, the class of products it generally hauled, and the state in which it was based. The survey also asks whether the truck was driven by an owner-operator or a company driver.

These data are well-suited to studies of organizational form, since theories of organizational form commonly take the transaction as the unit of analysis. Because individual trucks tend to be used for similar types of hauls from period to period, observing ownership and OBC use at the truck level is much like observing ownership and OBC use for a sequence of similar transactions.

This paper uses observations of diesel-powered truck-tractors—the front halves of tractor-trailer combinations. We eliminate observations of those that haul goods off-road, haul trash, are driven for less than 500 miles during the year, or have missing values for relevant variables. This leaves 19,308 observations for 1987 and 35,204 for 1992. The sample is larger for 1992 because the Census surveyed more trucks.

Table 1 contains owner-operator shares, by distance and year. In 1987, 14.6% of tractor-trailers were driven by their owners.[14] The share is higher for trucks used for longer hauls; over one-fifth of long-haul trucks were owner-operated. The right part of the table splits the sample according to whether trucks were generally attached to trailers where demands are usually unidirectional. “No backhaul” trucks include those attached to dump, grain body, livestock, and logging trailers. "Backhaul" trucks include those attached to all other trailer types; vans, refrigerated vans, platforms, and tank trucks make up most of this category (and the vast majority of trucks in general). About 18% of the "no backhaul" trucks were owner-operated, compared to 14% of trucks attached to other trailer classes. While the owner-operator share fell substantially between 1987 and 1992, from 14.6% to 10.1%, the cross-sectional patterns are similar in 1992. This table thus provides evidence consistent with P1 and P2, our two cross-sectional predictions about asset ownership: driver

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[14] Note that the sample contains trucks within both private and for-hire fleets. About half of the nation’s truck-tractors operate within private fleets. By definition, all trucks within private fleets are driven by company drivers. Also, the 1992 Survey contains more detailed distance categories than the 1987 Survey. We convert the five 1992 categories to the three 1987 ones when comparing the two years.

ownership is more prevalent when trucks are used for longer hauls, and when trucks are attached to trailers for which demands tend to be unidirectional.

Table 2 reports OBC adoption rates, by organizational form and distance, for 1992. OBC adoption is negligible during 1987, and is treated as zero for that year throughout the paper. Table 2 indicates that some owner-operators adopt OBCs, presumably because of their maintenance and coordination benefits. Adoption is higher for trucks driven by company drivers and, as reported also in Hubbard (2000), increases with how far trucks operate from home. Almost 35% of trucks used for hauls of 500 or more miles and operated by company drivers had either trip recorders or EVMS installed. Tables 1 and 2 thus indicate that OBC adoption coincided with ownership changes in the aggregate. Hauls in general moved from owner-operators to company drivers at the same time OBCs were beginning to diffuse. Ownership changes and OBC adoption were both greatest for long hauls.

Cross-Sectional Relationships, Individual Data

Let S_{iot} represent total surplus of haul i at time t, if a driver owns the truck, and S_{ict} represent total surplus of haul i, if a carrier owns the truck. Specify these as:

$$\begin{aligned} S_{iot} &= X_{it}\beta_o + \delta_o d_{it} + \varepsilon_{iot} \\ S_{ict} &= X_{it}\beta_c + \delta_c d_{it} + \varepsilon_{ict} \end{aligned} \tag{9}$$

where X_{it} is a vector depicting haul characteristics and d_{it} is a dummy variable that equals one if OBCs are installed on the truck used for the haul. ε_{iot} and ε_{ict} capture how haul characteristics not observed by the econometrician affect surplus when using owner-operators and company drivers, respectively.

Assuming that ownership choices are efficient, company drivers will be chosen if and only if $S_{ict} > S_{iot}$. Assuming that ε_{iot} and ε_{ict} are i.i.d. type I extreme value, the probability the carrier owns the truck, conditional on X_{it}, is:

$$P_{it} = \frac{e^{X_{it}(\beta_c-\beta_o)+d_{it}(\delta_c-\delta_o)}}{1+e^{X_{it}(\beta_c-\beta_o)+d_{it}(\delta_c-\delta_o)}} = \frac{e^{X_{it}\beta+d_{it}\delta}}{1+e^{X_{it}\beta+d_{it}\delta}} = \Lambda(X_{it}\beta+d_{it}\delta) \tag{10}$$

where $\Lambda(a) = \exp(a)/(1+\exp(a))$.

The top panel of Table 3 contains results from estimating this model using simple logits on the truck-level data from 1992. We present estimates for all distances, then for short, medium, and long haul trucks separately. The dependent variable is a dummy variable that equals one if the truck was driven by a company driver and zero if an owner-operator. The independent variables are a dummy variable that equals one if the truck has an OBC installed and zero otherwise, a vector of dummies that indicate how far from home the truck generally operated, and ln(trailer density). The latter is the number of trucks based in the same state that are attached to the same trailer type, normalized by the developed land in the state. This is a measure of local fronthaul market thickness; it is high for logging trailers in Oregon and low in Kansas, for example (See Hubbard (2001) for an extensive discussion.).

In the first column, the coefficient on the OBC dummy is positive and significant: trucks with OBCs tend to be driven by company drivers. This is true for short, medium, and long hauls, but the correlation between OBC use and truck ownership is weakest for short hauls. The cross-sectional evidence thus is consistent with P3 and P4, but is also consistent with hypotheses where adoption need not lead to changes in ownership. For example, one would expect OBC use and carrier ownership to be correlated in the cross-section if the returns to monitoring are greater when trucks are not driver-owned.

The time dimension of our data provides a significant advantage over most previous empirical research on organizational form in confronting this issue. We can go beyond cross-sectional analysis and base empirical tests on relationships between changes in contractibility and changes in organizational form, and then explore whether the first-difference relationships are causal. Doing so requires us to aggregate the data up to segments, or cohorts, that are observed in multiple periods. We discuss the issues that arise when using cohorts as the unit of analysis below. Later, we discuss the endogeneity problems first-differencing does and does not solve at more length.

Cohorts

The data are multiple cross-sections rather than panel data; we do not observe exactly the same trucks or hauls from period to period. To exploit the time dimension of the data, we construct "cohorts" of individual observations that are observed in both of our sample periods. We base cohorts on state-product-trailer-distance combinations. An example is "trucks based in California hauling food in refrigerated trailers long distances." We base cohorts on state-product-trailer-distance combinations because it aggregates the data up to narrowly-defined market segments, and this reduces within-segment heterogeneity in haul characteristics. Our empirical work will relate within-segment changes in OBC use to changes in driver ownership of trucks: does the owner-operator share decrease the most in segments where OBC adoption is greatest, and is there evidence that adoption causes ownership to change? This will provide evidence regarding whether and how changes in contractibility relate to changes in the comparative advantage of using company drivers relative to owner-operators.

The first column of Table 4 presents summary statistics for the 3676 cohorts in which at least one truck was observed in both years. On average, segments are based on relatively few observations of individual trucks. Because of this, many of our segments, particularly the very smallest ones, have either 0% or 100% company drivers in one or both years; nearly half have 100% company drivers in both. This is not surprising, given that most trucks are driven by company drivers, especially for short hauls. But it creates some empirical problems because our empirical specifications below are logit-based regressions that use log-odds ratios of the ownership shares as the dependent variable. While specifying the model in a regression framework allows us to difference out cohort-specific fixed effects, the log-odds ratios are only well-defined when cohorts have non-zero company driver and owner-operator shares in both years.

We have addressed the problem of 0% or 100% owner-operator shares in several ways. One is to simply use only cohorts with non-zero company driver and owner-operator shares in both years. This allows our empirical specifications to be connected to the framework and estimates discussed above, but leads the analysis to be based on a relatively small part of our data; only 426 of the 3676 cohorts satisfy this criterion. As reported in Table 4, these 426 cohorts tend to have many more observations per cohort than those with a zero company driver or owner-operator share in at least one of the years; they are only 12% of the cohorts, but contain over 30% of the observations in each year. The average owner-operator share tends to be larger for these cohorts, reflecting that populations in which owner-operators are rare are more likely to have zero owner-operator shares than those that have many. In both columns, the owner-operator share declined by about 30%. Below, we will show that the cross-sectional relationships between OBC adoption and ownership for this subsample are also similar to those in the broader population. Combined, this provides evidence that the relationship between ownership and OBC use within this subsample resembles that in the broader population, and provides some assurance that estimates based on this subsample do not misrepresent relationships between OBC adoption and the comparative advantage of driver ownership in the population as a whole. This approach provides our main empirical results.

We have also estimated linear probability specifications of the model. This is a potentially attractive alternative because the dependent variable is well-defined for both the "zero" and the "non-zero" cohorts. This approach has several drawbacks, however. One is related to a general problem with linear probability models: it treats changes in the owner-operator share from 0.05 to 0.10 the same as those from 0.50 to 0.55, even though the former may indicate a greater underlying change in the comparative advantage of driver ownership. Since many of our observations have owner-operator shares that are less than 0.2, this affects our results more than it would than if the owner-operator and company driver shares were more equal. Another, possibly more important, drawback arises in our first-difference specifications, and it arises precisely from using observations where the share of owner-operators is zero or one in one or both years. The problem is that changes in the owner-operator share do not fully reflect the underlying change in the comparative advantage of owner-operators for these observations.[15] This problem is particularly relevant for us because nearly half of the 3676 cohorts with at least one observation in both years have no owner-operators in either year. A first difference estimate would treat these cohorts the same as those that have a 50% share in both years—no change in the comparative advantage of owner-operators—even when the underlying comparative advantage actually decreased. If OBC adoption increased company drivers' comparative advantage relative to owner-operators within these cohorts, first difference estimates would not pick this up (as it is impossible for the owner-operator share to decrease further), and this effect would bias our estimates toward zero. Other truncation-related problems arise for cohorts that have no owner-operators in one of the two years, or that have all owner-operators in either or both years.

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[15] The econometric issues that arise here are similar to those in Chamberlain's (1980) analysis of the fixed effect logit model. The conditional maximum likelihood estimator he proposes does not apply directly to our case, where the observations are grouped rather than individual data. Because the dependent variable can take any value between zero and one, the sets upon which one would condition would be very small. To our knowledge, the econometrics literature has not addressed the issue of first-difference estimation of qualitative response models with grouped data. See Maddala (1987) for a discussion of limited dependent variable models using individual-level panel data.

Our third approach attempts to use the information in the cohorts with 0% or 100% owner-operators while retaining the logit-based specification. This approach treats the observed owner-operator shares as informative, but not fully-informative, of the true shares across the population of trucks within each cohort. Consistent with the theoretical specification outlined above, we assume cohorts with all or no owner-operators are observed not because one of the organizational forms has an insurmountable comparative advantage, but because we observe a finite, often small, number of observations within each cohort. To implement this approach, we estimate the true owner-operator share within each cohort with a weighted average that puts some weight on the mean share across all cohorts in the same distance category; the weight on the observed shares increases with the number of observations in the specific cohort. This results in estimates of the owner-operator shares that are bounded away from zero and one, and mitigates the truncation-related problems discussed above.[16] For consistency, we create estimates of the true OBC adoption shares using an analogous procedure. These estimates of the shares can be thought of as Bayesian, using our data to update priors about the true shares of driver ownership and OBC use within each cohort. We use the resulting posteriors, which can never be zero or one, in logit-based regressions analogous to those discussed above. The formulas for these "Bayesian" estimates are given in Appendix 1.

In the results section below, we present two sets of estimates that we will use for each of our tests. One set uses the observed ownership and adoption shares from the 426 cohorts described above. The other set uses the Bayesian estimates of the ownership and adoption shares rather than the observed shares.[17] All calculations and estimates involving cohorts use weights that reflect differences in the number of observations within cohorts and in the rate in which the Census sampled trucks.[18] Thus, while the latter set of estimates incorporate information from many small cohorts that

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[16] A cohort with two observations and zero owner-operators generates a different estimate of owner-operator share than a cohort with five observations and zero owner-operators, since the weights change. Thus our estimator captures the additional information about true shares in the larger cohort.

[17] Note that while our dependent and independent variables are constructed using a Bayesian procedure, the regression coefficients themselves are not Bayesian estimates.

[18] The formula is $(n_{r,87}*k_{r,87}+n_{r,92}*k_{r,92})/2$, where $n_{r,t}$ is the number of observations in cohort r and $k_{r,t}$ is the average Census weighting factor in cohort r in year t. Census sampling rates, and thus $k_{r,t}$,differ primarily across states, not across trucks within states during a particular year. The results in section 5 are robust to variations in weighting.

are omitted in estimates that use the observed shares and collectively make up much of the industry, most of the cohorts that are added receive little weight individually.

In addition, we present two sets of results from linear probability specifications in Appendix 2, one for the 426 “non-zero” cohorts, and one for all cohorts. As would be expected, the results are similar to our logit-based specifications when using only the non-zero cohorts but the estimates are small and not statistically different from zero when including all of the "zero" cohorts.

Aggregation-Related Biases

There is a potential aggregation-related bias introduced by using cohorts rather than trucks as the unit of analysis. This bias works against finding the relationships between OBC adoption and organizational change that we predict. Suppose that, as we assume in our model, OBCs and driver ownership are alternative ways of providing drivers incentives, and thus OBC adoption and shipper ownership are positively correlated at the individual truck level. Now suppose that cohorts differ in unobservable ways in the degree to which driver incentives are important. For those cohorts for which incentives are very important, OBC adoption will be high and carrier ownership will be low: in those cohorts where incentives are unimportant, OBC adoption will be low and carrier ownership will be high. Thus, aggregating the observations into cohorts biases us against finding a positive correlation between OBC adoption and company ownership. First-differencing eliminates this source of bias if the incentive problem is homogeneous among hauls within the same cohort. But if there is heterogeneity within cohorts, sampling differences from year to year can induce unobserved cohort-level changes in the degree of the incentive problem, and in turn, can lead OBC adoption and shipper ownership to be negatively correlated in first-difference specifications. Unobserved differences in the incentive problem tend to negatively bias cohort-based estimates of relationships between OBC use and shipper ownership, especially when within-cohort differences are large.[19] While we define cohorts narrowly to make within-cohort differences in the degree of the incentive problem as small as possible, this does not necessarily eliminate this problem.

We examine this problem's empirical relevance below by comparing estimates of cross-sectional relationships between OBC use and ownership from the individual and cohort data. Areas

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[19] See Deaton (1985) for a general depiction of this problem.

where the cohort-based cross-sectional estimates differ from the individual-based ones indicate situations where the bias described above is likely to affect our first-difference estimates, which necessarily rely only on the cohort data.

Cross-Sectional Relationships, Cohort Data

The cohort analog to equation (10) is:

$$s_{rt} = \Lambda(X_{rt}\beta + d_{rt}\delta) \tag{12}$$

where s_{rt} is the share of hauls in cohort r at time t for which company drivers are used, X_{rt} is a vector of average haul characteristics for cohort r, and d_{rt} is the share of hauls in cohort r for which trucks with OBCs are used. One can estimate the parameters of this equation by estimating the linear regression:

$$\ln(s_{rt} / (1 - s_{rt})) = X_{rt}\beta + d_{rt}\delta + \varphi_{rt} \tag{13}$$

Because we have two years of data, we estimate the system of equations:

$$\begin{aligned} \ln(s_{r,1987} / (1 - s_{r,1987})) &= X_{r,1987}\beta + d_{r,1987}\delta + \psi_r + \eta_{r,1987} \\ \ln(s_{r,1992} / (1 - s_{r,1992})) &= X_{r,1992}\beta + d_{r,1992}\delta + \psi_r + \eta_{r,1992} \end{aligned} \tag{14}$$

Returning to Table 3, the bottom two panels contain the "levels" estimates of δ from multivariate regressions using the cohort data. Note that $d_{r,1987} = 0$, since OBCs were not installed on trucks at this time. δ thus reflects cross-sectional relationships between OBC use and truck ownership during 1992. The dependent and independent variables are analogous to those in the top panel. In the middle panel we use observed ownership shares in calculating $\ln(s_{rt}/(1-s_{rt}))$ and d_{rt}, and therefore can use only the 426 cohorts that have non-zero owner-operator and company driver shares in both years.[20] In the bottom panel, we use the Bayesian estimates of the ownership and adoption shares. Since none of these estimates generate zero owner-operator or company driver shares, this panel uses all 3676 cohorts with observations in both years. Note that the estimates in the middle and

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[20] Cross-sectional estimates from specifications analogous to those in this panel could have been obtained via maximum likelihood methods, applying binomial probability formulas and using all 3676 cohorts with observations in both years. We use only the 426 "non-zero" cohorts here because the point of this panel is to compare cross-sectional estimates using these 426 cohorts with those that use the individual data. Like the estimates reported here, our main analysis estimates coefficients using the linear regression framework outlined above. Unlike maximum likelihood methods, this allows us to estimate coefficients from a logit-based model in a way that differences out cohort-specific fixed effects.

bottom panels are similar, indicating that our Bayesian estimates do not greatly distort the cross-sectional relationship between OBC use and ownership.[21]

The estimates for medium and long haul cohorts are similar to those when we use the truck-level data. However, the estimates from the short haul cohorts are not: the coefficient on OBC is strongly negative and, in the bottom panel, statistically significant. Combined, the results suggest that the aggregation-related bias described above does not much affect the medium or long haul estimates, but strongly affects the short haul estimates. One explanation for this is that there is little within-cohort heterogeneity in the degree of the incentive problem for medium and long hauls, but significant within-cohort heterogeneity for short hauls. This would be the case if incentive problems were driven more by idiosyncratic factors for short hauls than medium or long hauls.

Below we will find that this negative relationship for short hauls appears in first difference estimates as well, but we will not focus on this result because the cross-sectional evidence strongly suggests that it reflects a negative bias in the estimates.

5. OBC Adoption and Ownership Changes

This section contains the main empirical evidence in this paper, which concerns relationships between OBC adoption and ownership changes. Before discussing the results, we describe the conditions under which one can and cannot interpret our estimates as reflecting causal relationships.

The central issue regarding causality is that OBCs are not randomly assigned to trucks or hauls. In the levels estimates in Table 3, OBC use is econometrically endogenous if it is not independent of unobserved factors that affect ownership trade-offs; that is, if $E(d_{rt}| \psi_r + \eta_{rt}) \neq 0$. This would be the case if, for example, drivers within large fleets tend to be company drivers (perhaps because rent-seeking behavior is more of a problem when there is a valuable brand name) and OBC use is greater in larger fleets. Then if large trucking fleets are more common in some areas of the country than others, OBC use and driver ownership of trucks would be negatively correlated even if OBCs did not directly affect ownership patterns.[22] Correlations between OBC use and ownership

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[21] If these panels differed greatly, we would have little confidence in the first difference results using the Bayesian estimates presented below.

[22] Although we use fleet size effects to illuminate this point, it is important not to overstate the relevance of scale

would reflect unobserved cross-sectional differences in the incentive problems underlying the traditional ownership trade-off as well as any effects OBCs have on ownership.

In first-difference estimates, OBC adoption is econometrically endogenous if $E(d_{r,1992}| \eta_{r,1992} - \eta_{r,1987}) = 0$; that is, if OBC adoption is independent of unobserved changes in organizational form. This condition is much weaker than the corresponding condition when estimating the model in levels because ψ_r, which represents unobserved time invariant factors that affect ownership, has been differenced out. The condition allows for unobserved differences in incentive problems in the cross-section (driver ownership may create greater rent-seeking problems in some parts of the country than others), but requires such differences to be constant over time. Relationships between OBC adoption and changes in driver ownership therefore depict causal relationships only if, within market segments, incentive problems with drivers are stable over time. There is some reason to believe that such problems are stable: since the composition of demand evolves very slowly in this industry (e.g., shipping patterns in 1987 are similar to those in 1992), the characteristics of hauls in a segment are probably fairly similar from one period to the next.

While our main results will come from simple first-difference specifications, we will also present and discuss results from instrumental variables specifications. We do this to provide some additional evidence with respect to causality: while unobserved factors affecting ownership probably vary more cross-sectionally than over time, they might not be completely stable. For example, even though the nature of the hauls themselves may not change much over time, supply-side changes such as the entry of large firms into new geographic regions could lead OBC adoption to be correlated with unobserved changes in driver ownership.

In these additional specifications, we use product class dummies as instruments for OBC adoption. For these to be valid instruments, differences across products must drive differences in OBC adoption, but must not affect the underlying incentive issues that affect ownership. Using product dummies as instruments is attractive for two reasons. One is that entry in the trucking industry tends to be into new geographic markets and tends not to be specialized in narrow product

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effects with respect to adoption and ownership patterns. Owner-operators commonly work as subcontractors within large fleets. Although OBC use involves some costs that are independent of the number of trucks in the fleet, these costs are often small, particularly for trip recorders.

classes. This means that unobserved changes in incentive problems tend to vary geographically but not across products. Second, as described above, OBC adoption offers benefits other than improving contracts with drivers, and these benefits (but not the underlying incentive issues) vary systematically with the cargo. Thus product characteristics are shifters of OBC adoption, and should allow for the identification of causal effects.

First-Difference Estimates

Table 5 presents results from first-difference estimates. The dependent variable is the change in the log-odds ratio from 1987 to 1992 above; the independent variable of interest is the change in OBC use.[23] The left panel contains estimates using the observed ownership and adoption shares. In the first column, the OBC coefficient is positive and significant: cohorts with high OBC adoption moved the most toward company drivers during this time, consistent with our main theoretical prediction P3. The second column includes the EVMS adoption share separately; thus, the coefficient on OBC picks up the organizational implications of OBCs' incentive-improving capabilities and that on EVMS picks up the effects of their coordination-improving capabilities. The point estimates are both positive, but neither are statistically significantly different from zero. The third and fourth columns are analogous to the first two, but allow the coefficients to differ depending on haul length. In both, the OBC*Long coefficient is positive and significant, and statistically significantly larger than either the OBC*Medium and OBC*Short coefficients, although the latter may reflect the impact of aggregation-related biases on the OBC*Short coefficient. None of the EVMS coefficients are statistically significantly different from zero. The point estimates in the first and third columns imply that an increase in the OBC adoption rate from 0 to 0.2 is associated with an 11% overall decline in the owner-operator share and a 15% decline within the long-haul segment. The first column estimate implies that the twenty percentage point overall increase in OBC use between 1987 and 1992 was related to about one-third of the 30% decline in driver ownership of trucks during this time.

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[23] The specifications also include a constant, the change in trailer density, and distance dummies.

The evidence from this panel thus indicates that OBC adoption is correlated with movements toward company drivers, and that relationship between adoption and organizational change was greater for long than medium hauls. Furthermore, the organizational change appears to be related to OBCs' incentive-improving capabilities. The evidence thus is consistent with P3 and P4 above.

The right panel repeats the analysis using the Bayesian estimates of the ownership and adoption shares. These estimates produce similar evidence: improvements in the contractibility of good driving are correlated with a decrease in driver ownership of trucks. In the first column, the OBC coefficient is positive and significant. In the second, the OBC and EVMS coefficients are now both positive and significant, as the standard errors are lower than in the left panel because of the larger sample size.[24] This suggests that OBCs' incentive- and coordination-improving capabilities are both correlated with movements toward company drivers. As before, the OBC*Long coefficient is positive and significant. Unlike in the left panel, the OBC*Medium coefficient is as well: there is some evidence that OBC adoption is correlated with organizational change for medium hauls. The point estimates of the OBC*Long coefficient are greater than those of the OBC*Medium coefficient. The difference is statistically significant using a t-test of size 0.05 in the third column but not the fourth. The OBC*Short coefficients are negative and significant, which likely reflects aggregation-related biases. The EVMS*Distance interactions are all positive, with EVMS*Long being statistically significant. Except for the medium haul interactions, the magnitudes of the point estimates are similar to those in the left panel. For example, the estimates in the first and third column indicate that increasing the OBC adoption rate from 0 to 0.2 is associated with a 13% decline in the overall owner-operator share and a 17% decline within the long haul segment.

In sum, both panels provide strong evidence in favor of P3, our main proposition: cohorts where adoption was high also moved the most away from driver ownership of trucks. They also provide some evidence in favor of P4, as the relationship between adoption and organizational change is stronger for long-haul than medium-haul trucks. The evidence regarding P4 is not quite as

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[24] The standard errors reported here do not account for the fact that our dependent and independent variables are estimates, and thus likely overstate the precision of our point estimates. Discussions of statistical significance should be taken in this light.

strong, however, as the difference between the OBC*Long and OBC*Medium coefficients is not statistically significant in all of the specifications.

Table 6 reports estimates from analogous specifications that contain interactions between OBC adoption and a dummy variable that equals one if the cohort is a "no backhaul" cohort: one with dump, grain body, livestock, or logging trailers. We estimate these using only the medium and long haul cohorts, both because we suspect the short haul estimates are negatively biased and because firms generally do not try to fill backhauls when trucks operate close to home. From the second column in the left panel, the OBC coefficient is positive and significant while the OBC*"No backhaul" interaction is negative and significant. In the fourth column, we allow the effect of adoption to differ for EVMS. The point estimate of the OBC*"No backhaul" coefficient is almost the same as in the second column. It is not statistically significantly different from zero using a two-sided t-test of size 0.05, but is when using one of size 0.10. The right panel repeats the exercise, using the Bayesian estimates of the adoption and ownership shares. The evidence is similar. Consistent with P5, driver ownership declines less with OBC adoption when trucks use trailers for which demands tend to be unidirectional than bidirectional.

Combined with the cross-sectional differences in driver ownership, this result provides evidence that part of the cost of driver ownership is that it enhances drivers' incentives to engage in rent-seeking behavior. Driver ownership has traditionally been greater for hauls where demands for the equipment are unidirectional than bidirectional, because driver rent-seeking is not as common a problem. This difference has become more pronounced as good driving has become more contractible, consistent with the idea that combining OBC adoption with diminished driver ownership improves drivers' overall incentives more for classes of hauls where rent-seeking problems are more common.

Instrumental Variables Estimates

As discussed above, interpreting the first-difference estimates as causal relationships requires the assumption that OBC adoption is independent of unobserved changes in organizational form. In order to provide some evidence with respect to this interpretation, we rerun our analysis using instrumental variables. Our identification strategy exploits the fact that adoption is affected by many factors other than the incentive-improving capabilities of OBCs, and variation in haul characteristics that affect OBC adoption (but not ownership) can serve as valid instruments. Table 7 presents estimates from specifications in which we use a vector of 19 product class dummies as instruments for OBC adoption. In general, the patterns in the point estimates are similar to those in the simple first-difference specifications. In the first column of each panel, the OBC coefficient is positive and significant, and the coefficients are almost the same. These coefficients are greater than their counterparts in Table 5, which indicates that the simple first-difference estimates might understate relationships between OBC adoption and ownership changes. Assuming that unobserved changes in the incentive problem with drivers are independent across products, the Table 7 point estimates indicate that increasing adoption rates from 0 to 0.2 decreases the share of owner-operators by 2.6 percentage points. This suggests that absent OBC diffusion, the owner-operator share would have fallen by only about 3% between 1987 and 1992 rather than decreasing by 20%. The results thus imply that substantial share of the decline in driver ownership during this time is related to OBC-related changes in the contractibility of good driving.

The second column in each panel contains the distance interactions. As in Table 5, the OBC*Long coefficient is positive and significant in both panels; this provides evidence that OBC adoption led to organizational changes for long hauls. The OBC*Medium coefficient is negative and insignificant in the left panel and positive and significant in the right panel. It is significantly smaller than the OBC*Long coefficient in the left panel, but not in the right one. Like the simple first-difference estimates, the instrumental variables estimates provide some evidence that relationships between OBC adoption and ownership changes are greater for longer hauls, but the evidence regarding P4 is not as strong as that regarding P3.

The third column in each panel uses only the medium and long haul cohorts and contains the "no backhaul" interactions. The high standard errors on the OBC*no backhaul interactions in this table indicate that we are not able to estimate the difference between OBCs' effect on ownership for "backhaul" and "no backhaul" trailers precisely in specifications that use product dummies as instruments. The point estimate is positive in the left panel, but the standard error is extremely high. The point estimates in the right panel are similar to those in the second column of the right panel of Table 6, and suggest that OBCs caused greater ownership changes for hauls using "backhaul" trailers than "no backhaul" trailers. But since the negative estimate on the interaction coefficient is not statistically significantly different from zero, the evidence on this point from this table is relatively weak.

In general, the estimates in Table 7 are consistent with the simple first-difference estimates. Except for the OBC*no backhaul coefficient in the left panel (which has a very large standard error), the point estimates are quite similar to those in the other tables. The strength of the evidence from the instrumental variables estimates varies with the standard errors. It is greatest for our main proposition P3, which concerns the general relationship between adoption and ownership, and provides some additional evidence that this relationship is causal. It is weaker for our ancillary propositions P4 and P5, which concern differences in OBCs' effect on ownership. We suspect that this partly reflects that we are running up against limits of the power of our data when we try to estimate interaction effects in first-difference specifications using instrumental variables.

6. Adoption and Driving Patterns

In this section, we present some evidence on whether OBC use affects how company drivers drive. Although our data do not contain any direct information on drivers' driving patterns, the TIUS does ask truck owners to report individual trucks' average fuel economy. Because individual trucks' fuel economy reflects many factors other than how drivers operate them – for example, how they are maintained and the terrain over which they are driven – fuel economy data have not been traditionally used to evaluate individual drivers' performance. But if OBC use causes company drivers to drive better, systematic differences in driving patterns might show up in fuel economy data from thousands of trucks.

We investigate this by presenting results from some OLS regressions using the truck-level data from 1992. The dependent variable is the truck's reported fuel economy, in miles per gallon. The main independent variables are interactions between dummies that indicate whether drivers own their trucks (one if driver ownership, zero otherwise) and whether the different classes of OBCs are installed (one if installed, zero otherwise). Coefficients on these variables indicate whether trucks with OBCs are more fuel-efficient than those without them. Since fuel economy also varies with many other truck characteristics, we include a full set of additional controls in order to improve the precision of our estimates of relationships between OBC use and fuel economy.

Relationships between OBC use and fuel economy may reflect things other than contracting improvements with drivers. As noted earlier, OBCs supply information that can help mechanics maintain trucks better. To distinguish between the effects of maintenance and incentive improvements, we compare the relationship between OBC use and fuel economy for company drivers and owner-operators. Assuming that the maintenance value of OBCs is the same for company drivers and owner-operators, finding that this relationship is stronger for company drivers than owner-operators is evidence of their incentive-improving effect, because it suggests that the average fuel economy benefits among company driver adopters are greater than that among owner-operators.

Relationships between OBC use and fuel efficiency may also reflect adoption patterns. In general, selection issues work against finding relationships between OBC use and fuel economy: if OBCs tend to be adopted where agency costs are otherwise high, non-adopting company drivers probably drive better than the adopting ones would absent monitoring. The difference in the relationship between OBC use and fuel economy between company drivers and owner-operators would then understate OBCs' average incentive effect among company driver adopters. Finding that the fuel economy difference between trucks with and without OBCs is greater when comparing company drivers than owner-operators is thus evidence that OBCs induced fuel economy improvements.

Selection also might affect patterns across different types of OBCs. If EVMS are adopted more relative to trip recorders when monitoring's benefits are primarily coordination-related, one would expect the average fuel economy effect among EVMS adopters to be lower than among trip recorder adopters even if they can be used to improve drivers' incentives in the same way. We therefore allow the relationship between OBC use and fuel economy to differ for trip recorders and EVMS.

As stated above, we include many additional variables as controls. One set contains an extensive set of truck characteristics that affect fuel economy: dummy variables that indicate the truck's make, model year, engine size, the number of driving axles, and whether it has aerodynamic features, as well as the log of the truck’s odometer reading, which captures the effects of depreciation.[25] They also include variables that capture how the truck is used: how far from home it operates, whether it hauls single, double, or triple trailers, the average weight of the truck plus cargo, and whether it is attached to a refrigerated or specialized trailer. They include a set of dummy variables that indicate who maintains the truck: the driver, a garage, a trucking company, an equipment leasing firm, etc.

Table 8 reports results from four regressions. The owner-operator coefficient is negative and significant for short hauls, and statistically zero for medium and long hauls. There is no evidence that company drivers without OBCs drive less efficiently than owner-operators for medium and long hauls, and some evidence that they drive better for short hauls.[26] The trip recorder and EVMS interactions indicate that medium- and long-haul trucks with OBCs get better fuel economy than those without them. Among long-haul trucks, the point estimate on the trip recorder coefficient for company drivers is more than twice as high as that for owner-operators. The difference is statistically significant when using a t-test of size 0.10. (The owner-operator estimate is noisy because so few owner-operators drive trucks with trip recorders.) The point estimates indicate that on the average across long-haul trucks for which they were adopted, trip recorders' incentive effect improved fuel economy by at least 0.16 miles per gallon, assuming that selection biases the parameter estimates downward.[27] Our estimates imply that this is about equal to aerodynamic hoods' effect on fuel economy. The EVMS coefficients tend to be lower than the trip recorder coefficients, as expected. There is no significant difference in the coefficients on the EVMS interactions.

In sum, the difference between the long-haul trip recorder coefficients provides some evidence of OBCs' incentive-improving effects: the difference in fuel economy between trucks with and without trip recorders is greater when comparing company drivers than owner-operators. This evidence does not appear when comparing the EVMS coefficients, possibly reflecting that they are

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[25] We do not include these variables in our analysis of ownership because we assume that, unlike on-board computers, these variables' effect on the cost of a haul is the same regardless of whether a company driver or owner-operator is used.

[26] It is not clear, however, that driving better translates into higher fuel economy for short-hauls.

[27] For a truck that travels 100,000 miles/year, a 0.16 improvement in MPG translates to a $620 savings per year, assuming that fuel costs $1/gallon.

adopted in many circumstances for their coordination- rather than their incentive-improving capabilities.

7. Conclusion

This paper investigates what determines asset ownership in trucking; in particular, how contractibility affects whether drivers own the trucks they drive. Our evidence suggests that improved contracting (through the use of on-board computers) leads to *more* integrated asset ownership. Owner-operators are used for hauls where non-contractible decisions that affect trucks' value are important but are used less once decisions become more contractible, especially for hauls where allocating drivers control rights invites rent-seeking behavior. We also provide evidence on truck operating performance (in the form of miles per gallon outcomes) that is consistent with the ownership results. Differences in average fuel economy between trucks with trip recorders and without OBCs are greater among company-owned than driver-owned trucks, reflecting the improved incentives that the company drivers have after the adoption of OBCs.

More generally, this paper shows the importance of the “level playing field” approach to analyzing firms' boundaries. Rather than simply arguing that improved contracting should favor market-based as opposed to firm-based transacting, we have examined both the costs and benefits of integration, and modeled the interactions between contractible and non-contractible decision rights. Doing so has generated propositions about precisely when and how changes in contractibility should affect asset ownership. These propositions are supported by our empirical results.

The analysis in this paper may explain relationships between contractibility and firms' boundaries in other contexts, especially those in which the care of valuable assets is important. Presumably the prevalence of independent contractors in the construction trades is importantly influenced by the requirement to provide incentives for proper operation and maintenance of equipment. The results in this paper suggest that changes in monitoring technology could change the industry structure in this sector. Such changes could similarly affect the professions. The prevalence of "owner-operators" in law and medicine may be driven to a large degree by the need to vest in professionals the value of their reputational assets. It appears that changes in the ability of insurance companies and HMOs to monitor the actions of physicians is causing higher rates of integration in medicine, leading doctors to become employees rather than independent contractors.

Innovations in information technology have led economists, technologists, and business people to theorize about how new informational capabilities will affect the boundaries of the firm. We test a theory concerning one of its capabilities: expanding the set of contractible variables. Our evidence suggests that this capability leads to less subcontracting. But changing information technology offers many other new capabilities, some of which improve resource allocation ("coordination") along with incentives. In other research (Baker and Hubbard (2002)), we examine the organizational impact of some of these other capabilities, in particular how OBCs' coordination-enhancing capabilities affect shippers' make-or-buy decision. Combined with this paper, this other work furthers our understanding of how information affects the organization of firms and markets.

Appendix 1

Our Bayesian estimates of the shares take the form:

$$s_{rt}^{b} = \frac{a + n_{rt}}{b + N_{rt}} = \frac{b}{b + N_{rt}} s^{*} + \frac{N_{rt}}{b + N_{rt}} s_{rt} \tag{11}$$

where N_{rt} is the number of observations in cohort r at time t, n_{rt} is the number of positive observations, and s_{rt} is the share of positiveobservations. This expression is equal to the expectation of a random variable distributed B(a+n, b-a+N-n), where B denotes the Beta distribution. A result from conjugate distribution theory is that B(a+n, b-a+N-n) is the posterior distribution obtained by starting with initial priors B(a, b-a) regarding the unknown mean of a binomial distribution, and Bayesian updating using N independent draws from the distribution, n of which are ones. (Degroot (1970)) a and b are parameters that reflect the mean and variance of the distribution of initial priors. a/b = s* is the mean.

Intuitively, our Bayesian estimates are weighted averages of s* and s_{rt}, where the weight on the latter increases with the size of the cohort. We set s* to equal the mean ownership (or adoption) share for hauls in the same distance class in that year. For example, s* for our Bayesian estimates of the owner-operator share for each long haul cohort is 0.211 in 1987 and 0.139 in 1992 (See Table 1). We set b = 10; this implies that the observed shares and initial priors receive equal weight when cohorts contain ten observations. We have also estimated our models varying b from 2 to 20, and have found no substantial differences in any of our results.

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Table 1
Owner-Operator Shares, 1987 and 1992

	All Distances	<50 Miles	50-200 Miles	200+ Miles	Backhaul	No Backhaul
Owner-Operator Share, 1987	14.6%	8.4%	11.8%	21.1%	14.0%	18.1%
Owner-Operator Share, 1992	10.1%	4.5%	9.1%	13.9%	9.7%	12.4%
Change in Owner-Operator Share	-4.5%	-3.8%	-2.7%	-7.2%	-4.3%	-5.7%

No Backhaul includes dump, grain, livestock, logging trailers.
Backhaul includes all others (e.g., van, refrigerated van, platform, tank).

Table 2
1992 On Board Computer Adoption Rates

	Distance from Home Base (Miles)				
	<50	50-100	100-200	200-500	500+
OBC					
Owner-Operator	3.7%	3.1%	4.0%	7.0%	9.8%
Company Driver	7.1%	12.6%	21.1%	27.4%	34.8%
Trip Recorder					
Owner-Operator	1.7%	1.2%	0.9%	2.3%	2.4%
Company Driver	4.3%	7.8%	12.7%	12.0%	8.4%
EVMS					
Owner-Operator	2.0%	2.0%	3.1%	4.8%	7.4%
Company Driver	2.8%	4.9%	8.4%	15.4%	26.5%

Table 3
Truck Ownership and OBC Adoption -- Levels Estimates

	All Distances	<50 Miles	50-200 Miles	200+ Miles
Individual Trucks, 1992 Data				
OBC	**1.587**	**0.728**	**1.717**	**1.584**
	(0.071)	**(0.292)**	**(0.172)**	**(0.081)**
N	33283	7998	11429	13856
Cohorts, Observed Ownership and Adoption Shares				
OBC	**1.560**	-2.701	**1.204**	**1.698**
	(0.189)	(2.018)	**(0.389)**	**(0.228)**
N	426	38	123	265
Cohorts, Bayesian Estimates of Ownership and Adoption Shares				
OBC	**0.681**	**-3.552**	**1.381**	**1.447**
	(0.070)	**(0.367)**	**(0.153)**	**(0.106)**
N	3676	1049	1332	1295

Control variables (not shown) are distance from home dummies and ln(trailer density).

The dependent variable in the top panel is a dummy variable that equals one if the truck is driven by a company driver and zero otherwise.
The dependent variables in the bottom two panels are ln(company driver share/owner-operator share) in 1987 and 1992.

Table 4
Cohort Summary Statistics

	All Cohorts	Cohorts with Positive Owner-Operator and Company Driver Shares in Both Years
Cohorts	3676	426
Observations/Cohort, 1987	4.13	10.61
Observations/Cohort, 1992	6.42	17.80
Owner-Operator Share, 1987	0.14	0.27
Owner-Operator Share, 1992	0.10	0.18
Change in O/O Share	-0.04	-0.09
OBC Adoption, 1992	0.19	0.24
Trip Recorder Adoption, 1992	0.09	0.10
EVMS Adoption, 1992	0.10	0.14

Averages are computing using weights, where weight = (numobs87*expanf87 + numobs92*expanf92)/2

Table 5
Truck Ownership and OBC Adoption -- First Differences

Dependent Variable: ln(cd share/o/o share)92 - ln(cd share/o/o share)87
Cells are based on product-trailer-state-distance cohorts.

	Observed Ownership and Adoption Shares				Bayesian Estimates of Ownership and Adoption Shares			
OBC	**0.532**	0.238			**0.759**	**0.379**		
	(0.269)	(0.381)			**(0.100)**	**(0.145)**		
EVMS		0.550				**0.678**		
		(0.506)				**(0.190)**		
OBC*Long			**0.943**	**1.021**			**1.054**	**0.741**
			(0.306)	**(0.470)**			**(0.119)**	**(0.194)**
OBC*Medium			-0.549	-0.865			**0.617**	**0.504**
			(0.532)	(0.670)			**(0.192)**	**(0.240)**
OBC*Short			-2.655	-4.466			**-2.611**	**-2.699**
			(2.136)	(2.374)			**(0.466)**	**(0.558)**
EVMS*Long				-0.104				**0.458**
				(0.567)				**(0.224)**
EVMS*Medium				1.153				0.397
				(1.476)				(0.503)
EVMS*Short				10.780				0.298
				(6.184)				(1.137)
N	426				3676			

Control variables (not shown) are distance from home dummies and ln(trailer density).
Bayesian estimates use initial priors with distance-specific means for ownership and adoption shares.

Table 6
Truck Ownership and OBC Adoption -- First Differences

Medium and Long Haul Cohorts Only

Dependent Variable: ln(cd share/o/o share)92 - ln(cd share/o/o share)87
Cells are based on product-trailer-state-distance cohorts.

	Observed Ownership and Adoption Shares				Bayesian Estimates of Ownership and Adoption Shares			
OBC	**0.576**	**0.683**	0.333	0.424	**0.930**	**0.971**	**0.604**	**0.664**
	(0.284)	**(0.284)**	(0.404)	(0.404)	**(0.104)**	**(0.105)**	**(0.154)**	**(0.156)**
EVMS			0.434	0.461			**0.557**	**0.521**
			(0.513)	(0.514)			**(0.195)**	**(0.196)**
OBC*"No BH"		**-6.993**		-6.073		**-2.128**		-1.952
		(2.491)		(3.177)		**(0.579)**		(1.043)
EVMS*"No BH"				-1.764				-0.121
				(3.808)				(1.282)
N	388				2627			

Control variables (not shown) are distance from home dummies and ln(trailer density).
Bayesian estimates use initial priors with distance-specific means for ownership and adoption shares.

No BH includes dump, grain, livestock, logging trailers

Table 7
Truck Ownership and OBC Adoption -- First Differences
Instrumental Variables Estimates

Dependent Variable: ln(cd share/o/o share)92 - ln(cd share/o/o share)87

Cells are based on product-trailer-state-distance cohorts.

	Observed Ownership and Adoption Shares			Bayesian Estimates of Ownership and Adoption Shares		
OBC	**0.973**		1.093	**0.990**		**1.187**
	(0.426)		(0.601)	**(0.376)**		**(0.493)**
OBC*Long		**1.959**			**1.104**	
		(0.440)			**(0.585)**	
OBC*Medium		-0.358			**1.192**	
		(0.595)			**(0.530)**	
OBC*Short		**-6.019**			-0.855	
		(2.158)			(1.280)	
OBC*"No BH"			7.615			-2.805
			(5.574)			(1.879)
Sample	All	All	Medium, Long	All	All	Medium, Long
N	426	426	388	3676	3676	2627

Control variables (not shown) are distance from home dummies and ln(trailer density).

Bayesian estimates use initial priors with distance-specific means for ownership and adoption shares.

Product class dummies used as instruments for OBC adoption.

Table 8
1992: Fuel Economy, Vehicle Ownership, and Distance

Dependent Variable: MPG	All Distances	<50 Miles	50-200 Miles	200+ Miles
Variable				
Owner-Operator	**-0.042**	**-0.159**	-0.008	-0.015
	(0.017)	**(0.064)**	(0.033)	(0.019)
TR*Owner-Operator	0.063	-0.514	0.149	0.127
	(0.096)	(0.330)	(0.265)	(0.091)
TR*Company Driver	**0.186**	-0.011	**0.108**	**0.289**
	(0.019)	(0.067)	**(0.033)**	**(0.021)**
EVMS*Owner-Operator	**0.184**	0.299	**0.346**	**0.146**
	(0.064)	(0.343)	**(0.165)**	**(0.059)**
EVMS*Company Driver	**0.115**	-0.060	**0.165**	**0.126**
	(0.019)	(0.084)	**(0.042)**	**(0.019)**
R-squared	0.2102	0.1539	0.2411	0.2516
N	35203	8002	11647	15552

Regressions include controls for: distance from home, who maintains truck, refrigerated/specialized trailer, driving axles, vehicle make and model year, equipment dummies (such as for aerodynamic features), average weight, lifetime miles, and engine size.

Appendix 2

Table A1
Truck Ownership and OBC Adoption -- First Differences
Linear Probability Specifications

Dependent Variable: company driver share 1992 - company driver share 1987
Cells are based on product-trailer-state-distance cohorts.

OBC	0.043	0.048			0.025	0.019		
	(0.043)	(0.061)			(0.017)	(0.025)		
EVMS		-0.010				0.011		
		(0.081)				(0.034)		
OBC*Long			0.084	**0.151**			0.010	0.010
			(0.049)	**(0.076)**			(0.024)	(0.038)
OBC*Medium			-0.067	-0.115			0.071	0.041
			(0.086)	(0.108)			(0.031)	(0.039)
OBC*Short			-0.275	-0.457			-0.028	-0.015
			(0.345)	(0.384)			(0.050)	(0.059)
EVMS*Long				-0.103				0.001
				(0.092)				(0.046)
EVMS*Medium				0.171				0.081
				(0.239)				(0.066)
EVMS*Short				1.085				-0.046
				(1.001)				(0.112)
N	426				3676			