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

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We investigate how the contractibility of actions affecting the value of an asset affects asset ownership. We examine this by testing how on-board computer (OBC) adoption affects truck ownership. We develop and test the proposition that adoption should lead to less ownership by drivers, particularly for hauls where drivers have the greatest incentive to drive in non-optimal ways or engage in rent-seeking behavior. We find evidence in favor: OBC adoption leads to less driver ownership, especially for long hauls and hauls that use specialized trailers. We also find that non-owner drivers with OBCs drive better than those without them. These results suggest that technology-enabled increases in contractibility may lead to less independent contracting and larger firms.

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1. Introduction

What determines who owns assets in the economy? Grossman and Hart (1986) argue persuasively that asset ownership is irrelevant when contracts are complete. They provide two key insights regarding the relationship between asset ownership and contractibility. One is that ownership *per se* does not affect contractibility. Any contract that can be written between firms and employees (individuals who do not own productive assets) can also be written between firms and independent contractors (individuals who do). Another is a central implication of their model: contractibility affects optimal asset ownership, and therefore firms' boundaries. Changes in the set of contractible variables will affect whether workers are employees or independent contractors, or alternatively, whether firms produce internally or use subcontractors. In this paper, we examine relationships between asset ownership and contractibility using data from the United States trucking industry.

Nickerson and Silverman (1999) point out that several organizational theorists have cited trucks as "prototypical user-owned assets."[1] Yet most trucks in the United States, and almost all short-haul trucks, are not owned by their drivers. They are operated by "company drivers" – individuals who do not own the trucks they drive – rather than "owner-operators." We argue that ownership patterns in trucking are a consequence of two central "non-contractibles." The importance of each of these determines the optimal ownership of trucks. One non-contractible is the degree to which drivers engage in rent-seeking activities such as searching for hauls other than those prearranged by carriers. The other non-contractible, at least until the late 1980s, is how drivers operate trucks – in particular, whether they drive trucks in ways that maintain trucks' value.

In the late 1980s, an important technological innovation expanded the set of variables upon which carriers and drivers could contract. The development of on-board computers (OBCs), devices that continuously record various operating parameters of trucks (e.g., their speed), allowed carriers to construct better performance measures of how drivers operate trucks. Our hypothesis is that, consistent with the predictions of Grossman and Hart, this change in the contractibility of key

[1]These include Alchian and Demsetz (1972) and Milgrom and Roberts (1992). The latter actually remarks in a footnote that monitoring devices have reduced the benefits of driver ownership.

decisions should change the optimal ownership of trucks. We propose that it should increase the use of company drivers, especially for hauls where drivers have the greatest incentive to drive in suboptimal ways or engage in rent-seeking behavior.

We test this proposition using cross-sectional data from 1987 and 1992. These data contain truck-level information on OBC adoption and truck ownership. We find that OBC adoption leads to increased use of company drivers, particularly for hauls for which contracting problems are greatest: long hauls and hauls that use specialized trailers. This evidence supports the proposition and is our main empirical result.

We also examine relationships between trucks' fuel economy and OBC use. This provides a test for 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. 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.

These results help to understand relationships between current waves of information technology (IT) diffusion and changes in firms' boundaries. As Hubbard (1999a) points out, recent applications of IT -- particularly networking applications -- offer enhanced monitoring capabilities. These can increase contractibility. Our results indicate that when subcontracting decisions hinge on trade-offs between motivating care for productive assets and discouraging rent-seeking behavior, technology-enabled increases in contractibility will tend to lead to less outsourcing.[2] If firms' boundaries are defined by asset ownership, monitoring technologies' incentive-improving capabilities will lead to larger firms.

This paper extends two strains of the empirical literature on organizations. Our emphasis on relationships between contractibility and ownership is similar to work that examines how outlet characteristics influence contractual form in franchising (Brickley and Dark (1987), LaFontaine

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[2]Interestingly, Holmstrom and Milgrom's (1994) model predicts that increases in contractibility will lead to greater use of independent contractors Our evidence shows that this prediction is not true in trucking.

(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 general result that monitoring and ownership are substitutes is consistent with findings from this literature. 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.) Finally, the paper is related to recent work on technology and organizations in trucking (Chakraborty and Kazarosian (1999), Hubbard (1999a, 1999b), Nickerson and Silverman (1999)).

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 empirical framework. In section 5, we describe the data, present simple statistics that confirm the general patterns in the data and show that data censoring problems are unlikely to drive estimation results. In section 6, we present and interpret the estimation results. 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. In either case, they face several incentive problems in their agency relationship with their drivers. One is motivating drivers to complete hauls 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.[3]

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 visit friends or take on outside hauls ("milk runs") and still arrive on time. Their ability to do so is particularly high on hauls with infrequent scheduled stops because there is more room 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 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. Drivers must be motivated to accept hauls, and owner-operators have a greater ability to hold up carriers than company drivers do.

Company drivers have little leverage in negotiations with carriers over when they will carry their next load. They can, of course, quit. But doing so leaves them with no equipment and whatever prospect they have for finding alternative employment. Owner-operators, on the other

[3]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.

hand, have their trucks. They can access a (possibly thick) spot market for hauls. Spot markets for low-value, time-insensitive hauls exist in many regions, mainly for hauls that use non-specialized trailers such as platforms and enclosed, non-refrigerated vans.[4] These markets, usually mediated by brokers, offer owner-operators and carriers low-cost access to hauls and play an important role in helping them fill long "backhauls" when return trips are not prearranged. Spot markets are less common and thinner for hauls that use specialized equipment. Accessing these hauls usually requires more costly search.

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. Contractual solutions to this problem can be only partially successful. Even if carriers could restrict owner-operators' ability to use their trucks for alternative hauls (essentially through leasing the equipment; see below), they could not put other drivers in their trucks. Carriers therefore have less bargaining power with owner-operators than with company drivers.

This description of carriers' relationship with their company drivers and owner-operators is consistent with characterizations given by those in the industry. 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.[5]

The implication with respect to ownership patterns follows. 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 induces drivers to engage in rent-seeking behavior.

Regulatory Issues and Asset Ownership

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

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[4]High-value hauls are rarely available in the short run, either through markets or otherwise.

[5]See Ouelett (1994), for example.

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.[6] 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 cannot deny owner-operators access to their trucks, even if drivers unilaterally terminate leases prematurely. One reason for this is that operating authority requirements are intended to make it easier to identify which firm is liable in case of accidents, not create situations in which carriers can hold up drivers. The control right provisions in owner-operator leases are, for all intents and purposes, a legal fiction. They do not change the depiction of incentive conflicts above.[7]

On-Board Computers

On-board computers (OBCs) appeared on the market during the mid-to-late 1980s.[8] 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. 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. Dispatchers receive the information trip recorders collect

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[6]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.

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

[8]See Hubbard (1999a) for more details.

when drivers return to their base; drivers give dispatchers a chart, floppy disk, or data cartridge with the data. These data are useful for two reasons. First, they provide carriers better measures of how drivers operate trucks. For example, carriers can tell when drivers speed or take long breaks. Second, they provide mechanics better information about trucks' engines. This enables them to diagnose and fix problems better.

EVMS contain all trip recorders' capabilities, but have several additional features. First, they record trucks' location, sometimes via links to global positioning services. Second, they can transmit the information they collect to dispatchers in close to real time. Third, they allow dispatchers and drivers to send short text messages to each other. This feature enables dispatchers to initiate contact with drivers even when they are outside of radio range. Without EVMS, dispatchers generally have to wait for long-haul drivers to call in to communicate with them. EVMS' additional capabilities make them useful for improving resource allocation (scheduling) decisions as well as incentives and maintenance. This distinction is emphasized in Hubbard (1999a), which uses differences in adoption patterns to distinguish between situations where OBCs primarily improve incentives and primarily improve resource allocation decisions.

This paper investigates the organizational impact of the capabilities the two technologies share. Both technologies make how drivers operate trucks more contractible. Carriers using these technologies can observe not just arrival times, but whether drivers reach their destination by driving their trucks at a consistent pace. 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 carrier and a driver. The carrier has orders for cargo to haul, and wants to induce the driver to drive a truck to fulfill them. The haul's value, which includes the cost of wear and tear on the truck, is a function of how well the driver drives. We assume that arrival times are costlessly observable and verifiable throughout. Our first set of results is generated under the assumption that neither the value of a particular haul nor the way the driver drives is observable to both parties, so neither can be the basis for a contract between them.

The value in period t of using the truck for the carrier's hauls, V_t, is given by:

$$V_t = Y + g_1 e_{1t}, \tag{1}$$

where Y is a fixed quantity that does not vary with driver effort, e_{1t} is the effort that the driver puts into driving well on hauls in period t, and g_1 is the marginal product of driver effort in driving well. We define e_{1t} as the effort the driver puts in to driving well, above and beyond that required to arrive on time. We will refer to g_1, the marginal productivity of driving well, as the "scope for good driving." It varies with haul characteristics. In particular, it is lower for short hauls than long hauls because short haul trucks have more frequent scheduled stops. Stops serve as checkpoints, and drivers must drive well to meet them. Drivers have more leeway when stops are less frequent.

Drivers can also search for alternative hauls. The value in period t of using the truck for hauls the driver lines up, P_t, is given by:

$$P_t = Q + g_1 e_{1t} + g_2 e_{2,t-1} \tag{2}$$

where Q is a fixed quantity the does not vary with driver effort, e_{2t} is the effort that the driver puts into looking for other business in period t, and g_2 is the marginal product of looking for other business. P_t is a function of how well drivers drive in that period (e_{1t}) and how much effort they put in the previous period into lining up a haul ($e_{2,t-1}$). We assume that Y>>Q so that it is always efficient to use the truck for the carrier's haul.[9] Although e_{2t} never increases total surplus, it can increase the driver's share. We therefore refer to g_2 as the "scope for rent seeking." g_2 varies with haul characteristics. As described above, it is zero when search does not improve upon the opportunities found in spot markets and positive when it does.

The two types of effort in which the driver engages are costly. The driver's cost of effort is captured by the function:

$$C(e_{1t}, e_{2t}) = e_{1t}^2/2 + e_{2t}^2/2 \tag{3}$$

[9]Specifically, we assume $Y > Q + \max\{ ½ (g_1^2 + g_2^2), 5/8\, g_2^2 \}$.

Driving well is costly for two reasons. One is that it demands more attention. The other is that by driving well, drivers forego opportunities for on-the-job consumption in the form of longer breaks, milk runs, and so on. Searching for outside opportunities is costly because it requires time and energy.

Incentives and Surplus Under Company Ownership

When the carrier owns the truck, it bears costs associated with how the driver drives. Since e_{1t} is unobservable to the carrier, and thus non-contractible, carriers cannot induce drivers to drive well. Furthermore, since company drivers do not have the right to take alternative hauls, they have no incentive to line up other hauls. Thus, under company ownership, both e_{1t} and e_{2t} are zero. The total surplus generated by this arrangement is therefore equal to $S_c = Y$.

Incentives and Surplus Under Driver Ownership

When the driver owns the truck, two things change. One is that the driver now bears the costs and benefits of driving well, since he or she is the residual claimant on the truck's value. The other is that the driver now has the right to use the truck for other hauls. We assume that the carrier and the driver will split evenly any surplus difference between the using the truck for the carrier's and the driver's hauls. Thus, the pay-off to the driver in period t is $(V_t + P_t)/2$.

Since none of the parameters in the problem other than effort choice are time-dependent, the driver's effort choices are the same in each period. Solving the driver's effort choice under driver ownership yields the following levels of each type of effort.

$$e_{1t} = g_1, \; e_{2t} = g_2/2 \tag{4}$$

The outcome of the bargain between the carriers and driver results in value V_t. Thus, total surplus available under driver ownership is:

$$S_o = Y + g_1^2/2 - g_2^2/8 \tag{5}$$

The surplus generated under driver ownership is determined by two factors: the scope for good driving (g_1) and the scope for rent-seeking (g_2).

Comparing the surplus generated under the two alternative ownership arrangements yields the following result. When $2g_1 > g_2$, the driver owns the truck; otherwise, the carrier does.

Comparative Statics Under Unobservable Driver Effort

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 a few days, and then consume the rest of the time it *should* have taken them however they choose.

The model also predicts that carriers should own trucks when the scope for rent-seeking is large -- that is, when g_2 is large. This is more likely to be the case when hauls use specialized equipment. Thin spot markets make investments in bargaining positions productive to drivers. Thus, owner-operators will be used more when hauls employ non-specialized trailers.

This model thus yields the following 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 non-specialized equipment (such as platforms and dry vans) than specialized equipment (such as tank trucks and refrigerated vans).

Contractible Effort

This model also predicts the consequences of making good driving contractible. Suppose that the introduction of on-board computers (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 peg e_1 at or near the first-best level, g_1. Then company ownership with OBCs generates surplus equal to:

$$S_c^* = Y + g_1^2/2 - d \qquad (6)$$

where d is the per-period cost of OBC use.

In this model, OBCs generate no benefit when the driver owns the truck. Since owner-operators already drive optimally, technologies that improve their incentives to drive well yield no value. Thus, surplus under driver ownership remains:

$$S_o = Y + g_1^2/2 - g_2^2/8 \tag{7}$$

The margin between using company drivers with OBCs or owner-operators is defined by the equation:

$$S_c^* - S_o = g_2^2/8 - d = 0 \tag{8}$$

Company drivers with OBCs are preferred to owner-operators if $g_2 > 2(2d)^{1/2}$.

Figure 1 depicts the ownership patterns the model predicts for 1987 and 1992, before and after OBCs became available. In 1987, owner-operators are used whenever the scope for good driving is high relative to the scope for rent-seeking; that is, whenever $2g_1 > g_2$. In 1992, this is no longer the case. It is optimal to utilize company drivers with OBCs whenever both the scope for good driving and the scope for rent-seeking is high. In the region where $2g_1 > g_2$ and $g_2 > 2(2d)^{1/2}$, the northeast region in the figure, ownership changes. Hauls both adopt OBCs and move from owner-operators to company drivers. Ownership does not change in any of the other regions. This leads to our first proposition about the relationship between adoption and ownership.

P3: OBC adoption should drive the incidence of driver ownership down.

The model also predicts where adoption will lead to ownership changes and where it will not. The model predicts that adoption will only occur when both g_1 and g_2 are high. But this is because it focuses exclusively on OBCs' incentive-improving capabilities. Adoption will in fact occur when g_1 or g_2 are low because OBCs offer benefits other than incentive improvements. But when adoption takes place for maintenance- or coordination-related reasons, it should not affect truck ownership. Adoption should only lead to changes in asset ownership in the northeast region of Figure 1.

P4: OBC adoption should drive the incidence of driver ownership down more for long hauls using specialized trailers than for other hauls.

Testing P3 and P4 requires an empirical framework through which one can identify relationships between technological and organizational changes. The following section describes this.

4. Empirical Framework

Following from above, let S_{io} and S_{ic} represent total surplus of haul i, given drivers and carriers own the truck, respectively. Specify these as:

$$\begin{aligned} S_{io} &= X_i\beta_o + \epsilon_{io} \\ S_{ic} &= X_i\beta_c + \epsilon_{ic} \end{aligned} \tag{9}$$

where X_i is a vector depicting haul characteristics and whether OBCs are used. ε_{io} and ε_{ic} 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 $S_{ic} > S_{io}$. Assuming that ε_{io} and ε_{co} are i.i.d. type I extreme value, the probability the carrier owns the truck, conditional on X_i, is:

$$P_{ic} = \frac{e^{X_i(\beta_c - \beta_o)}}{1 + e^{X_i(\beta_c - \beta_o)}} = \frac{e^{X_i\beta}}{1 + e^{X_i\beta}} = \Lambda(X_i\beta) \tag{10}$$

If $E(X_i\varepsilon_{io}) = 0$ and $E(X_i\varepsilon_{ic}) = 0$, β indicates how X_i affects ownership. One then could estimate β using cross-sectional data. But these orthogonality assumptions are not reasonable a priori because factors not observed by the econometrician may affect technology choice and truck ownership independently. For example, trucks used for unobservedly time-sensitive hauls may have OBCs to improve coordination and be owned by carriers to mitigate rent-seeking by drivers. Correlations between levels of OBC use and ownership shares therefore do not necessarily imply that adoption affects asset ownership.

With panel data, one could address this endogeneity problem by allowing for haul-specific fixed effects. The panel version of the above model is based on the equations:

$$\begin{aligned} S_{iot} &= X_{it}\beta_o + \phi_{io} + \epsilon_{iot} \\ S_{ict} &= X_{it}\beta_c + \phi_{ic} + \epsilon_{ict} \end{aligned} \tag{11}$$

The likelihood function would be based on the expression:

$$P_{ict} = \Lambda(X_{it}\beta + \phi_i) \tag{12}$$

φ_i would pick up time-invariant factors that affect the efficiency of driver ownership for a particular haul – for example, the haul's time-sensitivity. β would be identified by relationships between changes in X_i (for example, OBC adoption) and changes in governance. This would mitigate the endogeneity problem described above because if both IT use and ownership were affected by an omitted time-invariant variable, the fixed effects would account for this.

The data used in the analysis are not panel data: they are repeated cross-sections. They do not track individual trucks or hauls from period to period. Therefore, we base our analysis on observations of cohorts rather than trucks. These cohorts are at the level of product-trailer-distance-state; for example, an observation is "trucks based in California used to haul food long distances in refrigerated vans." Cohorts are defined narrowly in order to base them on as similar hauls as possible, given the data. Although we lose information by aggregating truck-level data up to the cohort level, doing so enables us to exploit the time dimension of the data and address endogeneity issues with fixed effects estimators (Deaton (1985)).

Our specification is a cohort analog of that described above. Let s_{crt} be the share of company drivers in cohort r at time t. We specify s_{crt} and its analog s_{ort} as:

$$\begin{aligned} s_{crt} &= \Lambda(X_{rt}\beta + \phi_r + \phi_{rt}) \\ s_{ort} &= 1 - \Lambda(X_{rt}\beta + \phi_r + \phi_{rt}) \end{aligned} \tag{13}$$

X_{rt} are cohort means of variables observed by the econometrician. The most important variables in this vector are OBC adoption rates. The other terms are time-invariant and time-varying fixed effects. Note that (13) does *not* follow from aggregating the individual model. Although we use the same notation, the variables and parameters – in particular, β – are not the same as those in the individual model.

From these expressions, we obtain:

$$h_{rt} = \ln(s_{crt}/s_{ort}) = X_{it}\beta + \phi_r + \phi_{rt} \tag{14}$$

One can eliminate the cohort-specific fixed effects by taking first differences.

$$h_{rt} - h_{r,t-1} = (X_{it} - X_{i,t-1})\beta + \eta_{rt} \tag{15}$$

Here $\eta_{rt} = \varphi_{rt} - \varphi_{r,t-1}$. (15) is the base specification. The OBC coefficients in the parameter vector β identify relationships between within-cohort adoption rates and changes in ownership shares. η_{rt} picks up omitted variables that affect changes in cohorts' ownership shares. If OBC adoption is orthogonal to this residual term, simple regression estimates of β identify how adoption affects ownership. One can use these estimates to test propositions P3 and P4 from the previous section.

First-difference estimates greatly reduce concerns about endogeneity. But two issues remain. One is that omitted cohort-specific factors may affect adoption and ownership changes independently. For example, the strength of local Teamsters unions may have affected both how much carriers adopted OBCs and how much they moved toward using owner-operators as subcontractors between 1987 and 1992. The other is that errors-in-variables issues arise when aggregating individual observations up to the cohort level. Deaton (1985) shows that if one estimates the sample analog to (15), there is an errors-in-variables problem with respect to the cohort-specific fixed effects. First-differencing does not eliminate this source of error. It is captured in η_{rt} and may be correlated with the explanatory variables. We further discuss and address this issue below.

Equations (14) and (15) are only well-defined if s_{crt} and s_{ort} are both greater than zero. When estimating these equations, one can only use cohorts for which the owner-operator and company driver shares are positive in both years. This raises the prospect of selection bias. Below we provide evidence that while selecting cohorts on this basis does mean that the analysis is based on cohorts with higher-than-average owner-operator shares, it likely does not affect estimates of β.

5. Data

The data are from the 1987 and 1992 Truck Inventory and Use Surveys (TIUS). (See Bureau of the Census (1989, 1995), Hubbard (1999a).) 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 obtain information about 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.

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, 14.1% of tractor-trailers were driven by their owners.[10] The share is higher for long hauls than short hauls. This is consistent with P1. The right part of the table reports owner-operator shares for hauls using specialized and non-specialized trailers. Here and elsewhere in this paper, "non-specialized trailers" includes platforms and enclosed, non-refrigerated vans and "specialized trailers" includes all other trailer types. The most prevalent specialized trailers are refrigerated vans, dump trailers, and tank trucks. The owner-operator share is slightly higher for hauls using non-specialized trailers. This

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[10]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.

provides weak evidence in favor of P2.[11] Owner-operators' share fell between 1987 and 1992 from 14.1% to 11.1% overall, decreasing within each distance and trailer category. The percentage point decline is greater for long hauls than short hauls, and for specialized than non-specialized trailers.

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 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.

The first column of Table 3 presents summary statistics for the 3676 cohorts in which at least one truck was observed in both years.[12] Because cohorts are defined narrowly, on the average they are based on observations of very few trucks. As explained above, the main empirical analysis uses only cohorts with positive company driver and owner-operator shares in both years. Only 426 of the 3676 cohorts satisfy this criterion. The right two columns report summary statistics for the included and excluded cohorts. The included cohorts are based on more observations and have higher owner-operator shares than the excluded ones. The latter is because almost all of the excluded cohorts have no owner-operators in at least one of the two years. The included cohorts have larger changes in ownership and higher adoption rates than the excluded cohorts. The main empirical analysis is thus based on parts of the industry where the largest organizational and technological changes took place.

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[11]If one classifies dump trailers as non-specialized, the evidence for P2 is stronger. The difference between the non-specialized and specialized shares increases to 2.3%.

[12]All calculations and estimates involving cohorts weight them by the number of observations within the cohort and weighting factors supplied by the Census which depict differences in sampling rates across states. 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. The Census weighting factor reflects sampling intensity. The results in section 6 are robust to variations in weighting.

This is because the included cohort subsample is disproportionately comprised of long haul trucks.

Table 4 examines relationships between technological and organizational change. We divide cohorts according to whether their owner-operator share increased, decreased, or stayed the same between 1987 and 1992 and compare OBC adoption rates for the three groups. The top left panel uses all 3676 cohorts. On the average, cohorts where the owner-operator share decreased have an adoption rate of 0.22. This is greater than the 0.20 adoption rate for those where the owner-operator share increased. From the bottom three rows, the difference between the adoption rates for the "decreases" and "increases" is greatest for long hauls. Adoption is correlated with changes in asset ownership, particularly for long hauls.

The top right panel is analogous, but uses only the 426 included cohorts. Comparing this with the top left panel provides evidence for whether selection affects the analysis. These figures indicate that OBC adoption is higher for the "decreases" than "increases, " and the difference is about the same as in the left panel. This suggests that the included cohorts are representative of cohorts in general. However, the within-distance patterns are different. For medium hauls, the sign of the difference is different than for all cohorts: adoption in the "increase" cohorts is higher than for the "decrease" cohorts. For long hauls, the sign of the difference is the same as for all cohorts but the magnitude is about twice as large. There thus is some cause for concern that the included cohorts are not representative in ways that can lead one to overstate the extent to which OBC adoption is associated with movements toward company ownership for long hauls, and underestimate it for medium hauls. The former is more problematic because it would bias results in favor of finding that monitoring substitutes for ownership.

The bottom of table 4 shows that the dissimilarity between the "all cohort" and "included cohort" patterns is driven by cohorts with very few observations. It reports analogous figures from a subsample that does not include cohorts with five or fewer observations in either year. The difference in the adoption rates for the decreases and increases is similar for "all cohorts" and "included cohorts" in this subsample. The fact that the difference between the decreases and increases for "all cohorts" is small appears to be due to the fact that "all cohorts" contains many very small cohorts for which the calculated adoption rates and owner-operator shares are noisy measures of the true population values. Measurement error makes the difference in adoption rates between the decreases and the increases look smaller than they are.

As noted above, an empirical problem with cohort-based models is that in their sample analogs, cohort-specific fixed effects are error-ridden. This error is greatest for the cohorts that are based on the smallest number of observations. We address this issue in two ways. One is by estimating the model using instrumental variables. If the instruments are independent of the measurement error in the fixed effect, the parameter estimates will be unbiased. The other is by estimating the model dropping the smallest cohorts. We will therefore report estimates using only cohorts with five or more observations in each year as a robustness check.

6. Results

Table 5 contains results from estimating (14): the "levels" version of the model. In it, we report results from eight multivariate regressions. In each, there are two dependent variables: $\ln(s_{cr,1987}/s_{or,1987})$ and $\ln(s_{cr,1992}/s_{or,1992})$. In the top panel, we include OBC adoption rates, distance dummies, and ln(trailer density) as explanatory variables. The latter picks up differences in the thickness of the local trucking market (see Hubbard (1999b)). We restrict the coefficients on the explanatory variables to be the same in each year. OBC adoption rates only appear in the 1992 equation because adoption rates are zero by assumption in 1987. The four columns report the coefficient on OBC when we estimate the model using all included cohorts, short haul cohorts, medium haul cohorts, and long haul cohorts, respectively. In the bottom panel we include trip recorder and EVMS adoption rates separately.

The results indicate that cohorts with high OBC use also have high company driver shares. In the first column, the coefficient on OBC is positive and significant. Moving across the table, it is positive and significant for medium and long hauls, but not for short hauls. In the bottom of the table, the coefficients on trip recorder and EVMS are both positive and significant for medium and long hauls. This table indicates relationships between OBC use and ownership, but one is unable to determine whether this is because adoption caused ownership changes or because adoption took place for hauls for which company drivers were used in the first place.

Table 6 presents results from estimating equation (15). These are the first difference estimates. From the top panel, cohorts with high OBC adoption move disproportionately toward company ownership. Looking at the right side of the table, this is true only for long hauls. From the bottom panel, the trip recorder and EVMS coefficients are almost the same for long hauls. Neither are statistically significant for short or medium hauls. The estimates support P3 and part of P4: OBC adoption moves hauls toward company ownership, and does so particularly for long hauls.

These results produce two interesting contrasts. First, comparing the results in Tables 5 and 6, the medium haul coefficients lose statistical significance; those on OBC and trip recorder change sign as well. The positive and significant coefficients in table 5 therefore indicated that OBCs were adopted for medium hauls that used company drivers in the first place. In contrast, the coefficients on the long haul subsample remain positive and significant. Second, the trip recorder and EVMS coefficients are almost identical in the long haul specification in table 6. This suggests that there is a relationship between OBC's incentive-improving features and ownership change, but not their coordination-improving features. If OBCs' coordination-improving features influenced ownership, the coefficient on EVMS would differ from that on trip recorder.

Table 7 presents results when estimating (15) separately for non-specialized and specialized trailers. These estimates indicate that the relationships between OBC adoption and organizational change are strongest for long hauls using specialized trailers. Looking at the right-most column, the point estimates are positive but not statistically significant for non-specialized trailers. They are positive, significant, and large for specialized trailers. The estimates thus support P4.

In sum, relationships between OBC adoption and changes in truck ownership are strongest for hauls where both the scope for good driving and drivers' incentive to engage in rent-seeking behavior are high: that is, where g_1 and g_2 are high. OBCs are sometimes adopted where g_1 and g_2 are low, but there is little evidence that they induce ownership changes in such circumstances. These results are consistent with the proposition that OBCs serve as an incentive substitute to asset ownership because they enable carriers to encourage good driving without inviting rent-seeking behavior.

First Differences, Fixed Effects

We next present results from a series of specifications that add trailer, product, and state fixed effects in the first difference specifications. We do this for two reasons. First, it allows us to explore what is driving the results in table 6. If, for example, the parameter estimates become small and statistically insignificant when including a full set of trailer fixed effects, this would indicate that the results in table 6 are largely identified by systematic relationships between adoption and ownership changes at the trailer level. Second, it provides a guide for an identification strategy that lets us estimate (15) with instrumental variables. If the coefficients on the trailer fixed effects are not jointly significant, then controlling for adoption rates, there is no evidence that there exist systematic differences in ownership changes across trailer types. One can then use this as an identifying assumption in a moments-based estimator.

Table 8 presents results using the long haul subsample from a series of estimates. The first column repeats the right column of table 6. The next three include trailer, product, and state fixed effects, respectively. The 12, 14, and 49 fixed effect coefficients in these three specifications are estimated but not reported.[13] The last includes trailer, product, and state fixed effects. From the second column, the coefficients decrease somewhat when including trailer fixed effects – the trip recorder coefficient turns insignificant using a t-test of size 0.05 – but not much qualitatively changes. From the third column, they decrease more when including instead product fixed effects. Both the trip recorder and EVMS coefficients fall by 20-25% and turn insignificant. Part of the phenomena reported in table 6 is due to trailer and product-level effects, but most is not. From the fourth column, including state fixed effects makes the trip recorder coefficient fall by half. The trip recorder coefficient in table 6 is picking up relationships between trip recorder adoption and ownership changes at the state level. From the final column, including all three sets of fixed effects makes all the estimates noisy and not statistically significant.

The bottom of the table reports p-values for the hypothesis test that the fixed effects are jointly equal to zero. One can reject this null only for the last two specifications. The trailer and product dummies have little explanatory power. In specifications not reported here, we found that this also was true for specifications which used all distances and medium hauls. (There are too few short haul observations to perform such tests.) There is no evidence that omitted factors that induced ownership changes were related to trailers or products. This makes the trailer and product dummies good candidates for instruments.

GMM-IV Estimation

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[13]There are actually 20 product categories. We combine several of the least common ones into a miscellaneous category in these specifications.

Table 9 presents results from GMM estimation using trailer and product dummies as instruments. The second column uses only the trailer dummies. The point estimates remain positive, but all are very noisy – the standard errors are about twice as high as those in OLS estimation (reported in the first column). The third column uses only the product dummies. The point estimates on OBC and EVMS increase sharply. The OBC and EVMS coefficients are positive and significant using t-tests of size 0.05; the trip recorder coefficient is significant using a t-test of size 0.10. The fourth column uses both the product and the trailer dummies. The coefficients remain large and positive and the standard errors become about 20% smaller. The coefficients on OBC and trip recorder are significant using a test of size 0.05. That on EVMS is nearly the same as in the first column and is significant using a t-test of size 0.10.

In specifications not shown, we fail to find any relationship between OBC adoption and ownership changes for short or medium hauls.

The GMM-IV estimates indicate that the results in table 6 reflect causal relationships. OBC adoption led to changes in ownership for long hauls. Furthermore, the fact that the GMM-IV estimates are higher than the OLS estimates suggests that measurement error biases the OLS estimates toward zero: against finding relationships.

Figure 10 presents analogous estimates using only cohorts with more than five observations. In the first column the coefficient on OBC is positive and significant; OBC adoption is associated with movements toward company ownership. The coefficient on EVMS is positive, significant, and larger than that from the estimates using all included cohorts. The trip recorder coefficient is positive, not statistically significant, and lower than in the estimates above. The right three columns report the GMM-IV estimates. The number of overidentifying conditions is smaller than above because some trailer and product categories appear in the "all included cohorts" sample but not in the >5 observations subsample. The estimates here are noisier than those in table 9 for this reason, especially those which use trailer dummies as instruments. The coefficients in the two specifications which use product dummies as instruments are qualitatively similar.[14] There is little evidence that

[14]We also have estimated these specifications using the subsample of cohorts with more than ten observations in each year. This cuts N by half again to 74. The point estimates become even noisier, but are qualitatively similar to those in table 8.

the main results in tables 6 and 9 – that trip recorder and EVMS adoption moved hauls from driver ownership to company ownership – are due to the criterion used to determine which cohorts are included in the sample.

Adoption and Driving Patterns

In this subsection we investigate whether OBC use affects how drivers drive. According to our model, one should expect OBC use to lead drivers to operate trucks at more consistent speeds. If so, this should be manifested in better fuel economy. This section presents regression results in which we test whether, controlling for a host of truck characteristics, trucks with OBCs are more fuel efficient. There are two alternative interpretations if one finds that this is the case. One is that OBCs affect how drivers drive. The other is that OBCs supply information that helps mechanics maintain trucks better. To distinguish between these interpretations, 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 it affects fuel economy more for company drivers is evidence of their incentive-improving effect.[15]

We run this regression on 1992 observations of individual trucks. The dependent variable is the truck's miles per gallon, reported by its owner in the TIUS. The main independent variables are dummies that indicate whether drivers own their trucks (one if driver ownership, zero otherwise) and whether OBCs are installed (one if installed, zero otherwise). We include many additional variables as controls. Control variables include dummy variables that indicate the truck's make, model year, engine size, the number of driving axles, and whether it has aerodynamic features. 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 which indicates who maintains the truck: the driver, a garage, a trucking company, an equipment leasing firm, etc. Finally, we include the log of the truck's odometer reading to capture the effects of depreciation.

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[15]Selection issues work against finding such a relationship. One would expect OBCs to be adopted where agency costs are the highest. Non-adopting company drivers probably drive better, on the average, than adopting ones would if they were not monitored.

Table 11 reports results from twelve regressions. The top panel reports the coefficient on owner-operator in regressions that do not include OBC dummies. The coefficient is negative and significant for short hauls, and statistically zero for medium and long hauls. There is no evidence that company drivers drive less efficiently for medium and long hauls, and some evidence that they drive better for short hauls. This is inconsistent with the theoretical argument posed above. The second panel includes OBC adoption dummies. The coefficients on the trip recorder and EVMS dummies are positive and significant for medium and long hauls. That on trip recorder is more than twice that on EVMS for long hauls. Controlling for many variables which capture trucks' characteristics and how they are used and maintained, trucks with OBCs are more fuel efficient than those without them.

The bottom panel allows the coefficients on the OBC dummies to differ depending on whether the truck was driven by an owner-operator or company driver. Looking at 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 not significantly different from zero using a t-test of size 0.05, but is when using a test of size 0.10. (The owner-operator estimate is noisy because so few owner-operators drive trucks with trip recorders.) 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.[16] Our estimates imply that this is about equal to aerodynamic hoods' effect on fuel economy. There is no difference in the coefficients on the EVMS coefficients. The trip recorder contrast provides some evidence that company drivers with OBCs drive more cost-effectively than those without them. There is no evidence that EVMS use changes how drivers drive – perhaps because their primary purpose is improving dispatchers' scheduling decisions, not drivers' incentives.

7. Conclusion

This paper investigates what determines asset ownership in trucking; in particular, how contractibility affects whether drivers own the trucks they drive. We find that monitoring is a substitute for asset ownership. Owner-operators are used for hauls where non-contractible decisions

[16]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.

that affect trucks' value are important, but are used less once decisions become more contractible. We also provide evidence on truck operating performance (in the form of miles per gallon outcomes) that is consistent with the ownership results. Improvements in performance due to the installation of trip recorders are greater for company-owned drivers than for owner-operators, reflecting the improved incentives that the company drivers have after the adoption of OBCs.

More generally, this paper provides important support for the Grossman and Hart model of asset ownership. Owners – by definition – retain residual rights of control, and the equilibrium allocation of these residual rights is the one that induces the best incentives for maximizing the value of assets. This simple hypothesis has received little direct empirical testing; this paper provides such a test. The introduction of trip recorders on trucks does nothing to change the threat of hold-up, nor to reduce the transactions cost among drivers, carriers, and shippers. Trip recorders are a pure monitoring device, serving only to make contractible a previously unmonitored set of actions. Indeed, trip recorders are almost irrelevant to the contractual relationship between carriers and owner-operators. Yet, by changing the efficiency of an alternative governance arrangement (company ownership), they reduce the relative efficiency of the owner-operator governance form.

The analysis in this paper may explain how contractibility affects firm 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 is 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 vertical 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. We find that this capability leads to less subcontracting. But changing information technology offers many other capabilities, some of which improve resource allocation ("coordination") along with incentives. In future research, we plan to examine the organizational impact of some of these other capabilities, in particular how OBCs' coordination-enhancing capabilities affect shippers' make-or-buy decision. Results of this work will further improve our understanding of how information affects how firms and markets are organized.

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Table 1
Owner-Operator Shares, 1987 and 1992

	All Distances	<50 Miles	50-200 Miles	200+ Miles	Specialized Trailers	Non-Specialized Trailers
Owner-Operator Share, 1987	14.1%	8.6%	11.5%	19.8%	13.8%	14.4%
Owner-Operator Share, 1992	11.1%	4.8%	9.5%	15.3%	10.6%	11.7%
Change in Owner-Operator Share	-3.0%	-3.8%	-2.0%	-4.5%	-3.2%	-2.7%

Table 2
1992 On Board Computer Adoption Rates
by Distance from Home Base (miles)

OBC

	<50	50-100	100-200	200-500	500+
Owner-Operator	3.7%	3.1%	4.0%	7.0%	9.8%
Company Driver	7.1%	12.6%	21.1%	27.4%	34.8%
For-Hire Carrier	7.2%	11.5%	20.3%	26.4%	37.8%
Private Fleet	7.1%	13.1%	21.7%	28.8%	24.1%

Trip Recorder

	<50	50-100	100-200	200-500	500+
Owner-Operator	1.7%	1.2%	0.9%	2.3%	2.4%
Company Driver	4.3%	7.8%	12.7%	12.0%	8.4%
For-Hire Carrier	4.7%	6.3%	9.5%	8.0%	8.1%
Private Fleet	4.1%	8.4%	15.1%	17.5%	9.4%

EVMS

	<50	50-100	100-200	200-500	500+
Owner-Operator	2.0%	2.0%	3.1%	4.8%	7.4%
Company Driver	2.8%	4.9%	8.4%	15.4%	26.5%
For-Hire Carrier	2.5%	5.3%	10.8%	18.4%	29.8%
Private Fleet	3.0%	4.7%	6.6%	11.3%	14.8%

Table 3
Cohort Summary Statistics – Trailer-Product-Distance-State

	All Cohorts	All Included Cohorts	All Excluded Cohorts
Cohorts	3676	426	3250
Obs/Cohort, 1987	4.13	10.61	3.28
Obs/Cohort, 1992	6.42	17.80	4.93
Owner-Operator Share, 1987	0.14	0.27	0.08
Owner-Operator Share, 1992	0.10	0.18	0.06
Change in O/O Share	-0.04	-0.09	-0.02
OBC Adoption, 1992	0.19	0.24	0.16
Trip Recorder Adoption, 1992	0.09	0.10	0.08
EVMS Adoption, 1992	0.10	0.14	0.08

Note: "Included" cohorts are those with owner-operator shares between zero and one in 1987 and 1992.

Table 4
OBC Adoption by Sign of Ownership Share Change

	All Cohorts			Included Cohorts		
	Owner-Operator Share			Owner-Operator Share		
	Decreases	Increases	Same	Decreases	Increases	Same
N	821	683	2172	271	134	21
Mean Owner-Operator Share, 1987	0.33	0.06	0.01	0.31	0.17	0.24
Mean Owner-Operator Share, 1992	0.09	0.25	0.01	0.15	0.27	0.24
Mean OBC Adoption Rates, 1992						
All Distances	0.22	0.20	0.14	0.25	0.22	0.17
Short Hauls	0.07	0.08	0.07	0.08	0.07	
Medium Hauls	0.17	0.16	0.16	0.14	0.22	0.05
Long Hauls	0.29	0.26	0.24	0.32	0.25	0.24
Cohorts with >5 observations						
N	256	172	163	165	79	6
Mean OBC Adoption Rates, 1992						
All Distances	0.26	0.22	0.12	0.28	0.25	0.17
Short Hauls	0.06	0.08	0.03	0.08	0.11	
Medium Hauls	0.19	0.20	0.19	0.16	0.24	0.05
Long Hauls	0.36	0.27	0.37	0.35	0.27	0.21

Table 5
Truck Ownership and OBC Adoption – Levels Estimates

Dependent Variables: ln(company driver share/owner-operator share) – 1987, 1992
Cells are based on product-trailer-state-distance cohorts.

Variable	All Distances	<50 Miles	50-200 Miles	200+ Miles
OBC	**1.560**	-2.701	**1.204**	**1.698**
	(0.189)	(2.018)	**(0.389)**	**(0.228)**
Trip Recorder	**1.131**	**-4.817**	**1.241**	**1.435**
	(0.298)	**(2.140)**	**(0.511)**	**(0.367)**
EVMS	**1.851**	7.173	**1.132**	**1.850**
	(0.243)	(4.806)	**(0.804)**	**(0.279)**
N	426	38	123	265

Regressions are multivariate – separate equations for 1987 and 1992
Control variables (not shown) are distance from home dummies and ln(trailer densit
Sample includes all product-state-trailer-distance combinations where the fraction of owner-operators is between 0 and 1 in both years (the dependent variable is undefined otherwise).

Table 6
Truck Ownership and OBC Adoption – First Difference 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.

Variable	All Distances	<50 Miles	50-200 Miles	200+ Miles
OBC	**0.630**	-2.697	-0.612	**1.024**
	(0.252)	(2.199)	(0.517)	**(0.320)**
Trip Recorder	0.181	-4.465	-0.899	**1.082**
	(0.380)	(2.377)	(0.648)	**(0.484)**
EVMS	**0.956**	0.241	0.150	**0.990**
	(0.325)	(5.645)	(1.160)	**(0.386)**
N	426	38	123	265

Control variables (not shown) are distance from home dummies and ln(trailer densit
Sample includes all product-state-trailer-distance combinations where the fraction of owner-operators
is between 0 and 1 in both years (the dependent variable is undefined otherwise).

Table 7
Truck Ownership and OBC Adoption – Trailer Subsamples

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.

	Variable	All Distances	<50 Miles	50-200 Miles	200+ Miles
Non-Specialized Trailers Only					
	OBC	0.552		0.458	0.567
		(0.383)		(1.122)	(0.443)
	Trip Recorder	0.657		2.039	0.497
		(0.610)		(1.473)	(0.699)
	EVMS	0.499		-3.192	0.603
		(0.451)		(2.512)	(0.523)
	N	197	5	47	145
Specialized Trailers Only					
	OBC	0.573	-2.966	-0.762	**1.465**
		(0.343)	(2.403)	(0.584)	**(0.471)**
	Trip Recorder	-0.067	-4.957	**-1.466**	**1.661**
		(0.494)	(2.562)	**(0.714)**	**(0.686)**
	EVMS	**1.224**	7.725	1.186	**1.317**
		(0.499)	(6.321)	(1.301)	**(0.604)**
	N	229	33	76	120

Control variables (not shown) are distance from home dummies and ln(trailer density).
Sample includes all product-state-trailer-distance combinations where the fraction of owner-operators is between 0 and 1 in both years (the dependent variable is undefined otherwise).
Non-specialized trailers are platforms and enclosed non-refrigerated vans.

Table 8
Truck Ownership and OBC Adoption – Fixed Effects
Long Haul Trucks 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.

Fixed Effects:	None	Trailer	Product	State	Trailer, Product State
Variable					
OBC	**1.024**	**1.005**	**0.799**	**0.846**	0.204
	(0.320)	**(0.344)**	**(0.384)**	**(0.349)**	(0.463)
-LogL	1809.5	1807.1	1801.5	1770.1	1758.4
P-values for H0: Fixed Effects Equal 0		0.964	0.313	**0.004**	**0.020**
Trip Recorder	**1.082**	0.866	0.888	0.431	-0.271
	(0.484)	(0.526)	(0.539)	(0.533)	(0.654)
EVMS	**0.990**	**1.091**	0.738	**1.106**	0.517
	(0.386)	**(0.422)**	(0.466)	**(0.431)**	(0.553)
-LogL	1809.5	1806.9	1801.4	1769.4	1757.7
P-values for H0: Fixed Effects Equal 0		0.951	0.301	**0.003**	**0.016**

Control variables (not shown) are distance from home dummies and ln(trailer density).
Sample includes all product-state-trailer-distance combinations where the fraction of owner-operators is between 0 and 1 in both years (the dependent variable is undefined otherwise).

Table 9
Truck Ownership and OBC Adoption – GMM-IV Estimates
Long Haul Trucks 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

Variable				
OBC	**1.024** **(0.320)**	0.755 (0.669)	**1.861** **(0.512)**	**1.450** **(0.432)**
Number of OID Conditions:		11	17	27
Trip Recorder	**1.082** **(0.484)**	2.055 (1.153)	1.939 (1.064)	**2.232** **(0.824)**
EVMS	**0.990** **(0.386)**	0.117 (0.812)	**1.774** **(0.833)**	1.038 (0.638)
Number of OID Conditions:		10	16	26
Instruments:	None	Trailers	Products	Trailers and Products

N = 265.
Control variables (not shown) are distance from home dummies and ln(trailer density).
Sample includes all product-state-trailer-distance combinations where the fraction of owner-operators is between 0 and 1 in both years (the dependent variable is undefined otherwise).

GMM estimates. Test of overidentifying restrictions is never rejected.

Table 10
Truck Ownership and OBC Adoption – GMM-IV Estimates
Long Haul Trucks Only, Cohorts With >5 Observations In Each Year

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

Variable				
OBC	**1.104**	-0.238	1.583	1.376
	(0.460)	(1.194)	(0.884)	(0.726)
Number of OID Conditions:		5	13	17
Trip Recorder	0.469	-1.259	1.627	1.815
	(0.696)	(1.628)	(1.652)	(1.595)
EVMS	**1.408**	0.280	1.419	1.261
	(0.525)	(1.567)	(1.168)	(0.811)
Number of OID Conditions:		4	12	16
Instruments:	None	Trailers	Products	Trailers and Products

N = 149.
Control variables (not shown) are distance from home dummies and ln(trailer density).
Sample includes all product-state-trailer-distance combinations where the fraction of owner-operators is between 0 and 1 in both years (the dependent variable is undefined otherwise).

GMM estimates. Test of overidentifying restrictions is never rejected.

Table 11
1992: Fuel Economy, Vehicle Ownership, and Distance

Dependent Variable: MPG	All Distances	<50 Miles	50-200 Miles	200+ Miles
Variable				
Owner-Operator	**-0.049** **(0.017)**	**-0.166** **(0.062)**	-0.006 (0.032)	-0.029 (0.018)
Owner-Operator	**-0.041** **(0.017)**	**-0.165** **(0.062)**	-0.001 (0.032)	-0.019 (0.018)
Trip Recorder	**0.182** **(0.018)**	-0.030 (0.066)	**0.110** **(0.032)**	**0.281** **(0.021)**
EVMS	**0.119** **(0.014)**	-0.042 (0.082)	**0.174** **(0.041)**	**0.127** **(0.019)**
Owner-Operator	**-0.042** **(0.017)**	**-0.159** **(0.064)**	-0.008 (0.033)	-0.015 (0.019)
TR*Owner-Operator	0.063 (0.096)	-0.514 (0.330)	0.149 (0.265)	0.127 (0.091)
TR*Other Drivers	**0.186** **(0.019)**	-0.011 (0.067)	**0.108** **(0.033)**	**0.289** **(0.021)**
EVMS*Owner-Operator	**0.184** **(0.064)**	0.299 (0.343)	**0.346** **(0.165)**	**0.146** **(0.059)**
EVMS*Other Drivers	**0.115** **(0.019)**	-0.060 (0.084)	**0.165** **(0.042)**	**0.126** **(0.019)**
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.

Figure 1
Asset Ownership and OBC Adoption