Make Versus Buy in Trucking: Asset Ownership, Job Design and Information

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Explaining patterns of asset ownership in the economy is a central goal of both organizational economics and industrial organization. We develop a model of asset ownership in trucking, which we test by examining how the adoption of different classes of on-board computers (OBCs) between 1987 and 1997 influenced whether shippers use their own trucks for hauls or contract with for-hire carriers. We find that OBCs' incentive-improving features pushed hauls toward private carriage, but their resource-allocation-improving features pushed them toward for-hire carriage. We conclude that ownership patterns in trucking reflect the importance of both incomplete contracts (Grossman and Hart (1986)) and of job design and measurement issues (Holmstrom and Milgrom (1994)).

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1. Introduction

Explaining the patterns of asset ownership in the economy is a central goal of both organizational economics and industrial organization. Major progress towards this goal was provided by Grossman and Hart's seminal paper in 1986, which argues that asset ownership confers on owners residual rights of control that give them power and thus incentives to devote effort to value-increasing activities. In 1999, Holmstrom offered a critique of the property rights view in which he argues that it fails to explain why firms rather than individuals own assets. He suggests that firm ownership of assets is important precisely because it mutes the incentives that come with ownership, allowing the firm to operate as a "subeconomy" that can more precisely balance incentives and implement more complex multitask job designs.

In this paper, we argue that the pattern of asset ownership in trucking—in particular the decision by shippers about whether to use their internal fleet of trucks for a haul or contract with for-hire carriers—reflects the factors identified in Grossman and Hart's theory and those highlighted in Holmstrom's critique. Consistent with the former, ownership patterns reflect trade-offs that arise from providing for-hire carriers strong incentives to identify profitable uses for trucks. Consistent with the latter, ownership patterns also reflect the degree to which shippers demand simple transportation of goods, or a more complex combination of transportation, cargo handling, and service. This latter type of "service-intensive" trucking interferes with the efficient dispatch of the truck to the next haul. We argue that shipper ownership of trucks mutes incentives and thus favors service-intensive trucking in which drivers' jobs involve more than just driving trucks.

We develop a model that combines these theoretical insights. The model generates two sets of comparative static predictions. One set of predictions, including that service-intensive trucking is performed by private fleets, is consistent with well-known cross-sectional patterns in the industry. The other set of predictions concerns how changes in the informational environment affect ownership. We test this second set of predictions using data from the 1987, 1992, and 1997 Truck Inventory and Use Surveys, which contain detailed truck-level information about trucks' characteristics, ownership, and use. In particular, we test predictions on how the diffusion of different classes of on-board computers (OBCs) during the late 1980s and early 1990s alters the "make versus buy" decision for shippers. We predict that the adoption of certain types of OBCs should lead indirectly to more shipper ownership of trucks, by lowering the agency costs associated with complex job designs. We predict that the additional capabilities of other types of OBCs – those that provide location information and real-time communication – should lead to less shipper ownership of trucks, because these additional capabilities enhance the comparative advantage of for-hire carriage with respect to truck utilization and dispatch. We find evidence in favor of both of these predictions.

Our results strongly suggest causal links between informational and organizational changes in the trucking industry. They show that ownership patterns in trucking reflect the importance of both incomplete contracts (as stressed by Grossman and Hart (1986)) and of job design and measurement issues (like those stressed in Holmstrom and Milgrom (1991, 1994) and Holmstrom (1999)). These findings thus shed important light on theories of organizations. They also make a contribution to the long-running debate about how information technology (IT) diffusion affects the boundaries of the firm.[1] We note that information technology in general provides at least two capabilities—improved monitoring of agents and improved coordination of activities in the firm—and that the organizational impact of these capabilities can differ (Jensen and Meckling, 1992). In trucking, improvements in monitoring (and the attendant improvement in incentives) lead to larger, more integrated firms, while improvements in coordination (resulting in better asset utilization) lead to more diffuse asset ownership and smaller, less integrated firms. Whether these results generalize to other settings remains an open question.

The paper is organized as follows. In the next section, we describe the institutional setting that we model, defining the players, describing their roles in the provision of trucking services, and characterizing the contracting environment in which they operate. In Section 3, we present our model of job design and asset ownership. Section 4 describes OBCs and generates our main empirical propositions. In Section 5, we describe our data and present the main empirical

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[1] Leavitt and Whisler (1958), Malone, Yates, and Benjamin (1987), Brynjolfsson and Hitt (1997).

patterns. Section 6 contains our main empirical results regarding the relationships between OBC adoption and organizational change. Section 7 concludes.

2. Job Design, Search Incentives, and Asset Ownership in Trucking

This section describes the institutional framework. We describe the basic trade-offs involved in job design and asset ownership decisions and explain why these decisions might be related. Throughout the section, we will refer to several different parties. *Drivers* are individuals who drive trucks and may have other customer service oriented tasks. *Shippers* are firms or divisions with demands to move cargo from one place to another. *Carriers* are firms or divisions that supply transportation services. Carriers that supply services using trucks owned by shippers are private carriers (i.e., shippers' internal fleets). Carriers that supply services using trucks they own themselves are for-hire carriers. *Brokers* are third party informational intermediaries.

Driver Job Design: Driving and Service Provision

Drivers can engage in two sorts of activities: driving the truck and performing non-driving service activities, such as unloading the truck and transporting cargo to where recipients store it.[2] Each of these classes of activities generates value. Defining drivers' jobs to include cargo-handling activities allows carriers to offer high service options in which carriers' customers can ask drivers to help handle cargo. This gives carriers' (internal or external) customers flexibility in how many of their own workers they allocate to cargo handling. This is valuable because deliveries might take place at a time when customers' workers' time is better spent doing other things.

The benefits of giving drivers cargo-handling responsibilities differ across hauls.

In some circumstances, drivers' cargo handling effort offers no benefits. This is the case when they haul bulk goods such as gravel, ores, or grain. Machines pour the cargo into the trailer. When trucks reach their destination, drivers dump the cargo where the recipient wants it. Driver effort towards service is also unproductive when they haul goods for which handling requires special equipment. For example, special machines are usually necessary to take very heavy goods (large rolls of paper, sheet metal) on and off trucks. As a consequence, drivers hauling such goods have virtually no cargo handling responsibilities. They just drive trucks.

Drivers' service activities are potentially productive for other classes of hauls. For example, this is generally true when drivers haul packaged goods, because packaged goods are either lifted on and off trucks or transported with standard equipment such as hand trucks, conveyor belts or forklifts. Among packaged goods hauls, the benefits of giving drivers cargo-handling responsibilities differ systematically with the size of the delivery and the size of the shipper and receiver.

The benefits of giving drivers cargo-handling responsibilities tend to be higher when trucks deliver to multiple destinations than single destinations. When trucks deliver goods to a single destination, it is often possible to organize things so deliveries are "drop and hook:" drivers deliver one cargo-filled trailer, unhook their tractor, and pick up another trailer for the next trip. Organizing deliveries in this manner allows the front part of the tractor-trailer to be utilized at a higher rate. "Drop and hook" is impossible when trucks deliver to multiple destinations; tractors must sit idle while trailers are unloaded. This lowers the opportunity cost of giving drivers cargo-handling responsibilities; drivers would otherwise sit idle while trucks are being unloaded. Consequently, drivers tend to help unload trucks when they deliver to multiple destinations (e.g., delivery trucks), and do so less when they deliver a full truckload to a single destination.

The benefits also tend to be higher when trucks pick up or deliver to small establishments than large establishments. Small establishments ship and receive smaller volumes of goods than larger ones, and tend not to have specialized traffic departments. Personnel at small establishments handle cargo – load, unload, move, sort, and store it – less efficiently than larger establishments that have specialized departments. This makes driver's cargo handling effort more productive at the margin. Thus, for example, drivers are more involved in handling when they deliver to retailers than wholesalers. Drivers' cargo-handling efforts are also potentially productive when trucks haul hazardous goods such as gasoline or chemicals. Handling requires

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[2] See Ouellet (1994) for a detailed description of incentives and the organization of work in trucking.

certification, which drivers generally must have in order to haul such cargo. Drivers are often involved in unloading gasoline or chemicals because it diminishes the extent recipients must have certified personnel.

The drawback of giving drivers more cargo-handling responsibilities is that agency costs are higher.[3] We next discuss the agency problem carriers face with drivers.

All carriers face the problem of motivating drivers to pick up and deliver goods on time and drive in ways that preserve trucks' value. When drivers' jobs include cargo handling, carriers also must motivate drivers to load and unload cargo efficiently.

Motivating drivers to pick up and deliver goods on time is straightforward because it is relatively easy to evaluate drivers' performance in this dimension. The distances traveled and the return time at the end of the run are known. Carriers also normally have good information regarding whether drivers arrive late to intermediate stops – angry customers call them when they do – and have some information about the impact of factors outside of drivers' control, such as traffic and weather conditions. Thus, when drivers' jobs involve only driving from location to location, the main agency problem that remains is inducing drivers to drive well, because this is what remains non-contractible.

Incentive problems are more complicated when drivers' jobs include service activities. As is generally the case in multitasking problems, incentives must attend both to overall effort levels and the allocation of effort across tasks. In this case, the incentive problem created by multitasking is that carriers now must induce drivers to allocate effort between driving and service appropriately. Simple distance and arrival time data provide little indication of the fraction of time drivers spend driving and handling cargo. Handling cargo is strenuous work.[4] Drivers with cargo handling responsibilities have an incentive to take more time unloading cargo, then make it up by other means. Carriers may respond to this, in the spirit of Holmstrom

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[3] Following Jensen and Meckling (1976), agency costs here include both monitoring costs and the "residual loss" attributable to decisions that differ from first-best.

[4] Drivers whose jobs involve taking a fully-loaded trailer and delivering the goods to various destinations handle up to 40,000 pounds of cargo per day. Handling requires hand-lifting when trucks deliver to places without loading docks – such as most retail outlets.

and Milgrom (1991, 1994) and Baker (1992), by weakening drivers' incentives with respect to other tasks. For example, they balance incentives by de-emphasizing on-time arrivals or allowing more slack in schedules. In general, agency costs are higher when drivers have more responsibilities because of some combination of lower overall effort levels and a worse allocation of effort across tasks.

Market Clearing: Load Matching and Search

The demand for trucking services and the supply of truck capacity are highly differentiated. Shippers' demands are specific with respect to time, location, and equipment requirements. Likewise, truck capacity is idiosyncratic with respect to its geographic location and the characteristics of the trailer. Capacity utilization in the industry depends crucially on how efficiently supply and demand – trucks and hauls – are matched. Trucks and hauls are matched in a highly decentralized manner in which shippers, carriers, and third-party brokers search for good matches.

In practice, the main individuals involved in matching trucks to hauls are dispatchers and brokers. Dispatchers work for carriers, and seek to match hauls to trucks within their carrier's fleet. Brokers seek to match hauls to trucks owned by other parties. The role dispatchers and brokers play is Hayekian (Hayek, 1945), acquiring "on the spot" knowledge about demand and supply and matching them. They maintain rapidly changing data about shippers' demands and trucks' availability. Dispatchers and brokers are better at identifying good matches when they agglomerate more information about capacity and demands; this is one reason dispatchers who manage private fleets are often less able to find good matches than dispatchers at for-hire carriers or brokers. When dispatchers or brokers see a potential match, they attempt to assign the truck and driver to the haul and arrange for carriage.

The matching problem is particularly difficult in trucking because individual shippers rarely have demands that fill trucks for both legs of a round-trip. For this reason, once carriers receive service orders from shippers, they then search for *complementary hauls*. When individual shipments are too small to fill a truck, search takes the form of identifying other shippers with similar demands. When demands are unidirectional, search is directed at identifying shippers with demands that would fill the truck for the return trip (the "backhaul"). The value of using a truck for a shipper's (unidirectional) haul is higher when the truck is used for a highly complementary haul on the return trip – for example, a backhaul that begins close to and soon after the "fronthaul" ends.

Service levels affect the marginal productivity of search for complementary hauls. Thus, this marginal productivity is related to drivers' job design. For example, consider firms' search for backhauls.[5] Ideally, firms would like to find and commit trucks to high-value backhauls -- hauls for which a truck is particularly well-timed to serve. They are able to keep commitments to meeting narrow time windows for pick-ups with high probability when fronthauls involve low service levels, because there is little uncertainty regarding how long drivers will spend handling cargo. This tends not to be the case, however, when fronthauls involve high service levels because it is more difficult for firms to anticipate exactly when trucks and drivers will come free.[6] Firms generally cannot commit trucks to meeting narrow time windows unless they allow a significant time buffer. Finding a time-sensitive haul often offers little advantage over the alternative -- accepting a time-insensitive haul for which the truck can be used as soon as it comes free -- because on average such hauls would require the truck and driver to be idle for a few hours between hauls.

Asset Ownership and Incentives

This paper investigates shippers' make-or-buy decision: whether they use an internal or external fleet for a haul. We argue that asset ownership distinguishes private and for-hire carriage. In private carriage, shippers own trucks; in for-hire carriage they do not. Below we

[5] Similar arguments apply for firms' attempts to find complementary less-than-truckload shipments.

[6] In interviews, fleet managers and dispatchers indicated to us that forecasting how long deliveries take is much easier when drivers have fewer service responsibilities. They indicated that they could forecast how long a no-service delivery of a truckload of packaged goods would take within a half-hour window, but could only forecast how long a high-service delivery would take within a two to three hour window.

discuss how and why asset ownership affects the use of trucks, the search for complementary hauls, and driver job design.

Ownership rights over trucks matter because contracts are incomplete with respect to trucks' schedules. In particular, shippers and carriers do not write fully-contingent contracts with respect to trucks' schedules because the relevant contingencies are costly to identify *ex ante*, and to verify *ex post*. To see this, consider one class of scheduling decisions: how long a truck should wait at the loading dock to be loaded. A fully-contingent contract would stipulate how long trucks should wait as a function of all relevant states of the world, where states of the world are defined by factors affecting the benefits of delay and individual trucks' opportunity cost. Many of these factors are internal to shippers and carriers and are difficult to verify by outsiders. It is thus prohibitively costly to make contracts contingent on them. Schedule-setting is therefore a residual right of control that is, by definition, held by the truck's owner.[7]

The contractual incompleteness surrounding truck scheduling leads to the main implication of the allocation of ownership rights. In private carriage, shippers own trucks: if they want to alter trucks' schedules in ways that do not violate existing agreements, they can do so. They can unilaterally require that a truck picking up or delivering goods wait, for example. In for-hire carriage, carriers own trucks. If shippers want to change trucks' schedules, they must negotiate this with carriers.[8]

The possibility that schedules will have to be renegotiated leads to familiar sorts of transactions costs in for-hire carriage. Both parties have an incentive to improve their bargaining

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[7] In practice, it is common for contracts between shippers and carriers to have clauses that penalize shippers when they delay trucks. The penalties, however, are not state-dependent, and thus are set intentionally high to deter shippers from delaying trucks in states of the world where trucks' shadow value is high. Parties realize that renegotiation is likely to be efficient when trucks' shadow value is low, creating a situation that is analytically similar to those where schedules are non-contractible.

[8] In this paper, we abstract from the fact that there is a third possibility regarding truck ownership: drivers may own trucks. We analyze the trade-off involved in driver ownership and how OBCs affect this trade-off in Baker and Hubbard (2000). We also abstract from the fact that private fleets and for-hire carriers sometimes lease trucks from third parties. This is because the lessor holds the control rights important to the analysis – the right to determine how the truck is used on a day to day basis. We define the owner as the owner of these control rights.

position.[9] For shippers, this takes the form of identifying other carriers who could serve them on short notice; for carriers, this takes the form of identifying other local shippers with similar demands – finding *substitute hauls*. Exploring back-up plans expends real resources, and is thus costly. In private carriage, by contrast, disputes may arise between shippers and their private fleets' dispatchers (or shippers and brokers), but identifying other ways to use trucks does not improve dispatchers' or brokers' bargaining position because they cannot threaten to use trucks for other hauls. Neither private fleet dispatchers nor brokers have incentives to identify substitute hauls for the purpose of improving bargaining positions.

While transactions costs may be higher in for-hire carriage, truck utilization also tends to be higher. One reason for this was suggested above: dispatchers within for-hire fleets are more able to find complementary hauls than dispatchers within many private fleets because they are able to agglomerate more information. Another reason is that while dispatchers at private fleets can rely on brokers to find complementary hauls, brokers have weaker incentives to search than for-hire carriers because they do not own trucks. As noted above, finding a complementary haul sometimes involves effort that is specific to the truck – for example, its location at the moment. Absent truck ownership, intermediaries have weak incentives to make such investments. If brokers were to search specifically for a good match for a truck owned by another party, the other party could appropriate the value generated by brokers' efforts by threatening to use the truck for another haul. Search incentives are stronger for carriers than brokers because carriers own trucks, and thus can better appropriate the value of search efforts. This, in turn, leads to better matches and higher capacity utilization.

A third reason why truck utilization tends to be higher in for-hire carriage is that drivers are generally assigned fewer service responsibilities. Trucks spend more time on the road and, as noted above, load matching is easier when drivers' responsibilities are narrow.

The next section develops a model of asset ownership and job design that captures the institutional features described above and analyzes organizational relationships formally. This

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[9] Grossman and Hart (1986), Milgrom and Roberts (1990). Baker and Hubbard (2000) argue that this incentive is also central for understanding why truck drivers tend not to own the trucks they operate.

model generates comparative static predictions that explain several important cross-sectional patterns in the industry. It also generates predictions regarding how changes in the informational environment should affect the make-or-buy decision. Later in the paper, we take these predictions to the data.

3. A Model of Asset Ownership and Job Design

The model combines elements of Holmstrom and Milgrom (1991, 1994) and Grossman and Hart (1986). We embed multi-task models of driver job design and dispatcher effort towards finding hauls into a setting in which non-contractible truck scheduling problems make asset ownership important. The timing follows. Initially, a shipper's "fronthaul" and a matching truck are assumed to exist: we do not model the process of matching fronthauls to trucks. This haul may be one for which the value of service is high or low. We assume that parties cannot write a complete contract with respect to this haul *ex ante*. Organizational form is then chosen; at this point, asset ownership and drivers' job design are determined. Next, search for complementary backhauls (and possibly substitute fronthauls) occurs. Depending on asset ownership and the organizational form chosen, either a carrier or a broker chooses how much to search for hauls that complement or substitute for the shipper's haul. Parties then bargain; this determines which haul the truck is used for and how the surplus is split. Production then takes place (including provision of service by the driver) and payoffs are realized.

Complementarities between job design and asset ownership are critical to the results, and are a central feature of our model. To highlight this relationship and simplify the exposition, we develop a model first of driver job design, then overlay the shipper's "make-or-buy" decision. When shippers own trucks, this corresponds to "make"; when they do not, this corresponds to "buy." The "make" option has two possible solutions to the problem of matching trucks to hauls: using the shipper's own dispatchers or using brokers. We begin with a model of driver job design.

Driver Job Design: Driving and Service Provision

Let s be the scope of the driver's activities, and m be the marginal product of this scope.[10] For some hauls and shippers, service activities are valuable (high m), and for some they are less valuable. Motivating high service levels is costly, since it involves monitoring the mix of activities that the driver is performing. Let σ be a parameter that captures the ability of the carrier to monitor the driver's efficiency in performing high-service activities: the higher is σ, the lower is the marginal cost of monitoring. We specify V, the value of using the truck and driver for the shipper's haul, as:

$$V = \underline{V} + ms - M(s,\sigma) \tag{1}$$

where $\underline{V}$ is a fixed quantity, s is the scope of the driver's activities, m is the marginal product of this scope, σ is the degree to which the carrier can monitor driver activities, and M(s,σ) is agency costs. We assume $M_1>0$, $M_2<0$, $M_{12}<0$.

Given this set-up, the optimal amount of scope in the driver's job depends on the costs and benefits of such scope. Assuming an interior solution, optimal job design sets scope such that $m = M_1(s^*,\sigma)$. Raising the marginal product of scope (raising m) or raising the firm's ability to monitor driver activities (raising σ) raises the optimal amount of scope. We assume that this expression is invertible, so that we can express the result as $s^* = \phi(m, \sigma)$.

Load Matching

Following the discussion in section 2, we assume that search for complementary hauls adds value. Value is increasing in search levels because more effort produces better matches. We also assume that the marginal productivity of search is reduced when drivers are assigned more service-oriented activities. Finally, we allow the productivity of search to be lower if search is done by private fleet dispatchers rather than for-hire carriers' dispatchers or brokers.

We specify the value added of search for complementary hauls as:

$$\lambda(g_1 - \theta s)e_1 \tag{2}$$

where e_1 is the effort toward finding complementary hauls, and g_1 is the marginal product of this effort. θ captures the extent to which high service levels reduce the marginal product of search, $\theta > 0$. We also assume $\theta < g_1/\phi(m,\sigma)$; this regularity condition ensures that the marginal benefit of searching for complementary hauls is positive at the optimum.[11] λ is a discount factor that parameterizes the efficiency of private fleet dispatchers' search; $\lambda = 1$ when search is conducted by for-hire carriers' dispatchers or brokers and $0 \leq \lambda \leq 1$ when it is conducted by private fleet dispatchers. We specify the cost of searching for complementary hauls as $C_1 = e_1^2/2$.

We can now calculate an expression for total value, which is the value of using the truck and driver for the shipper's haul plus the value created by search, less the costs associated with search.

(3) $$TV = \underline{V} + \lambda(g_1 - \theta s)e_1 - C_1 + ms - M(s,\sigma)$$

We can also solve for shippers' optimal choice of e_1, given that they search for complementary hauls themselves using their own dispatchers. Maximizing TV with respect to e_1, we find:

(4) $$e_1^S = \lambda(g_1 - \theta s)$$

Total value as a function of s for this option is therefore:

(5) $$TV_S = \underline{V} + \tfrac{1}{2}\lambda^2(g_1 - \theta s)^2 + ms - M(s,\sigma)$$

We will use this expression later in determining the optimal organizational form.

We turn next to situations where shippers rely on brokers or for-hire carriers to search for complementary hauls. These situations are more complicated because shippers bargain with these other parties over the surplus generated by search.

Bargaining, Truck Ownership, and Residual Rights of Control

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[10] Our equation of scope with service levels reflects an (unmodeled) assumption that some significant amount of driving is always part of the driver's job: the driver is never doing *mostly* service. Thus, more service involves a greater mix of activities.

[11] This guarantees that $g_1 - \theta s^*$ is non-negative in the results below. The condition ensures that benefits of service are never so high so that the direct benefits of searching for complementary hauls are overwhelmed by its indirect costs.

The timing of the model is such that carriers and brokers can search for alternative uses of the truck before they negotiate with shippers over the terms of trade. These activities yield potential uses of the truck that are close substitutes for the shipper's haul. For simplicity, we assume that this search is over alternatives that involve the same level of driver service, but that using the truck and driver for the alternative is always less valuable than using them for the first shipper's haul (perhaps because the alternative haul's origin is more distant). Assume that the value created when the truck is used for an alternative shipper's haul is:

$$(6) \qquad P = g_2 e_2 + (g_1 - \theta s)e_1 + ms - M(s,\sigma)$$

where e_2 represents effort toward finding alternative hauls and g_2 represents the marginal productivity of this effort.[12] This formulation assumes that e_1, the effort that the dispatcher expends toward finding hauls that complement the first shipper's hauls, is equally valuable for the alternative shipper's hauls (e.g., the backhaul she finds would complement either outbound haul.) We specify the cost of searching for substitute hauls as $C_2 = e_2^2/2$.

We can now calculate the amount of search when carriers or brokers search for hauls. We assume that when shippers bargain with either for-hire carriers or brokers over the surplus, they split the difference between the value of the haul and the value of the carrier's or broker's outside alternative. A for-hire carrier's outside option is equal to P, the value of using the truck for an alternative shipper's haul. A broker does not have this outside option, because it does not own trucks. We therefore normalize brokers' outside option to zero.

A for-hire carrier chooses e_1 and e_2 to maximize:

$$(7) \qquad (V+P)/2 - \tfrac{1}{2}e_1 - \tfrac{1}{2}e_2 = (\underline{V} + 2(g_1 - \theta s)e_1 + 2ms - M(s,\sigma) + g_2 e_2)/2 - \tfrac{1}{2}e_1 - \tfrac{1}{2}e_2$$

This yields search effort equal to:

$$(8) \qquad e_1^F = (g_1 - \theta s), \; e_2^F = \tfrac{1}{2} g_2$$

If search is completed by a for-hire carrier, it will search both for hauls that complement and substitute for the shipper's. Total value under this organizational alternative is:

[12] Thus, $\underline{V}$ is the value of the first shipper's haul (net of service) and $g_2 e_2$ is the value of the alternative haul. We assume $\underline{V} > \frac{1}{2} g_2^2$.

(9) $$TV_F = \underline{V} + \frac{1}{2}(g_1 - \theta s)^2 - \frac{1}{8} g_2^2 + ms - M(s,\sigma)$$

A broker chooses e_1 and e_2 to maximize:

(10) $$V/2 - \frac{1}{2}e_1 - \frac{1}{2}e_2 = (\underline{V} + (g_1 - \theta s)e_1 + ms - M(s,\sigma))/2 - \frac{1}{2}e_1 - \frac{1}{2}e_2$$

yielding effort of:

(11) $$e_1^B = \frac{1}{2}(g_1 - \theta s),\ e_2^B = 0$$

Brokers search less intensively for complements, and not at all for substitutes. Total value under this alternative is:

(12) $$TV_B = \underline{V} + \frac{3}{8}(g_1 - \theta s)^2 + ms - M(s,\sigma)$$

Efficient Organizational Forms: Employment, Job Design and Asset Ownership

We begin the comparison of organizational forms by examining whether a shipper will use a captive dispatcher, or will rely on brokers to help find hauls for its trucks. This trade-off clearly depends on the extent to which the brokers' competitive advantage outweighs the appropriation problem that they faces due to their inability to appropriate the returns from finding good hauls. Using the expressions for TV_S and TV_B above, we generate the following proposition:

Proposition 1: Conditional on shippers owning trucks, shippers will use brokers if and only if $\lambda^2<3/4$.

Proof: See Appendix.

The proof uses the envelope theorem to show that this condition holds even after optimizing over s. Whether shippers use brokers therefore only depends on shippers' comparative disadvantage, and not on the other parameters of the model. This is a useful result because it implies that we can demonstrate our comparative statics with respect to the make-or-buy decision in general by analyzing the comparative statics of this decision with respect to the two "make" cases separately. We begin our main analysis of asset ownership by assuming that shippers use brokers ($\lambda^2<3/4$); we show that the same comparative statics hold if shippers find their own hauls in the Appendix.

In order to compare the total value created by private carriage versus for-hire carriage, we introduce an index variable, δ, that indicates asset ownership. $\delta=1$ indicates for-hire carriage, $\delta=0$ private carriage. Total value as a function of s and δ is:

$$TV(s,\delta) = \underline{V} + \tfrac{1}{8}(3+\delta)(g_1 - \theta s)^2 - \tfrac{1}{8}\delta g_2^2 + ms - M(s,\sigma) \tag{13}$$

Proposition 2: $TV(s,\delta)$ is supermodular in $(-s, -m, \delta, -\sigma, g_1, -g_2)$ on the domain where $s \geq 0$, $\delta \in \{0, 1\}$, and $0 < \theta < g_1/\phi(m,\sigma)$.

> Proof: Supermodularity requires that TV has non-decreasing differences in $(-s, -m, \delta, -\sigma, g_1, -g_2)$; this is equivalent to non-negative cross-derivatives when TV is continuously twice-differentiable. (Topkis, 1978) All terms except the second term are supermodular in $(-s, -m, \delta, -\sigma, g_1, -g_2)$ on this domain by inspection. The third term is supermodular if $g_1 - \theta s \geq 0$, which is guaranteed if $\theta < g_1/\phi(m,\sigma)$. The sum of supermodular functions is supermodular.

This result allows us to apply a theorem from Topkis (1978) (see also Theorem 5 of Milgrom and Shannon (1994)), and generate a set of monotone comparative statics that we can test with data on asset ownership and technology adoption.

Proposition 3: $-s^*$ and δ^* are monotone non-decreasing in $(-m, -\sigma, g_1, -g_2)$ on the domain where $s \geq 0$, $\delta \in \{0, 1\}$, and $0 < \theta < g_1/\phi(m,\sigma)$. $-s^*$ and δ^* are (weak) complements.

Proposition 3 generates predictions that are consistent with several well-known cross-sectional patterns in the industry.

One simple prediction is that s and δ should be inversely correlated: that is high service is correlated with shipper ownership of trucks. This is consistent with the stylized fact that drivers in private fleets engage in more service-related activities than drivers in for-hire fleets. This fact is reflected in evidence from the trade press and interviews that drivers in for-hire fleets are generally encouraged to be back on the road as soon as possible after delivering goods. They sometimes help to remove cargo from trucks when doing so hastens their departure, but they generally do not handle cargo once it is off trucks. In contrast, it is common for private fleet drivers to bring cargo into storerooms, and it is not unusual for them to be responsible for sorting it and putting it on shelves.

A second prediction is that δ should increase in g_1: that is, for-hire carriage is associated with hauls where effort toward identifying complementary hauls is particularly valuable. This is consistent with the stylized fact that for-hire carriage tends to be used more for small shipments and long-distance shipments than large and short-distance shipments. (See Bureau of the Census (1999b) and Hubbard (1999) for empirical evidence.)

A third prediction is that δ should decrease in m: for-hire carriage should be used less, the more valuable are drivers' cargo-handling activities. Cross-sectional evidence from Hubbard (1999) supports this: for example, controlling for the length of the haul and measures of local market thickness, hauls using non-refrigerated vans are less likely to be completed by for-hire carriers than hauls using dump trailers.

A fourth prediction is that δ should decrease in g_2; shippers should own trucks in situations where for-hire carriers would have a large incentive to search for substitute hauls. This is consistent with sentiment in the industry that private carriage tends to be used when shippers value time-flexibility, and results in Hubbard (1999) that private carriage becomes more prevalent as local markets become thin. Bargaining is more likely when agreements with for-hire carriers are more open-ended, raising firms' incentives to create back-up plans. Firms' incentives to do so are particularly acute when markets are thin because there is more at stake.

Our main empirical tests, however, examine relationships between informational improvements enabled by the adoption of on-board computers (OBCs) and changes in ownership. These exploit the predictions that increasing g_1 should lead firms to (weakly) increase δ, and increasing σ should lead firms to (weakly) decrease δ. If the productivity of searching for complementary hauls (g_1) increases, this should lead to two changes: one should observe shifts from private to for-hire carriage and decreases in the scope of drivers' activities. If firms' ability to monitor the allocation of drivers' effort (σ) increases, this should lead directly to increases in the scope of drivers' activities and indirectly to more shipper ownership of trucks.

Proposition 3 implies that sometimes changes in the model's parameters may not result in changes in the optimal organizational structure. One case is of particular interest to us. If $m = 0$, it is optimal to set $s = 0$ because there is no benefit from giving drivers service responsibilities. If this is true, the total value function is:

(14) $$TV(s,\delta) = \underline{V} + \tfrac{1}{8}(3+\delta)g_1^{\,2} - \tfrac{1}{8}\delta g_2^2$$

If m = 0, TV is independent of σ: there is no multitasking, and no multitasking-related agency problem. Therefore, if m = 0, changes in firms' ability to monitor the allocation of drivers' effort (σ) should have no effect on asset ownership.

The following section describes OBCs and generates empirical propositions relating OBC adoption to ownership changes.

4. On-Board Computers and Organizational Change

On-Board Computers

Two classes of OBCs began to diffuse in the trucking industry in the late 1980s: trip recorders and electronic vehicle management systems (EVMS).[13] Trip recorders measure trucks' operation. They record when trucks are turned on and off, their speed, sudden accelerations or decelerations, and various engine performance statistics (e.g., fault codes). Dispatchers and fleet managers receive the information trip recorders collect when drivers return to their base at the end of a trip. Drivers give dispatchers a floppy disk or a similar device. Dispatchers upload the information onto a computer, which processes the information and provides reports. These reports indicate how drivers operated the truck; for example, how quickly they drove, how long they allowed trucks to idle, and whether there were any non-scheduled stops. They also indicate how long drivers spent at each stop.

EVMS record the same information trip recorders do, but provide three additional capabilities. One is that they record trucks' geographic location, often using satellite tracking systems. Another is that they can transmit any information they collect to dispatchers in real time. Dispatchers can thus know where trucks are at any point in time. Third, they provide dispatchers a way of initiating communication with drivers. For example, dispatchers can send a text message that updates drivers' schedule. If the message is complicated, dispatchers can send a message that asks drivers to call in. This is a significant advance over the system firms have

[13] See also Baker and Hubbard (2000) and Hubbard (2000).

traditionally used to communicate with drivers who are outside radio range (about 25 miles). Traditionally, firms require drivers to call in every three or four hours. This requires drivers to frequently pull over, stop, and find a phone, even though much of the time neither dispatchers nor drivers have new information to communicate. Without EVMS, dispatchers often find it hard to verify trucks' location and must wait for distant drivers to call in before they can communicate instructions.

As Hubbard (2000) relates, there is an economically important distinction between these two devices. Trip recorders are useful for improving incentives, because they provide verifiable information about how trucks were operated. Importantly for this paper, they indicate how long drivers spent driving and how long they spent performing other tasks. Trip recorders are not generally useful for improving resource allocation decisions ("coordination"). They do not improve dispatchers' ability to match trucks to hauls in the very short run because they do not supply information in a timely enough fashion. They are generally not used to improve routing decisions made over the longer run – for example, by helping benchmark routes – because firms usually can obtain information about such things as how long routes take by other, less costly means.[14]

In contrast, EVMS are useful for improving both incentives and coordination. Their additional capabilities help dispatchers match trucks to hauls better, thereby increasing capacity utilization. Real-time information about trucks' location helps them schedule backhauls more efficiently, for example. These capabilities also enable them to communicate schedule changes to drivers in real time. Dispatchers can quickly reroute trucks in response to changes in market conditions. For example, suppose a truck on the road is half-full. If a dispatcher can find a shipper with cargo that can fill the truck, he can send a message to the driver asking him to make an additional pick-up and delivery.

We next discuss our main empirical propositions, which predict how OBC adoption should affect truck ownership. These propositions are based on the premise that trip recorder

[14]Many firms use software packages to help dispatchers schedule trucks. These packages often use information EVMS collect (for example, trucks' location), but rarely use the information trip recorders collect.

adoption increases σ and EVMS adoption increases both σ and g_1.

P1: Overall, trip recorder adoption should push hauls from for-hire to private carriage.

OBCs' incentive-improving capabilities allow carriers to better monitor how drivers allocate time, and thus effort, across tasks. Trip recorder adoption thus raises σ, which in turn should decrease the optimal choice of δ; carrier ownership of trucks should decrease. Proposition 3 above predicts that this should also lead the optimal choice of s to increase – the scope of drivers' jobs should increase. But we cannot test this prediction because the data do not contain information on the scope of drivers' activities.

P2: EVMS adoption should push hauls less toward private carriage than trip recorder adoption, and may push hauls toward for-hire carriage.

EVMS' coordination-improving capabilities make dispatchers' search more productive, and thus raise g_1. Knowing where trucks are allows dispatchers to better anticipate when trucks will come free, and hence helps them refine their search. Being able to initiate communications with drivers while they are in their cab enables them to better exploit the opportunities they identify. For example, they can quickly reallocate drivers and trucks across hauls in response to new opportunities. Because EVMS contain both incentive- and coordination-improving capabilities, EVMS adoption should increase both σ and g_1 and thus has a theoretically ambiguous impact on asset ownership. However, if EVMS adoption increases σ in the same way trip recorder adoption does, EVMS adoption should move hauls less toward private carriage than trip recorder adoption.

P3: P1 should only be true for hauls where drivers' cargo-handling activities are potentially productive. It should not be true for other hauls.

Trip recorder adoption should not lead to ownership changes when $m = 0$: for example for hauls of bulk goods or goods that require people other than drivers to load and unload. It should lead to ownership changes when m > 0. From above, this should be the case when trucks haul packaged goods, especially when they pick up or deliver to small outlets. It should also be the case when trucks haul goods for which handling requires certification, such as petroleum or chemicals. However, it should not be true for hauls of bulk goods or goods that cannot be lifted or transported with standard equipment.

5. Data

The data are from the 1987, 1992, and 1997 Truck Inventory and Use Surveys (TIUS).[15] The TIUS is a mail-out survey of trucks taken by the Census as part of the Census of Transportation. The Census sends forms to a random sample of truck owners. These forms ask questions about individual trucks' characteristics. Truck owners report the truck's type (pick-up, van, tractor-trailer, etc.), make, model, and many other characteristics. The TIUS also asks owners how trucks are equipped, including whether trucks have trip recorders or EVMS installed, and how trucks are used. Owners report how far from home individual trucks generally operated, the type of trailer to which they were typically attached, the class of product they generally hauled, the state in which they were based, and whether they were used for for-hire or private carriage. Publicly-available data from the Survey do not identify trucks' owners because of confidentiality restrictions. This paper uses only observations of truck-tractors (the front halves of tractor-trailers) and excludes those that were generally operated off-road, carried household goods (i.e., moving trucks), or were attached to trailers that do not haul goods (e.g., trailers with large winches permanently attached). Eliminating these observations leaves 21,236, 32,015, and 18,856 observations of tractor-trailers in 1987, 1992, and 1997 respectively. This is over 85% of the tractor-trailers in the original samples.

Table 1 shows private carriage shares in each of the three years. In each of these years, the overall share is about 50%, and is much higher for short hauls than long hauls. The overall

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[15]See Baker and Hubbard (2000), Bureau of the Census (1995, 1999a), and Hubbard (1999, 2000) for more on the TIUS. The 1997 survey is actually called the Vehicle Inventory and Use Survey.

share fluctuated during this period, increasing from 50.1% to 54.6% between 1987 and 1992, then falling back to 51.7% in 1997. The time trends differ for hauls of different lengths. The private carriage share increased for all distances between 1987 and 1992. It increased for short hauls but declined for medium and long hauls between 1992 and 1997. This paper's empirical tests examine how these changes relate to the diffusion of on-board computers.

Table 2 summarizes patterns of OBC adoption over time and across distances. In 1987, a negligible number of tractor-trailers had an OBC installed; we treat this number as zero throughout. In 1997, 34% of tractor-trailers had an OBC installed. Adoption rates were 8% for trip recorders and 26% for EVMS. OBCs adoption was higher on trucks used for long hauls; half of all long-haul trucks had an OBC installed.

The right panel reports adoption rates in the early and late periods of my sample: 1987-1992 and 1992-1997. Adoption patterns differed between the two periods in two important ways. One is that overall OBC adoption slowed. In 1992, almost 19% of trucks had an OBC installed; this share increased by only 15 percentage points between 1992 and 1997. Second, the composition of OBCs changed between 1992 and 1997. There was no net adoption of trip recorders during this period. Evidence from the trade press and interviews suggests that this reflects two offseting factors: new trip recorder adoption and upgrades from trip recorders to EVMS. In contrast, adoption of EVMS accelerated. The share of trucks with EVMS more than doubled between 1992 and 1997. The broad patterns in the data suggest a correlation between technological and organizational change: the movement from private to for-hire carriage between 1992 and 1997 coincided with a sharp change in the composition of OBCs from trip recorders to EVMS.

Table 3 provides further evidence of such relationships. The Survey asks truck owners to indicate the economic sector of their firm. This provides additional information when trucks are part of private fleets: it indicates where in the supply chain the truck was used, for example by indicating whether it is part of a manufacturer or wholesaler's fleet.[16] The top part of table 3

[16] When the respondent indicates "for-hire trucking," this provides no additional information about how trucks are used.

reports shares by sector in each of the three years. For example, in 1987 9.7% of tractor-trailers were part of manufacturers' private fleets. The middle part of the table reports changes in these shares over time. Assuming that the overall share of shipments from manufacturers and other sectors does not change from year to year, these data indicate where movements to and from private carriage took place. Under this assumption, the 0.2 percentage point increase in manufacturing must reflect movement from for-hire carriage, and not from the other private fleet categories. These figures therefore provide information about the incidence of movements to and from for-hire carriage.

This table indicates that between 1987 and 1992, the movement from for-hire to private carriage was greater for shipments from wholesalers and retailers than for those from manufacturers. The bottom part of the table indicates that within private fleets, OBC adoption tended to be greater in wholesalers' and retailers' fleets than manufacturers'. This adoption tended to be disproportionately trip recorders. Table 4 breaks these figures down by distance, and provide further evidence. Looking at the manufacturing, wholesale, and retail columns, both the movement toward private carriage and OBC adoption rates tend to be greatest for longer hauls and in downstream sectors.

Between 1992 and 1997, the patterns are different. Table 3 indicates that the increase in the for-hire carriage share comes largely at the expense of decreases in the manufacturing and wholesale shares: the main shifts to for-hire carriage were hauls from manufacturers and wholesalers. Among those trucks remaining in private fleets, OBC adoption was greater for manufacturers and wholesalers. As was generally true during this period, adoption tended to be EVMS.

In sum, organizational change and adoption differed early and late in our sample. The main movements from for-hire to private were early in the sample and were concentrated in wholesale and retail sectors, sectors where private fleets tended to have high trip recorder adoption rates. The movements from private to for-hire were later and were mainly in manufacturing and wholesale sectors.

Cohort Data

The bulk of our empirical analysis uses cohorts rather than individual trucks as the unit of observation. Like in our earlier work, we base cohorts on state-product-trailer-distance combinations; an example is "trucks based in New Jersey hauling chemicals in tank trucks long distances." There are 2773 cohorts with a positive number of observations in 1987, 1992, and 1997. About three-quarters of our original observations are in these cohorts. We will also estimate specifications in which the dependent variable is only well-defined for cohorts where the private and for-hire carriage shares are positive in each year. There are 691 cohorts that satisfy this condition; these contain about 35% of the original observations in each year.

The characteristics of the trucks in the original and cohort samples are similar with two exceptions. One is that the cohort sample tends not to contain trucks that are predominantly attached to uncommon trailers such as auto trailers, logging trailers, and specialized platform-types. This is especially true of the smaller subsample. Although hauls using such trailers collectively make up a significant share of the industry – especially short hauls – cohorts based on these individual trailers are often based on few observations and are usually dropped from the sample because either the for-hire or private carriage share is zero. One consequence of this is that the cohorts samples disproportionately contain long haul cohorts. The other difference is that, conditional on distance, the cohort samples are disproportionately comprised of hauls using refrigerated vans.[17] The reason for this is refrigerated vans almost exclusively haul a single product class: processed food. Refrigerated van cohorts tend to be larger and less likely to have zero for-hire or private carriage shares than cohorts associated with trailers that haul multiple product classes.

Table 5 provides some summary statistics for the cohorts. The left panel includes cohorts with positive observations in all three years, 1987 and 1992, and 1992 and 1997, respectively. We report the latter two because in some specifications we will estimate relationships between ownership change and OBC adoption for only the early and late part of our sample, and thus will base the analysis on cohorts with positive observations in two rather than three years. Most of

[17]Observations of refrigerated vans make up about 10% of the truck sample, but about 20% of the cohort sample.

these cohorts have few observations: the number of observations per cohorts is less than ten in each year. The right panel reports summary statistics for positive private and for-hire share subsamples. Note that while the cohorts are larger in these subsamples, the basic patterns with respect to changes in the private carriage shares and adoption rates are very similar to those in the left panel.

Table 6 provides evidence of relationships between technological adoption and organizational change at the cohort level. The top panel uses cohorts with positive observations in both 1987 and 1992. The first row indicates that averaging across cohorts, the private carriage share increased from 0.49 to 0.50 between 1987 and 1992. The next three rows split the cohort sample according to OBC adoption. On average, the private carriage share stayed the same for cohorts with low OBC adoption. Among cohorts with high OBC adoption, the private carriage share increased for those where trip recorder adoption was high but decreased slightly for those where EVMS adoption was high. The bottom panel reports results from a similar exercise that analyzes patterns between 1992 and 1997. The private carriage share decreased for the low OBC and high EVMS adoption cohorts (slightly more for the latter), but increased for high trip recorder adoption cohorts. In sum, relationships between OBC adoption and organizational change differ for trip recorders and EVMS. Cohorts with high trip recorder adoption moved toward private carriage more than cohorts with low OBC adoption. Cohorts with high EVMS adoption moved toward for-hire carriage slightly more than those with low OBC adoption, but this difference is very small. Nevertheless, the fact that cohorts with high EVMS adoption did *not* move toward private carriage is interesting in light of the fact that EVMS enable the same contractual improvements trip recorders do. This suggests EVMS' resource allocation-improving capabilities – which trip recorders do not have – have organizational implications that offset those of their incentive-improving ones.

6. Results

Table 7 contains four sets of regression estimates. These use cohort data from 1987, 1992, and 1997. In the left panel, the dependent variables are the levels and first differences of for-hire carriage shares; in the right panel, they are the levels and differences of the log-odds ratios of the for-hire and private carriage shares. In each, we report the estimates of the coefficients on two variables: OBC and EVMS. OBC is share of trucks with either trip recorders or EVMS installed; EVMS is the share with EVMS installed. The coefficient on OBC therefore picks up the relationship between OBCs' incentive-improving capabilities and changes in asset ownership, and that on EVMS picks up the relationship between EVMS' coordination-improving capabilities and asset ownership. The control variables in the levels specifications are similar to those in Table 5 in Hubbard (1999). They include a full set of dummy variables that indicate the cohort's trailer type (dry van, refrigerated van, tank truck, etc.), a dummy that equals one if the cohort is of trucks hauling mixed cargo, and ln(trailer density). Trailer density is the number of trucks in the state attached to a given trailer type, normalized by the state's urbanized area, and is a proxy for local market thickness for hauls using a particular trailer type. We allow the coefficients on the dry van and auto trailer dummies to vary across years to account for secular changes in contractual form over time (see Hubbard (1998)). The control variables in the first difference specifications only include the dry van and auto trailer dummies and ln(trailer density), because none of the coefficients on the other controls vary over time.

In both panels, the coefficients on OBC are negative and significant and those on EVMS are positive and significant. The coefficients in the left panel decline by about 40% in absolute value when moving from the levels to the first-difference estimates, but remain statistically significant and economically important. All else equal, the estimates suggest that cohorts with a 20 percentage point higher trip recorder adoption rate experienced a 2 percentage point greater increase in their private carriage share. Likewise, moving 20 percent of trucks from trip recorders to EVMS corresponds to a 3 percentage point increase in the for-hire carriage share. The magnitudes of the estimates in the right panel, which are based on only cohorts with positive private and for-hire shares in each year, are similar.

Overall, we find evidence consistent with our main propositions. Consistent with P1, trip recorder adoption is associated with movement from for-hire to private carriage. Consistent with P2, EVMS adoption is less associated with such movement. Assuming these reflect causal relationships, they indicate that OBCs' incentive- and coordination-improving capabilities affect the make-or-buy margin differently. Their incentive-improving capabilities move hauls from "buy" to "make;" their coordination-improving capabilities move them from "make" to "buy." The former shifts truck ownership from for-hire carriers to shippers; the latter from shippers to for-hire carriers.

Table 8 breaks these basic results down further. The top panel reports analogous estimates using all cohorts, and subsamples of short, medium, and long haul cohorts. The coefficient on OBC is negative for all three subsamples, and statistically significant for medium and long haul cohorts. The EVMS coefficient is positive and significant for all three subsamples, and of about the same magnitude.

The bottom part of the table estimates the coefficients using only 1987 and 1992, then only 1992 and 1997 data. In the earlier period, the pattern of a negative coefficient on OBC and a positive one on EVMS only appears within the long haul subsample. In contrast, this pattern appears strongly and consistently in the later period. In the latter period, the coefficients on OBC are negative in each subsample, and statistically significant for the short and medium haul subsample. Those on EVMS are positive and significant in each subsample.

Interactions: Multitasking Tests

In the model, OBCs' incentive-improving capabilities affect asset ownership indirectly, by lowering the agency costs associated with multitasking. If so, then the OBC coefficient should only be negative for hauls where drivers' cargo-handling effort is potentially productive. This is the basis of P3 above. To examine this, we create two interactions between OBC adoption and product categories. One is OBC*(processed food or mixed cargo). Trucks hauling processed food or mixed cargo tend to deliver packaged goods to retail outlets. Drivers' cargo handling efforts are potentially more valuable when they haul these goods than other, bulkier goods. Trucks hauling petroleum or chemicals carry cargo for which handling requires certification. We therefore test whether the OBC coefficient is more negative for hauls of these products than others.

Table 9 summarizes the results. The first column uses data from all three years. The coefficient on OBC alone is small and statistically insignificant. There is no relationship between OBC adoption and asset ownership when trucks haul goods in the omitted category, which contains raw materials and bulky goods.[18] The interactions on OBC*(food or mixed cargo) and on OBC*(petroleum or chemicals) are both negative and significant. The estimates provide support for P3, and are important evidence that OBCs' incentive-improving capabilities affect asset ownership through job design. There is no evidence that incentive improvements affect the make-or-buy decision for hauls where drivers' handling efforts are rarely productive. When drivers' handling efforts tend to be productive, hauls for which trip recorders were adopted moved from for-hire to private carriage.

The other two columns report estimates using only two of the years. The OBC own effects are statistically zero in both periods. The point estimates of the interactions are larger in the later period. This pattern is interesting because it suggests that early OBC adopters did not make organizational changes to the same degree later adopters did. This is consistent with widespread speculation that in general, organizational changes tend to lag behind IT adoption, even when they are complementary.

Instrumental Variables Estimates

The first difference estimates above indicate that cohorts in which trip recorder adoption increased moved toward private carriage, but those in which OBC adoption was disproportionately EVMS did so less. These results are consistent with the hypothesis that OBCs' incentive- and coordination-improving capabilities affect the make-or-buy decision in different ways. This subsection provides additional evidence regarding whether the estimates above indeed reflect causal relationships.

Alternative interpretations of these relationships center on the premise that both OBC adoption and organizational changes might be independently affected by some omitted factor. First-differencing addresses alternative hypotheses that time-invariant factors affect both OBC use and organizational choices independently, but does not address alternatives in which changes in unobserved factors do so.

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[18]The most prevalent product classes in the omitted category are fresh farm products, building materials, machinery, and lumber and wood products.

For example, one possible interpretation of the positive correlation between trip recorder adoption and movement toward private carriage is that both are due to changes in omitted haul characteristics. Suppose unobserved haul characteristics differ across cohorts; in some cohorts, shipping patterns are more regular than others. Suppose also that when shipping patterns are regular, private carriage tends to be used more (perhaps because intermediaries' efforts are less valuable) and trip recorders are disproportionately valuable relative to EVMS. Then increases in regularity would lead both to more private carriage and to trip recorder adoption. Similarly, unobserved factors may also explain why EVMS adoption might be correlated with movements toward for-hire carriage. Suppose unobserved shipper characteristics change over time; some shippers may both establish more sophisticated logistics practices and begin to value shipment tracing capabilities. This would tend to lead to less private carriage (because drivers' handling effort is less valuable) and increased EVMS adoption.

We investigate the validity of these alternative interpretations by presenting instrumental variables estimates. Factors that affect OBC adoption but do not directly affect organizational form are good instruments. We use four main instruments: the fraction of miles trucks are operated outside of their base state, the number of weeks per year trucks in the state are in use, and dummy variables that equal one if the truck is based in a western state, or in a New England state.[19] These are computed at the cohort level; hence, the first two of these are cohort-level averages. Fraction of miles out of state affects OBC adoption because drivers must keep track of how many miles trucks are operated in each state. State fuel taxes are paid on this basis. OBCs let drivers enter in this information on a key pad, and lower data entry and processing costs when trucks' owners calculate the tax they owe each state. This is more valuable for trucks that spend more time outside of their base state because they cross state lines more. State averages for number of weeks in use differ considerably across states, ranging between 35 and 45 weeks, and reflect differences in the cyclicality of truck shipments.[20] Trucks are idled more weeks per year

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[19]Here, we define any state west of Missouri a "western state."

[20]Some of this variation is likely climate-related. The bottom five states are Montana, Wyoming, North Dakota, Alaska, and South Dakota.

in areas where shipments are highly cyclical. OBCs' benefits are correspondingly lower in such areas. We assume that statewide averages in the number of weeks trucks are in use are unaffected by OBC adoption.[21] The two regional dummies are included because it is traditionally more difficult for drivers to contact dispatchers quickly in less densely populated areas. This is one reason why adoption tends to be above average in the west but below average in New England. We use these four variables and their interactions as instruments for OBC and EVMS.

Table 10 contains the estimates. The first column uses all cohorts. The first row includes OBC but not EVMS in the specification. The estimate is positive and significant; in general, OBC adoption moved hauls toward for-hire carriage. The middle panel includes both OBC and EVMS. Both point estimates are positive, but the standard errors are large – much larger than those in the top panel. The right two columns break the sample into two; the multitasking subsample includes trucks hauling food, mixed cargo, petroleum, or chemicals and the non-multitasking subsample includes all other trucks. For the multitasking subsample, the OBC coefficient is negative and the EVMS coefficient is positive; for other trucks, the OBC coefficient is very close to zero and the EVMS coefficient is positive. Once again, however, the standard errors are quite high.

The sharp increase in the standard errors when one includes EVMS indicates a problem with respect to identification: the instruments do a good job of proxying for exogenous factors that affect OBC adoption in general, but are not good predictors of whether OBC adoption takes the form of trip recorders or EVMS. We have not yet found a good econometrically-exogenous shifter of the relative costs or benefits of trip recorders and EVMS.

We can provide some evidence, however, by comparing estimates of the OBC coefficient across segments and years, and investigating how the coefficient changes according to whether OBC adoption was disproportionately EVMS. The right part of the table reports adoption rates of trip recorders and EVMS during the early and late periods of our sample. Between 1987 and

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[21]Individual trucks with OBCs do tend to be used more weeks than those without them, because trucks without OBCs are more likely to be idled when demand is low. But OBC adoption should have a minimal impact

1992, trip recorder and EVMS adoption were about equal overall. Adoption during this time was disproportionately trip recorders for the multitasking subsample and EVMS for other trucks. Between 1992 and 1997, adoption was disproportionately EVMS overall and for both subsamples.[22]

In the bottom left of the table, we report estimates from specifications that do not include the EVMS variable, but allow the OBC coefficient to differ in the two periods. From the first column, OBC adoption pushed hauls toward for-hire carriage more in the later than the earlier period. In the early period, it did so only for the non-multitasking subsample. In the later period, the point estimates are positive and about the same magnitude for both subsample, although only statistically significantly greater than zero for the non-multitasking subsample.

In sum, adoption of OBCs was only disproportionately trip recorders in one of the four subsample*period cells: the multitasking subsample in the earlier period. The estimates suggest that this is also the only one of the four cells in which OBC adoption did not push hauls toward for-hire carriage. This is additional evidence that trip recorder adoption pushed hauls toward private carriage, and EVMS' coordination-improving capabilities pushed them toward for-hire carriage.

Magnitudes

Although not the main focus of the study, we can also use our estimates to investigate the degree to which overall changes in the private carriage share between 1987 and 1997 were due to the diffusion of OBCs. Table 11 summarizes our analysis. The top line reports the actual private carriage shares in our sample in each of the three years. The bottom part of the table reports the estimated shares, absent OBC diffusion, computed using the simple and GMM-IV first difference estimates from Tables 8 and 11. The simple first-difference estimates suggest that OBCs had little overall impact between 1987 and 1992 – the diffusion of trip recorders and

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on number of weeks, averaged across all trucks in a state.

[22]We believe that the main reason adoption became disproportionately EVMS is that EVMS' prices fell considerably relative to trip recorders' during this period. If so, then this is an exogenous shock that changed the relative costs of the two OBCs, and cross-year comparisons are an instrumental variables strategy of sorts.

EVMS had offsetting effects – but caused 1.2 of the overall 2.9 percentage point decline between 1992 and 1997. The point estimates from the GMM-IV specifications imply that OBCs' overall impact was much larger. They imply that OBC diffusion strongly affected the make-or-buy margin. They indicate that absent OBC diffusion, the 4.5 percentage point increase in the private carriage share between 1987 and 1992 would have been almost twice as high, and the private share would have increased at a similar rate between 1992 and 1997. One interpretation is that OBCs' effect worked against a broad increase in the demand for high service levels.

We do not put a large weight on these quantitative conclusions, in large part because the GMM-IV point estimates in Table 10 are noisy. We are more confident, however, in stating two qualitative conclusions. First, there is no evidence that OBC diffusion caused the overall increase in private carriage share between 1987 and 1992; if anything, this increase would have been greater absent OBCs. Second, OBC diffusion played a significant and possibly large role in inducing shippers to outsource more between 1992 and 1997.

7. Conclusion

In this paper, we combine recent theoretical work from organizational economics with a detailed and disaggregated dataset to gain insight about the interaction between asset ownership, job design, and information. We believe that our results—that improved contracting technologies lead shippers to vertically integrate into trucking, while technologies that improve coordination lead to more outsourcing of trucking services—shed light on the role of firms and markets in the economy by highlighting their respective comparative advantages.

In describing and explaining the development of 19^{th} century capitalism, Chandler (1977) and others argued that that the development of modern communications technologies (e.g., the telegraph) enabled the growth of large, integrated firms. Large transportation, manufacturing, and retailing firms were impossible without a technology that enabled managers to coordinate large-scale economic activity. Yet we have found exactly the opposite effect in late 20^{th} century trucking: a new communications technology that improved coordination led to smaller, less integrated firms. Why the difference?

We believe that our new results arise because of our ability to distinguish empirically between informational changes that improve coordination as distinct from those that improve incentives. Such a capability is rare in empirical work on organizations. Yet it is essential to understanding the true role of firms and markets as competing mechanisms for organizing economic activity. Hayek (1945) argued that the true miracle of the market-based price system is its ability to utilize dispersed information about resources and coordinate their use in a way that no centrally planned economy (or firm) ever could. Given this comparative advantage of markets over firms, it is not surprising that a technological change that mitigates the Hayekian coordination problem should lead to a greater relative improvement in the efficiency of markets.

Holmstrom and Milgrom (1994) and Holmstrom (1999), by contrast, argue that the true advantage of firms over markets is their ability to craft delicately balanced incentives for agents engaged in multiple activities, in a way that the strong incentives generated by markets and asset ownership cannot. Given this comparative advantage for firms, it is again not surprising that a technological change that mitigates contracting problems should lead to a greater relative improvement in the efficiency of firms.

Information costs are at the core of nearly all economic theories of organizations. Thus, all of these theories predict that changes in information technology that change the cost of contracting and communication will affect the organization of economic activity. We find that the answer to the question: "Has IT adoption led to larger or smaller firms in trucking?" is "Yes," and show how the organizational implications of IT's incentive- and coordination-improving capabilities systematically differ. Future research will further inform debates regarding the organizational implications of IT diffusion by investigating whether this systematic difference in trucking is general.

Appendix

Proof of Proposition 1:

Equations (5) and (12) both take the form:

(A.1) $$TV = \underline{V} + \tfrac{1}{2} a(g_1 - \theta s)^2 + ms - M(s,\sigma)$$

By the envelope theorem,

(A.2) $$\frac{dTV(a,s^*(a))}{da} = \frac{dTV(s^*)}{da} = \tfrac{1}{2}(g_1 - \theta s^*)$$

The right hand side is positive if $\theta < g_1/\phi(m,\sigma)$. Therefore, TV is strictly increasing in a, and thus $TV_S > TV_B$ iff $\lambda^2 > 3/4$ since $a = \lambda^2$ in (5) and $a = 3/4$ in (12).

Q.E.D.

Demonstration of Comparative Statics When $\lambda^2 > 3/4$:

When $\lambda^2 > 3/4$, shippers find their own hauls rather than using brokers. Equation (13) becomes:

(A.3) $$\begin{aligned} TV(s,\delta) &= \underline{V} + \tfrac{1}{2}[\lambda^2(1-\delta)+\delta](g_1 - \theta s)^2 - \tfrac{1}{8}\delta g_2^2 + ms - M(s,\sigma) \\ &= \underline{V} + \tfrac{1}{2}[\lambda^2 + \delta(1-\lambda^2)](g_1 - \theta s)^2 - \tfrac{1}{8}\delta g_2^2 + ms - M(s,\sigma) \end{aligned}$$

Propositions 2 and 3 hold for this expression by the same logic as in the text.

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Table 1
Private Carriage Share: 1987, 1992, 1997
by Distance

	Private Carriage Share			Change in Share	
	1987	1992	1997	1987-92	1992-97
All	50.1%	54.6%	51.7%	4.5%	-2.9%
Short	68.1%	73.6%	75.6%	5.5%	2.0%
Medium	59.1%	65.5%	61.5%	6.4%	-4.0%
Long	28.0%	33.2%	31.1%	5.2%	-2.1%
N	21236	32015	18856		

Table 2

OBC Adoption: 1987-1997

By Distance

	1987-1997	1987-1992	1992-1997
OBC Adoption			
All	0.34	0.19	0.15
Short	0.13	0.07	0.07
Medium	0.28	0.16	0.12
Long	0.50	0.29	0.21
Trip Recorder Adoption			
All	0.08	0.08	0.00
Short	0.04	0.04	-0.00
Medium	0.08	0.10	-0.01
Long	0.10	0.09	0.01
EVMS Adoption			
All	0.26	0.11	0.15
Short	0.09	0.02	0.07
Medium	0.19	0.06	0.13
Long	0.40	0.20	0.20

Table 3

Truck Shares, OBC Adoption
by Sector of Truck Owner.

	Private Carriage				
Sector of Truck Owner	Manufacturing	Wholesale	Retail	Other	For Hire Carrier
Shares					
1987	9.7	8.8	4.2	27.4	50.0
1992	9.9	9.8	5.0	29.9	45.4
1997	8.0	8.5	5.2	29.9	48.2
Change in Share					
1987-1992	0.2	1.0	0.8	2.5	-4.6
1992-1997	-1.9	-1.3	0.2	0.0	2.8
OBC Adoption					
1987-1992	19.7	26.5	31.3	7.4	23.4
1992-1997	16.0	14.9	11.1	9.6	18.7

Other includes: agriculture, forestry/lumbering, construction, mining, contractor activities/special trades, business services, and utilities.

Table 4

Truck Shares, OBC Adoption

by Distance, Sector of Truck Owner.

	Private Carriage				
Sector of Truck Owner	Manufacturing	Wholesale	Retail	Other Private	For Hire Carrier
Change in Share, 1987-92					
Short	-0.3	0.3	0.6	4.8	-5.4
Medium	-0.1	0.9	0.3	5.4	-6.5
Long	0.9	1.7	1.6	1.1	-5.2
OBC Adoption, 1987-92					
Short	10.2	13.4	16.9	4.1	6.9
Medium	17.0	29.0	30.0	8.5	14.7
Long	26.6	30.2	43.3	15.2	30.1

Other includes: agriculture, forestry/lumbering, construction, mining, contractor activities/special trades, business services, and utilities.

Table 5
Cohort Summary Statistics – Trailer-Product-Distance-State

	Positive Number of Observations in:			Positive Private and For-Hire Shares in:		
	1987,1992,1997	1987, 1992	1992, 1997	1987,1992,1997	1987, 1992	1992, 1997
Cohorts	2773	3908	4101	691	902	836
Obs/Cohort, 1987	5.7	4.7		10.8	9.7	
Obs/Cohort, 1992	8.3	6.6	6.4	16.3	14.4	15.1
Obs/Cohort, 1997	5.1		4.1	9.5		8.5
Private Carriage Share, 1987	0.50	0.49		0.43	0.45	
Private Carriage Share, 1992	0.50	0.50	0.52	0.44	0.46	0.46
Private Carriage Share, 1997	0.48		0.50	0.39		0.44
Trip Recorder Adoption, 1987-1992	0.08	0.08	0.08	0.10	0.10	0.10
EVMS Adoption, 1987-1992	0.08	0.09	0.11	0.12	0.11	-0.01
Trip Recorder Adoption, 1992-1997	-0.01		-0.00	-0.01		0.13
EVMS Adoption, 1992-1997	0.16		0.16	0.18		0.17

Note: "Included" cohorts are those with owner-operator shares between zero and one in 1987 and 1992.
Averages are computing using weights, where weight = (numobs87*expanf87 + numobs92*expanf92+ numobs97*expanf97)/3 for samples using all three years.
Analogous weights are used for samples that use only two of the three years.

Table 6
Private Carriage Share and OBC Adoption
Cohort Data

	Mean Private Carriage Share			OBC Adoption, 1987-1992		
	1987	1992	Change	Trip Recorder	EVMS	N
All Cohorts	0.49	0.50	0.01	0.08	0.09	3908
Low OBC Adoption Cohorts	0.54	0.54	0.00	0.02	0.02	2972
High TR Adoption Cohorts	0.50	0.54	0.04	0.34	0.06	470
High EVMS Adoption Cohorts	0.33	0.32	-0.01	0.05	0.36	466

	Mean Private Carriage Share			OBC Adoption, 1992-1997		
	1992	1997	Change	Trip Recorder	EVMS	N
All Cohorts	0.52	0.50	-0.02	-0.00	0.16	4101
Low OBC Adoption Cohorts	0.57	0.55	-0.02	-0.05	0.02	2756
High TR Adoption Cohorts	0.50	0.54	0.04	0.37	0.02	263
High EVMS Adoption Cohorts	0.42	0.39	-0.03	-0.02	0.43	1082

The top (bottom) panel includes all cohorts with a positive number of observations in both 1987 and 1992 (1992 and 1997).

Low OBC Adoption Cohorts are those where OBC adoption was less than 0.15.
High TR Adoption Cohorts are those where OBC adoption was greater than 0.15, and TR adoption was greater than EVMS adoption.
High EVMS Adoption Cohorts are those where OBC adoption was greater than 0.15, and EVMS adoption was greater than TR adoption.

Table 7
OBC Adoption and Asset Ownership

Dependent Variable:	For-Hire Carriage Share		ln(for-hire share/private share)	
	Levels Estimates	First-Differences	Levels Estimat	First-Differences
OBC	**-0.144**	**-0.090**	**-0.952**	**-0.446**
	(0.021)	**(0.024)**	**(0.212)**	**(0.233)**
EVMS	**0.239**	**0.149**	**2.189**	**1.024**
	(0.024)	**(0.028)**	**(0.241)**	**(0.271)**
N	2773	2773	567	567

SUR estimates.
Left panel includes all cohorts with positive number of observations in 1987, 1992, and 1997.
Right panel includes all cohorts with positive private and for-hire carriage shares in 1987, 1992, and 1997.
Cohorts weighted Census' weighting factors, by number of observations.

Specifications include trailer dummies, mixed cargo dummy, distance dummies, and ln(trailer density) as controls, and allow the coefficient on the auto trailer and van dummy to vary across years to account for secular changes

Table 8
OBC Adoption and Asset Ownership

	All	Short Hauls	Medium Hauls	Long Hauls
Dependent Variables: Change in For Hire Carriage Shares, 1987-92, 1992-97				
OBC	**-0.090**	-0.043	**-0.103**	**-0.113**
	(0.024)	(0.049)	**(0.040)**	**(0.040)**
EVMS	**0.149**	**0.183**	**0.147**	**0.159**
	(0.028)	**(0.068)**	**(0.052)**	**(0.043)**
N	2773	736	1019	1018
Dependent Variable: Change in For Hire Carriage Share, 1987-92				
OBC	-0.043	**0.226**	-0.087	**-0.111**
	(0.031)	**(0.066)**	(0.052)	**(0.052)**
EVMS	0.048	-0.138	-0.017	**0.157**
	(0.043)	(0.124)	(0.019)	**(0.062)**
N	3908	1115	1405	1388
Dependent Variable: Change in For Hire Carriage Share, 1992-97				
OBC	**-0.087**	**-0.152**	**-0.116**	-0.058
	(0.026)	**(0.055)**	**(0.047)**	(0.040)
EVMS	**0.171**	**0.125**	**0.193**	**0.157**
	(0.029)	**(0.068)**	**(0.054)**	**(0.042)**
N	4101	1097	1531	1473

SUR estimates.
Includes all cohorts with positive number of observations in each relevant year.
Cohorts weighted by Census' weighting factors times number of observations.

Specifications include change in trailer density and auto trailer and van dummies as controls.
and allow the coefficient on the auto trailer and van dummy to vary across years to account for secular changes.

Table 9

OBC Adoption and Asset Ownership – Interactions

Multitasking Tests

Dependent Variables: Change in For Hire Carriage Share

	1987-92-97	1987-92	1992-97
OBC	-0.010 (0.036)	0.033 (0.046)	0.009 (0.034)
EVMS	-0.066 (0.040)	-0.002 (0.057)	**0.088** **(0.039)**
OBC*(Food or Mixed Cargo)	**-0.141** **(0.054)**	**-0.131** **(0.069)**	**-0.241** **(0.060)**
EVMS*(Food or Mixed Cargo)	**0.142** **(0.062)**	0.065 (0.094)	**0.164** **(0.064)**
OBC*(Petroleum or Chemicals)	-0.111 (0.074)	-0.091 (0.101)	**-0.184** **(0.076)**
EVMS*(Petroleum or Chemicals)	0.156 (0.092)	0.021 (0.171)	0.166 (0.089)
N	2773	3908	4101

SUR estimates.
Includes all cohorts with positive number of observations in each relevant year.
Cohorts weighted by Census' weighting factors times number of observations.

Specifications include change in trailer density and auto trailer and van dummies as controls.
and allow the coefficient on the auto trailer and van dummy to vary across years to account for secular changes.

Table 10

OBC Adoption and Asset Ownership

GMM-IV Estimates

Dependent Variables: Change in For Hire Carriage Shares, 1987-92, 1992-97

	All	Multitasking	Non-Multitasking
OBC	**0.331**	0.099	**0.389**
	(0.071)	(0.099)	**(0.092)**
P-value for Test of OID Restrictions	0.935	0.731	0.901
OBC	0.183	-0.300	0.099
	(0.394)	(0.324)	(0.395)
EVMS	0.171	0.485	0.355
	(0.451)	(0.371)	(0.470)
P-value for Test of OID Restrictions	0.905	0.733	0.899
OBC92	**0.205**	-0.028	**0.444**
	(0.108)	(0.131)	**(0.176)**
OBC97	**0.459**	0.332	**0.359**
	(0.121)	(0.230)	**(0.124)**
P-value for Test of OID Restrictions	0.980	0.852	0.867
N	2773	727	2032

Adoption Rates

	All	Multitasking	Non-Multitasking
TR92	0.09	0.13	0.06
EVMS92	0.09	0.10	0.09
TR97-TR92	-0.01	-0.02	0.00
EVMS97-EVMS92	0.16	0.18	0.14

Instruments include percent of miles out of base state, number of weeks in use per year, west dummy, New England dummy, and interactions among these

Includes all cohorts with positive number of observations in each relevant year.
Cohorts weighted by Census' weighting factors times number of observations.

Specifications include change in trailer density and auto trailer and van dummies as controls.
and allow the coefficient on the auto trailer and van dummy to vary across years to account for secular changes.

Table 11

OBC Diffusion and the Private Carriage Share

	True Share		
	1987	1992	1997
	50.1%	54.6%	51.7%

	Estimated Share, Absent OBC Adoption			*OBCs' Estimated Impact*	
Estimates	1987	1992	1997	1987-1992	1992-1997
Table 8, All	50.1%	54.9%	53.2%	0.3%	-1.2%
Table 10, All (GMM-IV)	50.1%	58.4%	62.8%	-3.8%	-7.3%