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Information Technology, Capabilities and Asset Ownership: Evidence from Taxicab Fleets

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Information Technology, Capabilities and Asset Ownership: Evidence from Taxicab Fleets

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Abstract:
We examine how information technology (IT) influences asset ownership through its impact on firms' and agents' capabilities. In particular, we propose that when IT is a substitute for agents' industry-specific human capital, IT adoption leads to increased vertical integration. We test this prediction using micro data on vehicle ownership patterns from the Economic Census during a period when computerized dispatching systems were first adopted by taxicab firms. The empirical tests exploit exogenous variation in local market conditions, to identify the impact of dispatching technology on firm asset ownership. The results show that firms increase the proportion of taxicabs owned by 12% when they adopt new computerized dispatching systems. The findings suggest that firms increasingly vertically integrate when they acquire resources that substitute for their agents' capabilities.

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1. Introduction

Information technology (IT) is profoundly changing how firms are organized, as falling communication costs alter the efficiency of internal firm governance relative to market exchange. Because efficiency and firm organization are inextricably linked (Coase 1937), it is, therefore, of great importance to develop a deeper understanding of how the efficiency enhancing features of IT influences firm organization. This paper explores the relationship between IT and the economic organization of exchange by focusing on how IT adoption substitutes firm capabilities for agents' capabilities. In doing so, the paper takes a first step toward integrating the insights of the literature on organizational economics with the literature on organizational capabilities in the context of information technology adoption.

This paper proposes conditions under which IT investments reduce the relative value of agents' investments in industry-specific human capital, leading to increased vertical integration. We focus, in particular, on how IT influences firm asset ownership when IT is a substitute for agents' industry-specific knowledge. Our key assumption builds on one of the central predictions of transaction cost and property rights theories: asset owners make non-contractible investments in industry-specific human capital that non-owners are unwilling to make (Williamson 1985; Grossman and Hart 1986).

We use the assumption that ownership and industry-specific human capital are correlated to characterize the *ex ante* equilibrium into which IT is introduced. We, then, show how communication cost reducing features of IT shift returns to firm asset ownership, relative to agent asset ownership, leading to a new equilibrium where firms are increasingly vertically integrated. Specifically, we propose that when information from centralized management is a substitute for industry-specific knowledge, providing additional centralized information is worth less to asset owners who have made industry-specific investments in knowledge than to non-owner agents. Under these conditions, the adoption of information technologies that lower centralized communication costs, leads to increased firm ownership of assets by decreasing returns to agent owners, relative to non-owner agents.

We test this prediction using micro data on taxicab firms' vehicle ownership patterns from the Economic Census during a period, (1992-1997), when new computerized dispatching systems, consisting of a centralized computer and a network of mobile onboard computers, substantially lowered the cost of communicating information between individual taxicab drivers and firm managers. The empirical context is particularly appealing as it allows us to disentangle the impact of IT on capabilities from its effect on monitoring or incentives because taxicab drivers' remain full residual claimants before and after the IT shock. Furthermore, the fact that local markets are distinct and heterogeneous allows us to exploit exogenous variation in local market conditions to identify the impact of adoption of computerized dispatching systems on firm asset ownership.

The results show that IT adoption leads to increased vertical integration when IT substitutes for agents' industry-specific knowledge. Specifically, when firms adopt computerized dispatching systems, they increase the proportion of taxicabs owned by the firm by 12%, relative to non-adopters. The findings suggest that by substituting firm capabilities for agents' industry-specific knowledge, IT adoption increases the returns to low-skill agents relative to high-skill agents, leading to increased vertical integration.

2. Conceptual Framework and Related Literature

Understanding patterns of asset ownership has been a central issue in organizational economics since Coase's (1937) conjecture that firms should coordinate transactions internally only when doing so is more efficient than coordinating those activities through markets. Organizational theorists refined Coase's (1937) insight by highlighting the importance of specific investments and contractual incompleteness, in the presence of potential *ex post* opportunism, in determining the boundaries of the firm (Williamson 1975, 1985; Klein, Crawford and Alchian 1978). Grossman and Hart's (1986) property rights theory extended earlier work on organizational economics by developing a model where asset ownership increases the likelihood that an agent will make specific investments when doing so improves the *ex ante* efficiency of exchange. While assumptions over the salience of *ex post* opportunism versus *ex ante* efficiency in contracting can generate different predictions, both theories predict that asset owners are more likely than non-owners to make specific investments that improve the productivity of the asset they own. Thus, it follows from the logic of organizational economics that by making specific investments agents generate valuable resources or skills (or capabilities), and by doing so the asset becomes more productive and the agent becomes "indispensible to (the) asset" (Hart and Moore 1990, p.1133).

In this paper, we examine the role of an important class of specific investments that make assets more efficient and agents indispensible to the assets: industry-specific human capital, which includes knowledge of industrial routines and processes, that is specific to a single industry. Thus, we emphasize how capabilities arise from agents' investments in industry-specific human capital. Building on the premise that asset owners' investments in industry-specific human capital create capabilities, we incorporate the idea that centralized information from the firm can be a substitute for an individual's industry-specific knowledge to develop a theory of organizational response to the adoption of information technology.

By focusing on the impact of IT on the value of the firm's agents' knowledge, we build on and extend a literature on IT and worker capabilities. This literature is often called the skill-biased technical change literature because of the stylized finding that IT adoption leads to increasing worker productivity amongst the most highly skilled workers (Krueger 1993; Bresnahan, Brynjolfsson and Hitt 2000). However, a nascent literature shows that IT can have the opposite effect—rather than being complementary to worker skills, IT adoption can also substitute for worker skills, leading to a lower skilled, or de-skilled, workforce *ex post* (Autor and Dom 2009). We develop the de-skilling result further, in the context of organizational economics and organizational capabilities, by showing that the boundary of the firm shifts away from market exchange toward vertical integration when IT substitutes for agents' industry-specific human capital.

This research also contributes to an important branch of the organizational economics literature, which examines the impact of IT adoption on the boundaries of the firm. Early theoretical work on information technology and asset ownership applied property rights theory to information assets, positing that increased alienability of information, or degree to which information can be transferred efficiently, should lead to a shift in asset ownership away from owners of inalienable information (Brynjolfsson 1994). The theory developed in this paper builds on Brynjolfsson (1994) by considering an IT shock that increases the alienability of information as a substitute for an agent-owners (inalienable) industry-specific human capital. However, in contrast to Brynjolfsson's (1994) emphasis on the incentive enhancing features of alienable information, we isolate, theoretically and empirically, a capabilities-based mechanism underlying the shift in asset ownership due to IT adoption.

By focusing on incentive features of IT, previous research on IT and firm boundaries has made great strides in applying organizational economics to questions of IT adoption and asset ownership. However, the early research does not consider how IT influences firm organization through its impact on capabilities. Yet, it is clear that IT systems expand the firm's ability to disseminate information to its agents, which might also influence the comparative governance costs of firm versus market exchange (Demsetz 1988). Indeed, the knowledge-based view of the firm suggests that the boundaries of the firm are sensitive to the efficiency with which the firm codifies and disseminates production information (Kogut and Zander 1992; Conner and Prahalad 1996). While the knowledge-based view of the firm offers a capabilities-based theory of firm boundaries, the precise mechanisms through which improved information flow might lead to changes in firm organization are less clear. We build on the knowledge-based view of the firm by integrating it with insights from the literature on IT and worker capabilities and with the organizational economics literature on organizational response to IT adoption, to develop a deeper understanding of how IT influences asset ownership through its impact on firms' and agents' capabilities.

We propose a simple theory, where IT reduces the relative returns to investments in industry-specific human capital, leading to increased firm asset ownership. Because IT allows the firm to communicate valuable production information at lower cost to its agents, it raises the productivity of workers who operated without the production information previously. However, communicating new information to workers who already possessed the required production knowledge has no impact on their productivity. Thus, the communication cost reducing feature of IT can reduce the relative returns to knowledge. When knowledge and asset ownership are jointly determined and positively correlated prior to the adoption of IT, as is standard in organizational economics models, the firm's ability to substitute centralized information for agent knowledge leads directly to increased firm asset ownership.

To make the theory concrete, consider a setting where there are two types of agents, asset owners and non-owners, both of whom work for a firm that manages their productive efforts with a legacy technology that disseminates centralized production information to agents. Asset-owners possess capabilities that arise from their prior investments in industry-specific human capital, which increases their productivity and their wages relative to non-owners. By contrast, non-owners do not possess industry-specific knowledge, and, therefore, rely more heavily on centralized information provided by the firm to direct their productive efforts.

From the baseline *ex ante* distribution of asset ownership in an industry, as described above, we examine how asset ownership changes *ex post* when there is an information technology shock that increases low-skill agents' productivity by more than high-skill agents'. We propose a simple and direct outcome of IT adoption: the composition of the firm's workforce will shift toward lower-skill workers, inducing a corresponding shift toward firm asset ownership. Consider, for example, an information technology shock that facilitates the dissemination of centralized information that substitutes for industry-specific knowledge. Since centralized information is a substitute for agent knowledge, IT adoption increases the value of low-skilled labor relative to high-skilled labor, leading the marginal agent-owner to sell their assets to the firm. IT adoption essentially renders the marginal agent-owner's industry-specific knowledge obsolete—the agent ceases to be indispensible to the asset. When agent asset ownership ceases to be efficient, the marginal agent-owner sells their assets to the firm. Thus, in general, when information technology increases non-owners' productivity by more than owners', IT adoption will lead to increased vertical integration.

We formalize the relationship between asset ownership changes and technology adoption that increases the productivity of non-owners by more than agent-owners in the Appendix, showing that if the relative productivity shock is large enough IT adoption leads to vertical integration. An important special case of when a shock is "large enough" occurs when IT is a substitute for industry-specific human capital. Therefore, we state the theory as a formal hypothesis when industry-specific knowledge and information technology are substitutes.

> *HYPOTHESIS 1: When information technology is a substitute for industry-specific human capital, information technology adoption leads to an increase in firm asset ownership.*

Our theory roots capabilities in organizational economics and links changes in patterns of asset ownership to a capabilities shock. Linking organizational economics and capabilities allows us to make a clear prediction about the conditions under which information technology leads to increased firm asset ownership. Thus, we predict a dynamic organizational response to IT adoption, given an initial equilibrium in the asset ownership market, through the impact of IT on capabilities.

The key assumptions underlying the prediction that information technology adoption leads to increased firm asset ownership are (1) that asset owners make efficiency enhancing specific investments in industry-specific knowledge *ex ante* and (2) that information technology is a substitute for industry-specific knowledge. The literature on organizational economics predicts that the first assumption should hold whenever (a) industry-specific knowledge is complementary to a physical asset and (b) contracts over the bundle of these complementary assets are incomplete. Where assumptions (a) and (b) hold, industry-specific knowledge forms the basis for individual-level capabilities and assumption (1) is satisfied.

The validity of the second assumption, concerning the substitutability of information technology for industry-specific knowledge, is likely to vary across industries and with the specific features of the information technology adopted. In particular, IT will substitute for industry-specific knowledge when managerial direction and agent knowledge are substitutes and IT lowers communication costs from the corporate center. Thus, the relationship between IT adoption and changes in the boundary of the firm depend crucially on the nature of managerial versus agent capabilities and the IT resource acquired.

Bloom, Garicano, Sadun and Van Reenen (2009) make a related point, showing how communication and information processing features of information technology influence firm organization differently. Indeed, in other contexts where information processing features of IT are of first order importance, as opposed to the communication features we emphasize, IT adoption could lead to less vertical integration. For example, in Argyres's (1999) study of the design of the B-2 bomber, he shows that by reducing information processing costs and standardizing communication, IT improves coordination and reduces asset specificity facilitating vertically disintegrated project organization. Similarly, Baker and Hubbard (2004) find that the adoption on-board computers (OBC) in trucking fleets ameliorates external contracting problems, pushing the boundary of the firm toward driver-ownership of vehicles. We describe why our empirical context fits assumption (2) below.

3. Institutional Context

Taxicab fleets began using computers during the 1970s, but automated data dispatch systems did not arrive until the early 1980s. By the early 1990s, firms began adopting computerized dispatching systems, comprised of a central computer that coordinates vehicles and communicates information and vehicle-level on-board computers. Basic computerized dispatching systems, called "partially automated" systems, require drivers to send a signal to the central computer, indicating their location by entering a zone number into a simple onboard computer, and human dispatchers to announce ride allocations, using a separate communication system (usually a radio). More advanced "fully automated" systems deploy in-car devices with two-way communication capability, allowing the back-end optimization algorithm to communicate directly with onboard computers in taxicabs. These systems also automatically monitor pickup and drop-off actions, such as turning the meter on and off. During the sample period, fixed costs associated with fully automated systems were around $750,000, while per vehicle costs were about $1,000, including the onboard computer (Gilbert, Nalevanko and Stone, 1993).[1] The most advanced computerized dispatching systems are GPS-based, which eliminate the need for drivers to enter zone numbers and track a vehicle's exact location at all times. GPS-based systems are substantially more expensive than partially and fully automated systems. Though in principle more advanced dispatching systems should lead to larger shifts in firm asset ownership, in this paper, we do not attempt to distinguish between the effects of different computerized dispatching systems due to limitations in the data.[2]

Historically, some firms were organized around relatively sophisticated radio-based dispatching systems, while other firms often had rudimentary dispatching systems, sometimes as basic as hand-written notes on bulletin boards. Firms with more advanced dispatching systems usually owned most or all of their own taxicabs and used their dispatching capabilities to support a network of inexperienced shift drivers—typically non-owner drivers—while firms with simple, low-cost, dispatching systems catered to experienced owner-operators who managed their own block of business but banded together, often as cooperatives or associations, to share maintenance and administrative costs.

Taxicab drivers' incentive contracts do not vary with asset ownership—drivers are almost always full residual claimants even if they do not own the taxicab they drive (Schaller and Gilbert 1995). However, capability is correlated with asset ownership. In the absence of computerized dispatching, experienced drivers are far more productive than inexperienced drivers because they have developed a deep understanding of

[1] Estimates of the cost of partially automated systems vary widely based on the exact functionality of the system, but the basic system is probably about half the cost a fully automated systems.

[2] In our data, most computerized dispatching systems were described as "partially automated" or "fully automated," but, in our field research, we found that there was no general standard for distinguishing between "partially" and "fully" automated systems. By contrast, there was broad agreement on what constituted a GPS-based system. However, only about 20% computerized dispatching systems were characterized as GPS-based systems, and most had been adopted very close to the end of the testing period, which limited our ability to evaluate the impact of GPS-based systems on changes in asset ownership (Transit Cooperative Research Program Report, 1998).

demand patterns in their markets. [3] While inexperienced drivers tend to inefficiently chase rides, experienced drivers know where to go and importantly when to wait for rides to materialize without wasting time and gasoline driving across town.[4] Relative to radio dispatching, computerized dispatching levels the playing field by more efficiently allocating vehicles to rides.[5] Inexperienced drivers enter pre-assigned high-volume zones and wait in an orderly (virtual) queue until they are assigned a ride, leading to significantly improved utilization at lower cost. On the other hand, computerized dispatching is much less valuable for experienced drivers because they do not depend on an efficient queuing system to operate at close to full capacity—they already know where to go to find rides. Thus, the benefits of computerized dispatching are disproportionately gained by inexperienced drivers.

In addition to non-owner drivers and owner-operators who contract with firms for shared services, there is a third type of driver: independent owner-operators, typically very experienced drivers who choose to operate without any firm affiliation or support. Driving independently represents owner-operators' outside option when they contract with fleets, as owner-operators are free to switch between being independent and working for firms. We do not explicitly consider how independent owner-operators are affected by firm adoption of new dispatching technology. Implicit in our theory is the idea that independent owner-operators do not benefit from contracting with taxicab firms for dispatching services *ex ante* because their high levels of industry-specific knowledge allows them to achieve maximum productivity without contracting for dispatching. Given the maintained assumption that IT is a substitute for industry-specific knowledge, the direct effect of IT adoption would never lead independent owner-operators to contract with the firm for dispatching services as an owner-operator. A more dynamic model might explicitly incorporate the asset ownership decisions of independent owner-operators who choose to contract with firms after IT adoption, and, indeed, many

[3] The value of knowledge as a productivity shifter is particularly salient when tasks are non-routine. Autor and Dorn (2009) report that taxicab drivers have the fourth least routine job of 354 Census occupations, as measured by the 2000 Census Routine Task Index, after "fire fighting, prevention and inspection" (#2) and ahead of" police, detectives and private investigators" (#6).

[4] Schaller and Gilbert (1995) report that the top quartile of New York City taxicab drivers earn 59% more than the bottom quartile. Woollett, Spiers and Maguire (2009) show that experienced taxicab drivers in London develop a remarkably deep understanding of the spatial structure of the city.

[5] Gilbert, Nalevanko and Stone (1993) report that dispatch times fell by 50-60% following the adoption of computerized dispatching. Our own estimates reveal that average fleet utilization increased by 15%-20%, following the adoption of computerized dispatching systems, though both results are estimated as treatment on the treated effects, not average treatment effects.

formerly independent drivers did contract with firms during our sample period.[6] However, independent owner-operators who become agent-owners can be treated analogously to agent-owners in our simple model, so modeling the additional dynamics adds little insight to the theory articulated herein.

Importantly for this study, unique local regulatory, competitive and geographic factors can influence the costs and benefits of computerized dispatching systems. Most of these factors are exogenous to the choices taxicab fleet operators make, with respect to information technology adoption, providing the natural experiment missing from many studies of technology adoption. Local regulations determine retail prices, fix the number of permits or medallions, devise a permit allocation system, limit the transferability of permits, set restrictions on the entry and exit of fleets and may require either fleets or individuals to own operating permits. Differences between cities, such as regulated fare changes, may also influence the adoption of computerized dispatch systems by changing the benefits of adoption. Moreover, the geography of a city can influence the distribution of rides between dispatched fares and curbside hails. The paper exploits this natural variation in markets to control for the endogenous nature of the adoption decision.

Since onboard computers installed in taxicabs are specific to the firm's dispatching system, transaction cost economics asset specificity mechanism represents a leading alternative hypothesis to our theory of vertical integration in response to a capabilities shock. The nature of asset specificity is often context dependent and subtle, which means that it must be considered carefully.[7] Since the onboard computers installed in taxicabs are specific to the firms dispatching system the asset specificity hypothesis certainly has face validity. However, there are at least two compelling reasons to believe that contractual hazards are not severe with respect to contracting over the installation and use of onboard computers in the taxicab industry. First, it is apparent in the data that many firms deploy onboard computers in owner-operator

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[6] The U.S. taxicab industry was buffeted by two major shocks during the mid-1990s. The first, the subject of this paper, was technological as new computerized dispatching systems reached the taxicab market. The second shock, a regulatory change that led to widespread diversification into limousines decreased vertical integration as formerly independent driver-owners increasingly contracted with firms (Rawley and Simcoe 2009). The net effect of the two shocks was a secular decline in vertical integration levels between 1992 and 1997. In this paper we investigate the effects of computerized dispatching on asset ownership, controlling the effect of diversification.

[7] See for example the role of reputational capital as a firm-specific asset in the trucking industry (Nickerson and Silverman 2003)

vehicles. In the average firm that uses computerized dispatching, 31% of vehicles are owner-operator taxicabs (see Figure 1).[8] The fact that the practice of contracting through market exchange to deploy onboard computers in owner-operator vehicles is widespread indicates that such contracts are not particularly fraught with hazards. Bolstering this claim, industry interviews confirm that firms often recoup their investment costs by levying a surcharge on owner-operators for their use of the system. Second, the highly regulated nature of the taxicab industry suggests that contracts are enforceable by regulators who typically have wide latitude to levy fines and penalize drivers and firms. Assuming that firms acquire the onboard computers on behalf of owner-operators, as is customary in the industry, the key potential contracting hazard is that owner-operators would quit the firm taking the onboard computer with them. However, non-performance is directly observable, which suggests that it is unlikely to pose a significant contractual hazard. While it seems possible and even likely that firm-specific asset specificity influences the cross-sectional pattern of asset ownership in the industry, in addition to industry-specific asset specificity we describe in our theory, we shall control for time-invariant firm-specific effects in our empirical specification.

4. Empirical Strategy

4.1 Data

The core dataset from this paper comes from the 1992 and 1997 Economic Census. The Economic Census began tracking taxicab firms in 1992 and has continued to track them every five years. The Economic Census is a comprehensive dataset that includes every taxicab firm in the United States with at least one employee (SIC code 412100): 3,184 in 1992 and 3,337 in 1997. From this universe of taxicab firms, 787 firms are "substantial entities"—firms that have at least $10,000 of taxicab revenue and two taxicabs—that maintained operations during the full sample period between 1992 and 1997.[9] Economic Census micro-data is extremely valuable because it includes the number of taxicabs by ownership type (e.g., fleet-owned versus driver-owned), allowing for an unusually precise measure of within-firm changes in vertical integration over time.

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[8] 31% = 1 – 69% of non-owners (FOWN), represented in Figure 1 as the (1997) black bar for firms that adopted dispatching technology (TECH) between 1992 and 1997

[9] Approximately 2,000 observations in 1992 and 1997 are administrative record (AR) firms—very small firms, typically those with only one employee, that the Economic Census does not actually survey but rather imputes values for.

The Economic Census does not, however, contain information on dispatching technology. [10]

To capture dispatching system data, we augmented the 1998 Transit Cooperative Research Program (TCRP) survey [11] with our own survey of all taxicab operators in the Dun and Bradstreet (D&B) business register with taxicab SIC code 412100 and at least two employees.[12] We merged the resulting 635 (363 TCRP observations and 272 author survey observations) observations with the 3,153 observations in the 1997 Economic Census by zip code or county code. The merging process generated 409 unique matched observations, 197 from the TCRP survey and 212 from the authors' survey.[13] Of the 409 matched observations, 244 operated continuously between 1992 and 1997 and reported valid data in both years to the Economic Census, representing 31% of all substantial entities.

Table 1 shows summary statistics for the firms in our test sample and for all firms that meet our sampling criteria in 1992 or 1997, including firms that entered or exited the industry between 1992 and 1997. 36% of the taxicab firms in the test sample adopted computerized dispatching between 1992 and 1997 (87 firms). The average firm in our sample had 52 taxicabs, 89% of which were owned, in 1992, compared to an average fleet size of 19 taxicabs (20,014 taxicabs / 1,020 fleets) with 82% owned (16,426 taxicabs owned / 20,014 taxicabs total) in the full set of substantial entities in the Economic Census. In 1997, the average firm in our sample had 67 taxicabs in their fleet, 65% of which were owned, compared to an average fleet size of 27 taxicabs

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[10] In addition to the quantitative data described in this section, we conducted 73 semi-structured interviews with city taxicab regulators, fleet owners and mobile information technology network technology vendors and taxicab drivers. These interviews provided a wealth of insights and anecdotes that greatly improved this paper. For so freely sharing with us the wealth of knowledge they have accumulated regarding the U.S. taxicab industry, we are particularly indebted to C.J. Christina, Jason Diaz, Thomas Drischler, Stan Faulwetter, Alfred La Gasse, John Hamilton, Marco Henry, Kimberly Lewis, Joe Morra, John Perry, David Reno, Aubby Sherman, Doug Summers and, especially, Craig Leisy.

[11] We are grateful to Tom Cook and Gorman Gilbert for generously sharing the detailed responses to the TCRP survey with us.

[12] There were 1,929 taxicab operators in the D&B business register. 391 surveys were returned undeliverable and 403 firms responded with complete questionnaires (26%) response rate. We verified that late respondents were not statistically different from early respondents as a check on non-response bias. 272 of the firms in our survey were both different from those that responded to the TCRP survey and began operations before 1997.

[13] The 226 unmatched observations were primarily small firms. Small firms are more difficult to match by zip code or county code because there are often many small firms in the same area. A disproportionate number of TCRP respondents could not be matched because the TCRP data only contains county-level geographic information, whereas the authors' survey also includes zip code.

(29,960 taxicabs / 1,106 fleets), 61% of which were owned (18,303 taxicabs owned / 29,960 taxicabs total).

The test sample contains accounts for fully 63% (52 taxicabs/firm in the test sample x 244 firms in the test sample / 20,144 total taxicabs in firms in the Economic Census) and 55% (67 x 244/ 29,960) of all taxicabs in fleets in 1992 and 1997, respectively. While our test sample captures a significant proportion of the substantial entities in the industry, larger firms are clearly oversampled. Because we are interested in estimating the effect of dispatching technology adoption on the set of firms at risk to adopt, not necessarily the population treatment effect of computerized dispatching adoption all taxicab firms, it is most interesting to analyze a set consisting primarily of larger substantial entities. Therefore, for our research question, an oversample of the largest firms is actually preferable to a representative sample of all taxicab firms, though the burden remains on us to show that non-response bias is not driving our results, which we do in the robustness checks below.

Table 2 shows the size distribution of firms in the test sample in 1992, and the percentage of firms that adopted computerized dispatching (for the first time) by 1997, according to the firm's1992 size category. As expected, the smallest firms, those with exactly two taxicabs, never adopt computerized dispatching technology, while 70% of fleets with over fifty or more taxicabs in 1992 adopted computerized dispatching systems by 1997. The rate for the largest size category is approximately three times the rate of firms with less than 25 taxicabs (23% adoption rate), which supports our contention that large firms are more likely to adopt computerized dispatching systems and underscores the importance of estimating the average treatment effect as opposed to the population average treatment effect.

4.2 Empirical Specification

Figure 1 illustrates the secular decline in vertical integration and previews our main result, showing vertical integration levels in 1992 and 1997 for our treatment group, firms that adopted computerized dispatching systems, and our control group, firms that did not adopt computerized dispatching systems. In 1992, the 87 firms that subsequently adopted computerized dispatching systems owned 91% of their vehicles, while the 157 firms that did not adopt computerized dispatching systems by 1997 owned 86% of their vehicles. By 1997, after the secular decline in levels of vertical integration, firms that adopted computerized dispatching systems owned 69% of their vehicles, a decrease in the level of vertical integration of 17%, while firms that did not adopt computerized dispatching systems owned 62% of their vehicles, a decrease of 29%. Thus, net of the secular decline in vertical integration levels, firms that adopted computerized dispatching systems increased their level of vertical integration by 12% relative to firms that did not adopt. In the statistical tests that follow, we show that the relationship between the adoption of computerized dispatching and asset ownership changes apparent in the raw data approximates the average treatment effect of interest.

To measure the impact of adoption of mobile information technology on changes in vertical integration, we use the change in the fraction of vehicles owned by the fleet (ΔFOWN), which is continuous and bounded between negative one and one, and a binary explanatory variable ΔTECH that is equal to one when the firm adopts a mobile information technology network and zero otherwise, as in OLS equation (1):

$$(1)\ \Delta FOWN_i = \alpha + B_T \Delta TECH_i + \mathbf{X_{c,i} B_c} + \varepsilon_i.$$

Variables that could plausibly shift, directly or indirectly, the boundary of the firm are in $\mathbf{X_{c,i}}$ including: changes in firm size, measured by changes in the logged values of taxicab capital and the square of changes in the logged taxicab; changes in the degree to which taxicab firms are horizontally integrated measured by log limousine capital and log limousine capital squared; changes in the level of vertical integration in other fleets in the same market—to control for time varying market-level effects on changes in the firm's own level of vertical integration; and changes in the number of taxicabs and limousines under management operated by competing fleets in the same market (county)—a proxy for the competitive dynamics of the firm's operating environment.

Taking firm-level first differences in model (1) is similar to using firm fixed effects when there are only two periods of observations and first differences are taken in all of variables, as (1) controls for time-invariant firm-specific heterogeneity. The result is a specification that is equivalent to a firm and time fixed effects model, to within a constant, which controls for time-invariant firm characteristics as well as number of time-varying firm and market characteristics, without biasing the estimated standard errors downward as fixed effects models do. We take advantage of the first differences specification by clustering at the market (county) level as we do not need to cluster at the firm level to correct the standard errors.

In the ideal experiment, one would randomly assign computerized dispatching to firms and observe how their asset ownership patterns changed relative to firms who were not assigned the technology. However, the decision to adopt computerized dispatching is an endogenous choice that may be influenced by unobserved time-varying firm-specific factors that are also correlated with changes in asset ownership. Even OLS specifications that control for time-invariant firm characteristics and changes in firm size may not identify the impact of computerized dispatching on asset ownership because the benefits of computerized dispatching vary based on unobservable (to the econometrician) firm and market characteristics that may also be correlated with asset ownership decisions.

On the one hand, the OLS results may be biased downward if firms adopt computerized dispatching when *ex ante* they contract with less knowledgeable (or capable) drivers, since less knowledgeable drivers benefit more from computerized dispatching. We control directly for driver ownership of taxicabs, which is probably the most important single determinant of driver knowledge, but there are potentially other, unobservable, factors that influence the distribution of driver capabilities across firms. Thus, adopters may be precisely the firms that have less reason to vertically integrate further following adoption. Similarly, selection effects that drive firms with strong *ex ante* relationships with owner-operators to adopt computerized dispatching leads to downward biased estimates of the impact of computerized dispatching on asset ownership since stronger relationships with owner-operators facilitate implementation of the dispatching system. On the other hand, one might worry that reverse causality effects could bias the OLS results upward, if, for example, firms were more likely to adopt computerized dispatching when they faced difficulties attracting independent owner-operators historically and sought to induce these drivers to contract with the firm by offering additional services. We address the potential for endogeneity in the technology adoption decision using a propensity score matching techniques to control for observable differences between firms and a two-stage least squares (2SLS) instrumental variables (IV) approach to control for unobservable differences between firms.

Our propensity score matching technique follows Rosenbaum and Rubin (1983), who show that in the absence of unobservable characteristics that are correlated with both the dependent and explanatory variables, matching treatment and control groups on all relevant observable characteristics creates a valid counterfactual against which to measure treatment effects. As in Rosenbaum and Rubin (1983), we calculate the propensity score of the probability of adopting computerized dispatching systems, using the latent variable (y*), which predicts whether the firm selects a binary treatment y (y=mobile information technology network adoption):

$$(2)\ y_i^* = \mathbf{x_i}\boldsymbol{\beta} + e_i,$$

where we observe y = 1 [y*>0] when the firm adopts computerized dispatching systems between 1992 and 1997; **x** includes all observable characteristics of firms in 1992 that might plausibly have an effect on the adoption decision and *e* is an error term, which is assumed to be normally distributed with mean zero and variance one in a probit specification. We then drop firms off the common support of the propensity score distribution of the probability of adopting computerized dispatching systems and weigh included firms by the inverse probability of being treated to create a balanced sample of treated and control observations (Imbens 2004).

Table 3 shows the variables included in the vector **x** in (2), their coefficients from the probit predicting adoption of computerized dispatching systems (first column) and the marginal effects of **x** at the average value of each regressor on the firms propensity to diversify (second column). Following the standard propensity score matching approach, our model is complete with highly correlated regressors and interactions between terms that capture marginal effects that might be expected to influence computerized adoption decisions. A more parsimonious version of the matching model that only controls for the main effects of the variables of interest generated similar “second stage” (e.g., matched) outcomes, though with lower explanatory power in the first stage.

As expected, the most important single factor influencing adoption was the (log) number of taxicabs in the firm in 1992 (see Table 3). In an attempt to capture the marginal effect of lagged firm size on market and firm characteristics that might influence adoption decisions, *log number of taxicabs* in the firm in 1992 also enters the matching equation as an interaction with *urban*, *total factor productivity (TFP)* and *corporate*, though these effects are not statistically significant. The smaller in magnitude, though still large and statistically significant, negative effect of *log taxicab capital* on the adoption of computerized dispatching reflects the fact that number of taxicabs, which is highly correlated with *log taxicab capital* (correlation coefficient = 0.83), is the key driver of adoption of computerized dispatching not the composition of taxicabs between driver-owned and fleet-owned. Consistent with the rationale for using average fleet size of other firms in the same market as an instrument, lagged other firms' size *(avg. taxicabs* $market_{-i}$*)* has a positive and statistically significant effect on the propensity to adopt computerized dispatching systems even when controlling for the firm's own size.

Table 3 also shows a comparison of means for control and treatment groups before after matching. Matching reduces, but does not eliminate, the lagged firm and market size differences between the two populations. Since our main concern is that initial size differences between the two populations may influence subsequent adoption decisions in ways that are difficult to control for in our OLS model, the resulting match is a step in the right direction, but not a definitive control for endogeneity. Our main identification strategy must, therefore, rely on our instrumental variables approach, though we proceed with the matched results as a robustness check.

One of the advantages of studying the taxicab industry is that it is comprised of hundreds of distinct independent local markets. Our sample of 244 firms covers 173 markets (counties). We exploit market level variation to address the potential for unobservable characteristics of firms to bias our results using lagged (e.g., 1992) average fleet size of other firms in the same market (*AVGTAXIS)*, as well as the (logged) components of market population density, population *(POP)* and land area *($MILES^2$)*, as instruments for adoption.

Lagged size of other fleets in the same market, *AVGTAXIS*, should not cause firms to adopt a computerized dispatching system or cause changes in firm asset ownership, particularly when controlling for the firm's time invariant characteristics as well as the change in the firm's own size. However, lagged average size of other fleets in the same market may be correlated with a firm's adoption of a computerized dispatching system to the extent that the firm is operating in a market where supply and demand, or regulatory characteristics of the market, tend to exogenously increase the average size of firms, and, therefore, create conditions under which firms have a higher demand for coordination technologies. One might also expect that inter-firm awareness of new computerized dispatching technology increases when a firm operates in a market where other firms adopt computerized dispatching. Therefore, the instrument lagged average size of other firms in the same market, *AVGTAXIS*, should be correlated with the adoption of computerized dispatching, $\Delta TECH$, yet the instrument also satisfies the exclusion restriction, meaning that its effect on changes in the extent to which firms are vertically integrated only operates through its correlation with the adoption of computerized dispatching systems.

Because firms in our sample chose where to operate and made their initial asset ownership decisions before the existence of computerized dispatching, the components of population density, *POP* and $MILES^2$, are also exogenous to the decision to adopt computerized dispatching, $\Delta TECH$, and to changes in asset ownership, $\Delta FOWN$. However, increasing population density can reasonably be expected to lead to increased adoption of computerized dispatching technology because the complexity of taxicab operations tends to increase in urban markets where optimally matching vehicles to rides is contingent on where and when other rides terminate. Because computerized dispatching helps manage system complexity, population density should generate a powerful first stage estimate of a firm's likelihood to adopt computerized dispatching systems, yet *POP* and $MILES^2$ are also valid instruments that should only influence changes in vertical integration through their correlation with $\Delta TECH$. Therefore, we specify the first stage of our 2SLS model as using model (3), which predicts the decision to adopt computerized dispatching, $\Delta TECH$, based on the three instruments *AVGTAXIS*, *POP*, and $MILES^2$ along with the controls $\boldsymbol{X_c}$ from the OLS regression model (1).

$$(3): \Delta TECH_i = a + \Gamma_1 AVGTAXIS_i + \Gamma_2 POP_i + \Gamma_3 MILES^2_i + \mathbf{X_{c,i}B_c} + e_i.$$

In the second stage of the 2SLS model, the fitted values from (3), $\Delta TECH\text{-}HAT$, replace the endogenous regressor $\Delta TECH$, to generate a prediction of the impact of technology adoption on fleet asset ownership that can be interpreted as causal as in (4).

$$(4): \Delta FOWN_i = \alpha + \beta \Delta TECH\text{-}HAT_i + \mathbf{X_{c,i}B_c} + \varepsilon_i.$$

Our instruments rely on market-level variation as we could not identify exogenous variables that might generate fleet-level variation in the incentive to adopt computerized dispatching systems that also satisfied the exclusion restriction for a valid instrument. Thus, our identification strategy is vulnerable to omitted variables that are correlated with both our market-level instruments and changes in asset ownership at the firm level. In particular, one may be concerned that independent owner-operators are more likely to contract with fleets in markets where *AVGTAXIS* is larger. If our firm and market controls do not capture heterogeneous firm-level effects in the behavior of independent owner operators that are correlated with *AVGTAXIS*, the exclusion restriction would be violated and the instrument would be invalid. However, given that the specification controls directly for time invariant firm-specific factors and time varying firm and market factors that are expected to influence shifts in the independent owner operator population's contracting behavior, we view the risks of omitted variable bias in the 2SLS set-up to be limited. Moreover, because the 244 fleets in our panel operate in 174 different local markets, we are not concerned that the instrument will fail to generate sufficient variation in the first stage.

5. Results

The central tests of the hypothesis are within-firm regressions on changes in the boundary of the firm, following the adoption of computerized dispatching systems. Table 4 shows the results of tests on the survey respondent set with no controls. The OLS (column 1) model demonstrates a strong unconditional correlation between adoption and increases in vertical integration as the fraction of vehicles that are fleet-owned, compared to driver-owned, increased by 12% in firms that adopted computerized dispatching systems compared to those that did not adopt. Propensity score matched and weighted results (column 2) that control for observable differences between firms are statistically indistinguishable from the unmatched OLS estimates.

While OLS and propensity score matched estimates are approximately equal to the raw difference in the change in means between adopters and non-adopters, point estimates of the adoption of computerized dispatching on asset ownership are larger when controlling for unobserved heterogeneity in the adoption decision. With an F-statistic of 8.2, the correct signs on the instruments and statistically significant t-statistics on two of the three instruments in the first stage of the 2SLS model (column 3) the instruments are strong, while the second stage of the 2SLS procedure generates a point estimate that is more than three times larger than the estimates in columns 1 and 2. Although the second stage estimate on adoption is much noisier from the OLS and propensity score matched estimates, the differences in the point estimates are marginally statistically significant at the 10% level. The interpretation of the 2SLS result is that if IT adoption were randomly assigned, the impact of Δ*TECH* on firm asset ownership would be larger than at firms that do (endogenously) adopt the technology. If the 2SLS inference is valid, the endogenous adoption of computerized dispatching biases the true impact of adoption on asset ownership toward zero.

The noisier point estimates generated by the 2SLS model might reflect the fact that the instruments vary at the market, but not the firm level, and, therefore, fail to pick up within-market variation in the computerized dispatching adoption decision, but could also imply that the 2SLS results are misestimated due to some important time-varying source of heterogeneity outside the model that is correlated with the instruments and asset ownership. To test the robustness of the empirical model, and, particularly, the validity of the 2SLS results, to specification we include additional controls in Table 5.

Table 5 includes firm and market-level controls that may influence changes in asset ownership. Several controls do appear to influence changes in vertical integration. As in Rawley and Simcoe (2009), we find that increasing diversification into limousines (*Δlog limousine capital*) leads to decreased vertical integration because firms replace non-owner taxicab drivers with more professional owner-operators to manage diseconomies of scope. Also, when firms grow their taxicab business quickly (*Δlog taxicab capital* ^{2}), they rely more heavily on attracting owner-operators, which leads to lower levels of firm ownership of taxicabs. While the inclusion of a number of controls explains a much larger proportion of the variance of changes in asset ownership (the R^2 jumps from 0.03 to 0.20 in the OLS specification), the magnitude and statistical significance of the results are nearly identical with controls as in the specifications without controls. The stability of the estimates on computerized technology adoption suggests that the effect is robust and that omitted variables bias is probably not severe in this context.

With controls, the 2SLS estimate of the impact of information technology on asset ownership is large and statistically significant, but the difference between the 2SLS and OLS point estimates ceases to be statistically significant. Unfortunately, we cannot be certain whether the lack of statistical significance on the difference in the coefficients is a result of effectively controlling for sources of firm-specific heterogeneity in our OLS specification, or if the result is being driven by the noise in the 2SLS estimate. The Durbin-Wu-Hausman test for the necessity of the instruments, in the presence of the full set of controls, was equivocal as it did not reject the hypothesis that the instruments are necessary only at the 10% level. A more pressing concern is that an F-statistic of 4.0 in first stage may indicate that the second stage results are being spuriously generated by the many weak instruments problem. To verify that the 2SLS results are not being driven by the many weak instruments problem, we re-estimated the 2SLS models using only our main instrument—lagged average size of other firms in the same market—and found the magnitude of the 2SLS estimates to be even larger (though noisier) and still statistically significant at the 5% level. We also tested for overidentification using Sargan's J-test and found that the J-statistic was significant at the 1% level. Overall the diagnostic tests on the instruments suggest that our instruments are valid and our identification strategy sound, though we cannot be certain that the OLS results are biased downward due to endogeneity.

We use two robustness checks to verify that our results are not being driven by non-response bias. First, since non-respondent ("unmatched") firms are smaller on average than firms in our test sample and the average adoption rate in the sample is 36%, most of the missing technology adoption data appears to be from firms that have not adopted computerized dispatching. Therefore, we treat all unmatched firms as non-adopters and re-run all of the OLS regressions, including these firms along with a dummy variable for unmatched firms. We find that the robustness check generates nearly identical estimates of the impact of adoption of computerized dispatching systems on asset ownership, suggesting that the effect of excluding the unmatched firms from our main analysis does not bias the results. Second, we re-run the tests, excluding small firms, with and without the unmatched firms using different definitions of small (e.g., more than 5 taxicabs, 10 taxicabs, 20 taxicabs) and find similar (though progressively nosier) results as with the larger set. We conclude that our results are not driven by non-response bias.

Taken together, the results show that the adoption of computerized dispatching leads to a 12% increase in fleet ownership of taxicabs. [14] The robust evidence supports the core hypothesis of the paper that the adoption of information technology leads to an increase in firm asset ownership when centralized information provided by information technology is a substitute for agents' industry-specific knowledge.

[14] As an additional robustness check, we ran all of our OLS models using a Tobit specification to account for the potential truncation of the dependent variable (at minus one and one). Perhaps because only twenty-two observations (10% of the sample) are truncated, fifteen left censored and seven right censored, all of the results are qualitatively identical in the Tobit specification. Results are available from the authors upon request.

6. Conclusion

This paper integrates insights from the literature on capabilities with the fundamental predictions of organizational economics to show how information technology influences asset ownership decisions. Consistent with the standard predictions of organizational economics, we assume asset-owners make investments in industry-specific human capital to increase the efficiency of their assets that are tantamount to skills or capabilities. We build on the assumption that asset-owners possess greater capabilities *ex ante* to propose that when managerial direction is a substitute for agents' industry-specific knowledge, information technology that reduces the costs of communicating information from the corporate center leads to increased firm asset ownership. Thus, firm IT capabilities crowd out agent knowledge-based capabilities, and the resulting de-skilling effect shifts ownership of assets toward firms.

We test this proposition in the context of the adoption of computerized dispatching systems in taxicab firms. Our main result shows that when taxicab firms adopt computerized dispatching systems, they shift toward owning 12% more of the vehicles in their fleet. The evidence supports the contention that information technology adoption leads to increased firm ownership of assets when the provision of centralized information is a substitute for agents' industry-specific knowledge.

This research has implications for research and practice alike. For organizational scholars, this paper provides a simple framework for integrating organizational economics and organizational capabilities, by analyzing how the substitutability of firm and agent capabilities influences the boundary of the firm. For managers, this research suggests that information technology adoption and vertical integration strategies should be jointly determined when IT impacts agents' performance heterogeneously.

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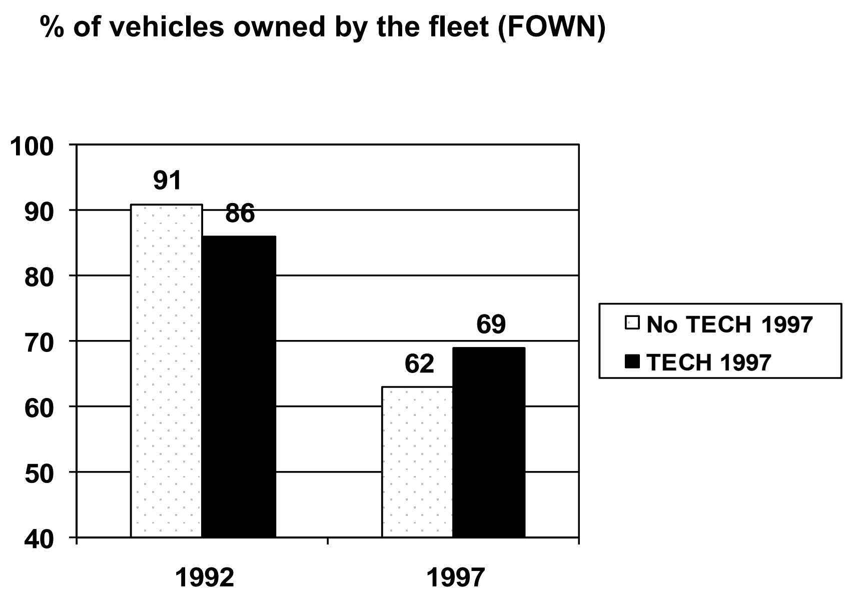
Figure 1 Extent of vertical integration for mobile information technology adopters and non-adopters before and after adoption

TECH 1997 (black bar) refers to firms that adopt mobile information technology between 1992 and 1997 (n=83 in both years), while No TECH 1997 (light bar) refers to firms that do not adopt computerized dispatching systems between 1992 and 1997 (n=161 in both years). Overall n=244 in both years.



The test sample includes firms that responded to at least one of the taxicab technology surveys (TCRP or author), could be matched to the Economic Census and meets all of the following sampling criteria: SIC code 4121 (taxicabs) in 1992, taxicab revenue ≥ $10K, and at least 2 taxicabs in both 1992 and 1997.

Table 1 Descriptive Statistics

n=244	1992		1997	
	Mean	Std dev	Mean	Std dev
Adoption of computerized dispatching	0.02	0.17	0.36	0.48
Fleet-owned taxicabs (share)	0.89	0.30	0.66	0.39
Total taxicabs	52	112	67	131
Fleet-owned taxicabs	46	110	45	112
Driver-owned taxicabs	6	29	22	72
Taxicab capital ($000)	546	1,321	864	1,887
Total limousines	0	0	7	17
Limousine capital ($000)	7	52	74	189
Taxicab revenue (000)	1,283	2,808	1,640	3,954
Corporation	0.84	0.38	0.84	0.39
Market fleet-owned taxicabs$_{-i}$ (share)	0.63	0.33	0.36	0.23
Taxicabs in the market	171	391	328	508
Limousines in the market	44	112	113	242
County population (000)	730	1,079	814	1,170
County square miles	1,018	1,455	1,038	1,594
All firms	Total 1992		Total 1997	
Taxicab revenue ($M)	521		669	
Number of taxicabs	20,014		29,960	
Number of fleet-owned taxicabs	16,426		18,303	
Number of fleets	1,020		1,106	

The test sample includes firms that responded to at least one of the taxicab technology surveys (TCRP or author), could be matched to the Economic Census and meets all of the following sampling criteria: SIC code 4121 (taxicabs) in 1992, taxicab revenue ≥ $10K, and at least 2 taxicabs in both 1992 and 1997.

"All firms" includes firms that meet the sampling criteria in at least one year (1992 or 1997).

Note that Census Bureau restrictions prohibit publication of minimum and maximum variable values.

Table 2 Size distribution of firms and dispatching technology adoption in the test sample

1992 fleet size	Number of firms by 1992 size category (count)	Average size by firm by 1992 size category (taxicabs per firm)	Percentage of firms adopting TECH 1992-1997
2 taxicabs	8	2	0%
3-4 taxicabs	32	4	19%
5-9 taxicabs	48	8	15%
10-24 taxicabs	59	16	25%
25-49 taxicabs	40	36	38%
≥ 50 taxicabs	57	164	70%
Total	244	52	34%

The test sample includes firms that responded to at least one of the taxicab technology surveys (TCRP or author), could be matched to the Economic Census and meets all of the following sampling criteria: SIC code 4121 (taxicabs) in 1992, taxicab revenue ≥ $10K, and at least 2 taxicabs in both 1992 and 1997.

Table 3 Selection equation predicting adoption of computerized dispatching systems

	Probit output			Means before and after matching					
	Coef.	∂y/∂u at **ū**		No TECH	TECH	t-stat on Δ	No TECH	TECH	t-stat on Δ
Total factor productivity	-0.30 (0.32	0.02 (0.03		0.05 (0.07)	0.10 (0.08)	-0.5	0.04 (0.07)	0.10 (0.08)	-0.6
Log total taxicabs	1.26 (0.36	0.15 (0.06	*	2.17 (0.10)	3.29 (0.20)	-5.6	2.24 (0.11)	3.29 (0.22)	-5.0
Log taxicab capital	-0.64 (0.21	-0.07 (0.05	*	4.23 (0.17)	5.39 (0.29)	-3.7	4.32 (0.18)	5.39 (0.29)	-3.3
Fleet owned taxicabs (share)	0.64 (0.40	0.64 (0.40		0.91 (0.02)	0.86 (0.04)	1.3	0.91 (0.02)	0.86 (0.04)	1.4
Log total taxicabs market	-0.11 (0.07	-0.27 (0.15		2.77 (0.18)	3.30 (0.26)	-1.7	2.76 (0.19)	3.30 (0.26)	-1.7
Log total limousines mrkt.$_{-i}$	0.04 (0.09	0.02 (0.02		1.98 (0.16)	2.35 (0.19)	-1.5	2.05 (0.17)	2.35 (0.19)	-1.1
Corporation indicator	-0.26 (0.45	-0.08 (0.06		0.81 (0.03)	0.88 (0.04)	-1.3	0.82 (0.03)	0.88 (0.04)	-1.2
Log county population	0.12 (0.14	0.04 (0.02		12.67 (0.10)	13.01 (0.14)	-2.0	12.71 (0.11)	13.01 (0.14)	-1.7
Log county miles^2	-0.12 (0.10	-0.04 (0.02		6.34 (0.09)	6.12 (0.17)	1.3	6.33 (0.09)	6.12 (0.17)	1.1
Urban indicator	0.16 (0.53	0.16 (0.53		0.11 (0.02)	0.18 (0.04)	-1.5	0.11 (0.03)	0.18 (0.04)	-1.4
Avg. taxicabs per firm market $_{-i}$	0.01 (0.00	0.04 (0.02	*	11.75 (1.47)	28.46 (4.50)	-4.4	11.08 (1.44)	28.46 (4.50)	-4.4
Urban x log total taxicabs	-0.15 (0.14	-0.02 (0.02		0.24 (0.07)	0.70 (0.19)	-2.7	0.27 (0.08)	0.70 (0.19)	-2.4
TFP x log total taxicabs	0.10 (0.10	0.03 (0.03		0.48 (0.17)	0.98 (0.29)	-1.6	0.45 (0.18)	0.98 (0.29)	-1.6
Corp x log total taxicabs	0.02 (0.17	0.02 (0.02		1.84 (0.12)	3.01 (0.22)	-5.2	1.94 (0.12)	3.01 (0.22)	-4.6
Constant		Y							
Pseudo R^2		0.21							

N	244	161	83		140	83	

* Significant at the 5% level

Table 4 Adoption of coordination technology and asset ownership: no controls

Dep. variable = Change in the % of vehicles in the fleet owned by the firm (ΔFOWN)						
	(1) OLS		(2) Matched		(3) 2SLS	
Adoption of computerized dispatching (TECH)	0.13	**	0.13	**	0.48	**
	(0.06)		(0.06)		(0.19)	
Constant	-0.29	***	-0.41	***	-0.40	***
	(0.04)		(0.05)		(0.07)	
R^2 / Psuedo-R^2	0.03		0.02		n/a	
N	244		223		244	
<u>2SLS 1st stage summary statistics</u>						
F-statistic					8.2	
t-statistic on avg. taxicabs/fleet in the market $_{-i}$					4.1	
t-statistic on log market population					2.2	
t-statistic on log market size (miles^2)					-1.0	
Adjusted R^2					0.08	

Standard errors are robust and clustered at the market (county) level.
The test sample includes firms that responded to at least one of the taxicab technology surveys (TCRP or author), could be matched to the Economic Census and meets all of the following sampling criteria: SIC code 4121 (taxicabs) in 1992, taxicab revenue ≥ $10K, and at least 2 taxicabs in both 1992 and 1997.
*** Significant at the 1% level, ** Significant at the 5% level, * Significant at the 10% level

Table 5 Adoption of coordination technology and asset ownership: controls

Dep. variable = Change in the % of vehicles in the fleet owned by the firm

	(1) OLS		(2) Matched		(3) 2SLS	
Adoption of computerized dispatching (TECH)	0.12	**	0.13	**	0.45	**
	(0.06)		(0.06)		(0.22)	
Δlog taxicab capital	0.05		0.04		0.06	
	(0.05)		(0.05)		(0.05)	
Δlog taxicab capital^2	-0.01	*	-0.01		-0.02	*
	(0.01)		(0.01)		(0.01)	
ΔFleet-owned taxicabs market$_{-i}$ (%)	0.04		-0.04		-0.00	
	(0.07)		(0.08)		(0.08)	
Δlog(taxicabs in the market$_{-i}$)	0.01		0.01		0.02	
	(0.02)		(0.02)		(0.02)	
Δlog(limousines in the market$_{-i}$)	0.02		0.03		0.03	
	(0.02)		(0.02)		(0.03)	
Δlog limousine capital	-0.04	**	-0.04	**	-0.02	
	(0.02)		(0.02)		(0.02)	
Δlog limousine capital^2	-0.01	*	-0.01	*	-0.01	**
	(0.00)		(0.00)		(0.00)	
Δlog county population	0.02	**	0.02	**	0.03	***
	(0.01)		(0.01)		(0.01)	
Constant	-0.14	***	-0.15	***	-0.27	***
	(0.05)		0.05		(0.10)	
R^2 /Psuedo-R^2	0.20		0.20		n/a	
N	244		223		244	
<u>2SLS 1st stage summary statistics</u>						
F-statistic					4.0	
t-statistic on avg. taxicabs/fleet in the market $_{-i}$					3.5	
t-statistic on log market population					2.4	
t-statistic on log market size (miles^2)					-1.5	
Adjusted R^2					0.12	

Standard errors are robust and clustered at the market (county) level.
The test sample includes firms that responded to at least one of the taxicab technology surveys (TCRP or author), could be matched to the Economic Census and meets all of the following sampling criteria: SIC code 4121 (taxicabs) in 1992, taxicab revenue ≥ $10K, and at least 2 taxicabs in both 1992 and 1997.
*** Significant at the 1% level, ** Significant at the 5% level, * Significant at the 10% level

Appendix: When does technology adoption lead to changes in asset ownership?

This appendix uses a simple model to show how technology adoption influences asset ownership when agents have industry-specific human capital. We assume that an agent's utility (*U*) depends on output (V), a cost paid to the firm (C) for the right to generate V using the firm's assets and technology resources, and disutility of effort (*t*):

$$U = V - C - t.$$

We further assume that output depends on asset ownership and (firm) technology adoption: $V = V(FOWN, TECH)$. Asset ownership is measured by an indicator *FOWN*, which equals one the asset is owned by the firm, and zero otherwise. Information technology adoption is represented by the indicator variable *TECH*.

Costs are also determined by asset ownership and agent productivity: C = C(FOWN, V). We assume that non-owners have no bargaining power, so firms set a rental fee that keeps them at their reservation utility, which we normalize to zero:

$$C(1, V) = V - t.$$

Owner-agents have an outside option—working independently—which is worth *x*. Because of their ability to work independently, these agents will only remit some fraction α of their output to the firm:

$$C(0, V) = \alpha[V - x].$$

Finally, we assume that firms stand ready to buy assets from owner-agents at a price that depends on the bargaining parameter Γ, $0 < \Gamma < 1$, and the difference in their earnings from contracting with asset owners relative to non-owners:

$$P = \Gamma[C(1, V(1,TECH)) - C(0,V(0,TECH))].$$

We now ask when technology adoption will lead to increased fleet ownership, focusing on the case where some agents made specific investments in industry-specific human capital in the pre-period.

First, consider an agent who has made an industry-specific investment in knowledge before the new technology arrives. The agent will prefer to own their asset if and only if:

$$U = V(0,0) - C(0,V(0,0)) - t > \Gamma[C(1, V(1,0)) - C(0,V(0,0))] = P \quad . \qquad \text{(A1)}$$

Once the new technology arrives, an agent-owner will sell their asset to a firm when:

$$U = V(0,1) - C(0,V(0,1)) - t < \Gamma[C(1, V(1,1)) - C(0,V(0,1))] = P \quad . \qquad \text{(A2)}$$

Subtracting (A2) from (A1), and substituting for C yields

$$(1 - \alpha + \Gamma\alpha)[V(0,0) - V(0,1)] > \Gamma[V(1,0) - V(1,1)].$$

To interpret this condition in terms of capabilities, note that it is equivalent to

$$[V(1,1) – V(1,0)] / [V(0,1) – V(0,0)] > (1 – \alpha + \alpha\Gamma)/ \Gamma. \qquad \text{(A3)}$$

The right side of (A3) depends only on the parties' relative bargaining power, and is always greater than or equal to one. In general, one can interpret this quantity as a threshold that captures the extent to which *TECH* must substitute for agent-owners' industry-specific knowledge before agent-owners will sell their assets to firms.

The left side of (A3) is greater than 1 if and only if *FOWN* and *TECH* are complements in the non-owners total output function V relative to any positive benefits owner-agents might receive from *TECH*. One can interpret this complementarity between technology adoption and non-owner agents in terms of capabilities. By increasing the firm's communication ability, technology adoption yields greater benefits to non-owners, who rely on centralized information to increase their output; while *TECH* reduces the relative value of agent-owners industry-specific knowledge. The result shows that given a productivity shock from information technology adoption that is "large enough" for non-owners relative to agent-owners, *TECH* leads to de-skilling and increased firm asset ownership.[15]

[15] Taken literally, (A3) suggests that if all owner-agents would make the same asset ownership decision once the firm adopts *TECH*. However, one might add a driver specific perturbation to the cost function to produce smooth changes in the probability of fleet ownership following technology adoption.