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How Do Mobile Information Technology Networks Affect Firm Strategy and Performance? Firm-Level Evidence from Taxicab Fleets

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How Do Mobile Information Technology Networks Affect Firm Strategy and Performance? Firm-Level Evidence from Taxicab Fleets[*]

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Abstract

This paper examines how the adoption of mobile information technology networks impact firm strategy and performance in the U.S. taxicab industry. Using a rich, novel firm-level data set from the Economic Census, I test transaction cost economics' prediction that adoption of mobile IT networks leads to shifts in the boundary of the firm toward increased fleet ownership of vehicles. I then exploit the homogeneity of the industry's production function and exogenous variation in local market conditions to precisely measure the impact of adoption of mobile IT networks on productivity. I find strong evidence that firms respond to adoption of mobile IT networks by changing their organizational structure, shifting toward owning a greater fraction of vehicles in their fleets (as opposed to contracting with independent driver-owners for vehicles). I then use a precise and economically meaningful measure of firm performance to show that adoption of mobile IT networks causes firms to become more productive. The results suggest that adoption of mobile IT networks increases asset utilization by improving within-firm coordination but that firms must simultaneously shift toward a more highly vertically integrated structure to fully capture the benefits of mobile IT networks.

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1. Introduction

Information technology (IT) networks are profoundly changing how firms coordinate production decisions within firms. This paper examines how the adoption of mobile IT networks affects firm strategy and impacts firm performance in the U.S. taxicab industry. Using a precise and economically meaningful measure of firm performance, I find evidence that adoption of mobile IT networks causes firms to become more productive than non-adopters. Moreover, consistent with the predictions of transaction cost economics (Williamson 1975 and 1985), firms respond to adoption of mobile IT networks by changing their organizational structure, shifting toward owning a greater fraction of vehicles in their fleets (as opposed to contracting with independent driver-owners for vehicles). The results suggest that adoption of mobile IT networks increases asset utilization by improving within-firm coordination but that firms must simultaneously shift toward a more highly vertically integrated structure to fully capture the benefits of mobile IT networks, although I cannot formally reject the null hypothesis that the asset utilization and asset ownership effects operate independently.

This paper addresses endogeneity issues in the relationship between adoption of mobile IT networks, firm productivity and asset ownership in two important ways. First, by linking mobile IT network adoption directly to firms, empirical tests that focus on within-firm changes in productivity and the boundary of the firm control for unobserved time-invariant characteristics of firms that may bias cross-sectional results. Second, because U.S. taxicab markets are geographically isolated from one another this paper essentially examines one-hundred and fifty distinct local markets. I exploit the exogenous variation in local market conditions using an instrumental variables approach to control for unobservable characteristics of firms that may be correlated with both adoption and productivity and/or the boundary of the firm. The instrument I deploy for adoption is lagged average fleet size of other fleets in the same market. The effect of lagged size of other fleets in the same market should be orthogonal to changes in "own" firm boundaries and productivity. However, lagged average fleet size may be correlated with adoption to the extent that markets with larger average fleet size are the kinds of markets where adoption is more likely to be prevalent.

I find strong evidence that adoption leads to higher rates of fleet ownership of vehicles and increases firm productivity. The results are consistent with transaction cost economics and suggest that there are complementarities between the adoption of mobile IT networks and fleet ownership of vehicles.

The rest of this document is organized as follows:

Section 2 explores the conceptual foundation for this paper and describes the related literature. Section 3 describes the institutional context in which mobile IT networks are used in the U.S. taxicab market. Section 4 develops explicit adoption and productivity hypotheses. Section 5 describes the data and the empirical strategy. Section 6 discusses the results. Section 7 concludes.

2. Conceptual framework and related literature

Mobile information technology networks are fundamentally altering how firms organize production. Given the rapid growth of mobile IT networks in the modern economy, gaining a deeper understanding of the relationship between the adoption of mobile IT networks, firm strategy and performance is of great importance. To address these questions the paper builds on and integrates contract theory and the empirical literatures on information technology and firm boundaries.

Understanding patterns of asset ownership has been a central issue in organizational economics since Coase (1937), who argued that firms should coordinate transactions internally only when doing so is more efficient than coordinating those activities through markets. Contract theorists extended and refined Coase's insight by highlighting the importance of contractual incompleteness in the presence of potential opportunism, in particular the problem of hold-up with respect to firm specific investments, in drawing the boundary of the firm (Williamson 1975, 1985; Klein, Crawford and Alchian 1978). When taxi fleets implement mobile IT networks they force independent owner-drivers, who could formerly contract with the fleet for generalized radio-based dispatching services, to choose between being excluded from the fleet's network or adopting specialized on board computers (OBC). OBC are usually incompatible with other fleets' dispatching systems and therefore cannot be easily redeployed. Thus, following the adoption of a mobile IT network, fleets and their pool of potential driver-owners face a joint investment decision over OBC that has the potential to fundamentally change their contracting relationship. As predicted by contract theory, which emphasizes the role of asset specificity in the vertical integration decision, adoption of mobile IT networks leads to a shift in the boundary of the firm toward fleet ownership of vehicles as fleets acquire independent owner-operators who do not wish to invest in OBC as non-integrated agents of the fleet.

While there are alternative theoretical lenses through which to view boundary of the firm questions besides transaction cost economics, the issues of incomplete contracting, hold-up and asset specificity are particularly salient in this context. Indeed, one of the contributions of this paper is its sharp theoretical focus on the role of transaction cost economics in the context of technological change. Given our expectation that mobile IT networks increase the efficiency of coordinating a network of distributed assets, and the fact that adoption of OBC is a firm-specific investment that cannot be easily redeployed to another firms mobile IT network, transaction cost economics should particularly well suited to render predictions about the effect of adoption on the boundary of the firm. By contrast, agency theory and the property-right theory of the firm rely on variation in incentives between employees and contractors (Grossman and Hart 1986), a notion that seems far less germane in an industry where high-powered incentives are nearly ubiquitous across ownership states. Since most taxi drivers are full residual claimants there is little room to consider the incentive changing effects of investments in mobile IT networks in taxicab fleets.

By integrating technological change into a transaction cost economics framework the paper builds on and extends the literature on information technology and firm strategy. While the theoretical implications of mobile IT networks on the boundary of the firm are relatively straightforward in this context, examining the empirical relationship between investments in mobile IT networks and firm strategy from a transaction cost economics perspective is an important step in developing our understanding of the strategic implications of mobile IT networks specifically and coordination technologies more generally. In a recent paper, Bartel, Ichniowski and Shaw (2005) find evidence that adoption of stand-alone information technology changes the organization of production in valve manufacturing firms. This paper considers similar questions but differs from theirs in that I consider the impact of the adoption of mobile IT networks on firm strategy and performance.

The two papers most closely related to this work, Hubbard (2003) and Baker and Hubbard (2003) study of the effect of OBC adoption on truck utilization and the boundary of trucking fleets. Hubbard (2003) finds evidence that OBC improves asset utilization and Baker and Hubbard (2003) find that incentive-improving features of OBC push the boundary of the firm toward driver-owned vehicles, while coordination-improving features of OBC pull the boundary of the firm back toward fleet-ownership. However, Baker and Hubbard (2003) could not link OBC adoption to fleets and therefore could not control for omitted variables that affect both the technology adoption decision and the boundary of the firm. This paper builds on Hubbard (2003) and Baker and Hubbard (2003) by examining within-firm changes in performance and the boundary of the firm, following the adoption of mobile IT networks. This distinction is important because unobserved heterogeneity amongst adopting and non-adopting biases cross-sectional analyses. By examining changes in productivity and the boundary of the firm within-firm, the empirical design controls for time-invariant characteristics of firms which may affect both adoption and performance and/or boundary of the firm decisions. I explicitly control for unobservable characteristics of firms that may bias the results using an instrumental variables (IV) approach that exploits the exogenous characteristics of the local markets in which taxicab fleets operate.

3. Institutional context

Taxi fleets began using computers during the 1970s, but fully automated data dispatch systems did not arrive until the early 1980s. Even then adoption of mobile IT networks, comprised of a central coordination and communication technology and specialized vehicle-level on-board computers, was limited to a handful of firms until the early to mid-1990s. These systems use a mobile data terminal installed in each vehicle. Basic mobile IT networks systems called "partially automated" systems require drivers to indicate their location by entering a zone number into the terminal and transmitting it to the computer, which organizes vehicles into queues for each zone. When a customer requests a ride, the computer determines the caller location using a built-in street directory and sends a message to a central dispatcher. More advanced systems called "fully automated" systems deploy in-car devices with two-way communication capability, allowing the back-end optimization algorithm to communicate directly with vehicles. These systems also automatically monitor pickup and drop-off actions, such as turning the meter on and off. The most advanced mobile IT networks are GPS-based, which eliminates the need for drivers to enter zone numbers and tracks a vehicle's exact location at all times.

Computerized dispatch greatly simplifies the coordination of large taxicab fleets. It can also end claims of dispatcher favoritism by drivers, end call stealing by other cab companies using radio scanners, and can simplify communication between dispatchers and foreign-born drivers. However, non-GPS-based systems do not verify the location of a cab and cannot prevent drivers from manipulating the dispatch system by misrepresenting their current status or location. Nevertheless, a 1993 case study of 16 fleets with an average of 300 cabs documented 50 to 60 percent reductions in dispatch time at an average cost of $1 million (Gilbert, Nalevanko and Stone, 1993). More advanced systems rely on in-car terminals with two-way communication ability. These in-car terminals are three to four times as expensive as one-way communication terminals. By contrast the back-end computing cost for a fully-automated system is only 50%-100% more expensive than the back-end computing cost for a partially automated system. Thus, economies of scale in purchasing are actually steeper for partially-automated systems than for fully-automated and GPS systems.

Besides strategic issues, local regulatory, competitive and unique geographic factors can influence the costs and benefits of installing computerized dispatching. Most of these factors are exogenous to the choices of taxi fleet operators and provide the natural experiment missing from many studies of technology adoption. Local regulations[1] can set retail prices, fix the number of permits or medallions, devise a permit allocation system (e.g., lottery or auction), set limits on 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

[1] Taxi regulation is usually promulgated at the city level. As of 1997 seven states used a uniform code to regulate taxis: Arkansas, Connecticut, Colorado, Delaware, Kentucky, New Mexico, Rhode Island. Kentucky has subsequently changed to city-level regulation.

changes, may also influence the adoption of automated dispatch systems by changing the benefits of adoption. Moreover, the unique geography of a city can influence the distribution of rides between dispatched fares and curbside hails. The paper exploits this natural variation in markets by using market-level instrumental variables to control for the endogenous nature of the adoption decision.

4. Hypotheses

The first hypothesis is derived directly from transaction cost economics' emphasis on hold-up and incomplete contracts, proposing that adoption of mobile IT networks leads to *changes* in the boundary of the firm toward more fleet ownership of networked assets:

> (H1) Adoption of mobile IT networks should lead to an increase in the fraction of vehicles that are owned by the fleet relative to those owned by drivers but operated by the fleet.

The "productivity paradox" in information technology (IT), the dearth of causal evidence connecting IT adoption and productivity, has been addressed empirically in a number of recent papers (Brynjolfsson and Hitt 1996, 2003; Hubbard 2003; Bartel, Ichniowski and Shaw 2005). However, only Athey and Stern (2002) have done so convincingly using mobile IT networks rather than traditional stand-alone IT. But mobile IT networks are unique and important in their own right, particularly because they directly shift the returns to activities that require coordination.[2] Because mobile IT networks improve coordination by bringing information to

[2] Baker and Hubbard (2003) point out that mobile IT networks can also have monitoring benefits. However, in this empirical context monitoring is far less important to taxicab fleets because drivers typically have very high powered incentives (e.g., they are full residual claimants) whether they own the

bear on resource allocation decisions across a networks of assets, the effect of mobile IT networks on productivity are fundamentally different from traditional stand-alone IT, which raises the productivity of isolated assets in ways that do not affect coordination directly. Thus this paper hypothesizes that there is a causal relationship between mobile IT network adoption and firm productivity, due to coordination benefits:

(H2) Adoption of a mobile IT network should increase firm productivity.

The relationship between productivity and coordination with respect to mobile IT networks speaks directly to the importance of assessing the impact of the adoption of mobile IT networks on productivity in conjunction with considerations of the boundary of the firm. Because contract theory predicts that adoption of mobile IT networks should exhibit positive dependency with changes in asset ownership for reasons of efficiency, this setting is a natural place to consider the empirical evidence in support of complementarities in the production function, in the sense of Milgrom and Roberts (1990). I expect that the marginal effect of mobile IT network adoption on productivity should be higher in the presence of larger shifts in the boundary of the firm toward centralized ownership:

(H3) The firm's production function should exhibit complementarities between adoption of mobile IT networks and increasing fleet ownership of vehicles.

While there is broad support for the hypothesis that complementarities between IT and organizational change are an important part of the productivity equation, there is relatively little evidence of specific business practices that increase the marginal returns to IT adoption. This

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taxicab or lease it from the firm. I shall therefore emphasize the coordination benefits inherent in mobile IT networks throughout the paper.

paper examines the complementarities question directly in an industrial context where the econometrician can directly observe both shifts in asset ownership and changes in productivity.

5. Data and Empirical Design

5.1 Data

The core dataset from this paper comes from the 1992 and 1997 Economic Census of Transportation and Warehousing firms (ECTW). The ECTW began tracking the private-for-hire industry in 1992 and has continued to track the industry every five years (2002 data has been collected but not yet released). The ECTW is a comprehensive dataset that includes every taxi firm in the United States with at least one employee (SIC code 412100): 3,184 in 1992 and 3,337 in 1997. I augment the standard ECTW data with the accompanying supplementary files on vehicle inventory and segment revenues. This micro-data is extremely valuable as it includes firm revenue, line of business revenue, number of taxis by ownership type (e.g., fleet-owned versus driver owned) and organizational form (e.g., partnership, cooperative etc.) which allows for a very precise measure of each firm's factor inputs and output. There are approximately 1,000 firms in the 1992 and 1997 ECTW with complete records, which comprise between 60-80% of the $2 billion PHV industry.[3] The ECTW does not, however, contain mobile IT network adoption information.

To generate the dataset used for this paper I merge technology adoption data from the Transit Cooperative Research Program (TCRP) and from my own supplemental survey with the ECTW data. The TCRP survey conducted by the Institute for Transportation Research and Education at

[3] 1,829 observations in 1992 and 1,719 observations in 1997 are considered incomplete and unusable because they do not contain the number of taxicabs in their fleet. This set is primarily administrative record (AR) observations – very small firms that the Economic Census does not actually survey but rather imputes values for.

North Carolina State University in conjunction with the International Taxicab and Livery Association and Multisystems, Inc. A report including summary statistics from the survey was published in 2002 under the title "TCRP Report 75: The Role of the Private-for-Hire Vehicle Industry in Public Transit" (1998). A survey questionnaire was mailed to 13,751 private-for-hire operators (taxi, limousine and other private transportation providers) identified from previous studies of which 1,691 were returned undeliverable. 677 operators responded to the survey, representing at least one fleet from each state. 363 taxi fleets completed all the fields of interest for the analyses in this paper including questions about dispatching technology, and number of vehicles by ownership type.[4] I augmented the TCRP survey with our own survey of the largest 2,000 taxicab operators in the Dun and Bradstreet national database of firms with taxicab SIC codes (e.g., 412100). 391 surveys were returned undeliverable and 403 firms responded with complete questionnaires (25% response rate). 272 of the firms that responded to the authors' survey began operations before 1997. I merged the 635 (363 TCRP observations and 272 author survey observations) technology observations with the 3,153 observations in the 1997 ECTW by zip code or county and firm size and generated 409 complete observations.[5] Of these 409 observations 532 were in both the 1992 and 1997 ECTW.

See Table 1 for summary statistics and Table 2 for correlations between key variables. It is interesting to note in Table 1 that the secular shift in the industry is *away* from fleet ownership of taxis toward driver ownership of taxis. Yet I predict the opposite in mobile information technology adopters, expecting a shift *toward* fleet ownership in these firms.

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

[5] The 226 unmatched observations were primarily very small firms that could not be matched precisely where there were multiple small fleets within a market and fleets that are in the technology survey data set but failed to report line of business revenue in the ECTW.

In addition to the quantitative data, I conducted 73 semi-structured interviews with city taxi regulators (37), fleet owners and mobile IT network technology vendors (26) and taxi drivers (10) focusing on the relationship between regulatory change, lateral entry and driver ownership. These interviews provided a wealth of insights and anecdotes that greatly facilitated hypothesis development for this paper.[6]

One of the key advantages of studying the taxicab industry is that it is comprised of hundreds of distinct independent local markets. The ECTW contains geographic information about firm location at the level of zip code, which allows us to take advantage of this natural source of variation in the industry. To do so, I attach additional geographic information such as population density, income per capita and regulatory information; group firms into markets; and create market-level variables that allow us to exploit the high degree of cross-sectional variation in the data by market.

A second important advantage of the taxi industry is that taxi prices are set by local regulation in every major market. This means that productivity regressions with market-level fixed effects capture differences in physical output per unit of input across firms rather than relying simply on revenue measures of output as most productivity studies do. A number of papers have demonstrated the perils of relying on deflated revenues to measure total factor productivity (TFP) including Klette and Griliches (1996), Katayama, Lu and Tybout (2003) and most recently Foster, Halitwanger and Syverson (2005), hereafter FHS, who find that prices and technical efficiency

[6] I are indebted to C.J. Christina (New Orleans, LA), Jason Diaz CEO of Taxipass (New York, NY), Thomas Drischler (Los Angeles, CA), John Hamilton (Portland, OR), Stan Faulwetter (San Jose, CA), Alfred La Gasse Executive Vice President of the Taxi Limousine and Paratransit Association (TLPA), Kimberly Lewis (Washington, D.C.) Joe Morra (Miami, FL), Marco Henry, President of Yellow Cab (Bloomfield, CT), John Perry (Mentor Engineering), David Reno (Boston, MA), Aubby Sherman (Detroit, MI), Doug Summers (Digital Dispatch Systems) and especially Craig Leisy (Seattle, WA) for so freely sharing with us the wealth of knowledge they have accumulated regarding the U.S. taxicab industry. I also wish to thank the hundreds of taxi company executives who responded to our written mail survey and to our requests for interviews at the TLPA conference in Boston, MA in 2006. I acknowledge excellent assistance from YooMin Hong, Elisa Wong and especially Stephanie Simos in conducting survey research.

tend to be inversely correlated. They conclude that, "previous work linking (revenue-based) productivity to survival has confounded the separate and opposing effects of technical efficiency and demand," an issue which this paper squarely addresses. FHS call physical output measures of technical efficiency TFPQ to differentiate it from traditional measures of TFP. This paper follows their notation by using TFPQ to represent the technical efficiency of the firm.

Empirical tests are supported by the relatively simple and homogenous production function in the taxicab industry, since simple production functions control for heterogeneous influences on factors of production and allow the econometrician to isolate the effects of unobserved organizational characteristics on observed productivity. This approach minimizes measurement error in the key reduced-form establishment-level productivity measure I employ, total factor productivity in quantities (TFPQ).

Following the standard approach for measuring plant (e.g., fleet) total factor productivity in quantities (TFPQ) for firm *i* at time *t* is computed as the log of its physical output *q* minus a weighted sum of its logged capital *k* and labor *l* inputs. That is,

$$(1)\ TFPQ_{it} = q_{it} - \alpha_{kt}k_{it} - \alpha_{lt}l_{it}$$

The key feature of (1) is that output is measured in physical units, rather than in dollars. When output is measured in dollars rather than in physical units, TFP measures are contaminated by price differences across firms. In this dataset we do not observe physical outputs or market prices, only revenues in dollars. However, we can easily recover TFPQ as a measure of physical output in this case by including a market fixed effect in a standard Cobb-Douglas production function, because market prices are fixed for all firms in a market. Market fixed effects have the added advantage of eliminating unobservable market level characteristics that influence returns. I compute TFPQ in each time period (e.g., at time t={1992,1997}) so that the market fixed effects can vary over time (see appendix I for TFPQ calculations).

5.2 Empirical specification and strategy

To measure the effect of adoption on changes in the dependent variables (total factor productivity, TFPQ; and fraction of vehicles owned by the fleet, FOWN) I first calculate changes in the dependent variables directs and use (2a) and (2b) to estimate the impact of lateral entry on changes in productivity and asset ownership patterns.

(2a) $\Delta TFPQ_i = \beta_{\Delta 0} + \beta_{\Delta T}\Delta TECH_i + \mathbf{X_{c1,i}\beta_{\Delta c}} + \varepsilon_{\Delta i}$

(2b) $\Delta FOWN_i = B_{\Delta 0} + B_{\Delta T}\Delta TECH_i + \mathbf{X_{c2,i}B_{\Delta c}} + e_{\Delta i}$

By taking differences in the dependent variables at the firm level equation (2a) and (2b) eliminate unobservable time-invariant firm characteristics that impact TFPQ. Computing firm-level differences directly is equivalent to using firm fixed effects when there are only two periods of observations and differences are taken in all of variables.[7] This approach yields a very precise measure of the impact of mobile IT networks on ΔTFPQ as the result controls for both time-varying market-level fixed effects and firm fixed effects. Asset ownership regressions are differenced at the firm level but not at the market-level. However, there is little reason to expect that market characteristics have much impact on changes in asset ownership. Indeed, including market level fixed effects or an additional control that accounts for the

[7] To generate the precise firm-fixed effects result I use (2a) and (2b) with differences in the variables computed directly and $\beta_{\Delta 0} = 0$. In the specifications reported in this paper I include $\beta_{\Delta 0}$ also include time-invariant factors in (2a) and (2b) as additional controls. The result is very precise measure of ΔTFPQ as it is constrained by time-varying market-level fixed effects and firm fixed effects.

rate of change in asset ownership in each market has little effect on the coefficient estimates.

Variables that could plausibly shift, directly or indirectly, the supply or demand structure of the local taxicab market are included in $\mathbf{X_{c,i}}$. Most controls are common to (2a) and (2b), they are: a controls for firms size, measured by changes in taxicabs under management[8]; log population in the market (county); log square miles in the market; and changes in the log of the number of taxis under management operated by competing fleets in the same market – a proxy the competitive dynamics of the firm's operating environment is. I include controls for organizational form in the asset ownership regressions (2b) since it is possible that different organizational forms face different shocks to their capital budgets, but unlikely that organizational form influences changes in productivity.

The main tests rely on within-firm changes specifications. In appendix II I show the results of cross-sectional tests on levels of total factor productivity (TFPQ) and asset ownership using:

$$\text{(3a) } TFPQ_{it} = \beta_0 + \beta_T TECH + \mathbf{X_{c1,it}\beta_c} + \varepsilon_{it}$$

$$\text{(3b) } FOWN_{it} = B_0 + B_T TECH + \mathbf{X_{c2,it}B_c} + e_{it}$$

In the ideal experiment I would randomly assign technology and factors of production to firms and observe how their TFPQ and asset ownership patterns changed relative to firms who did not adopt the technology. However, the decision to adopt a mobile IT network is an endogenous firm choice that may be influenced by unobserved factors that are also correlated with changes in

[8] Alternative measures of firm size like non-parametric measures of firm size generate very similar results. Since log taxi capital is used in the first stage of the total factor productivity regressions I do not use it again as a control in equation (2a).

TFPQ and asset ownership. I address the potential for selection bias in the technology adoption decision using an instrumental variables (IV) approach that exploits the high degree of variation in market characteristics in which taxi fleets operate. Specifically, I use lagged (e.g., 1992) average fleet size for other firms in the same market as an instrument for adoption.

Lagged size of other fleets in the same market should not cause "own firm" to adopt a mobile IT network or cause changes in "own firm" productivity or asset ownership. However, lagged average size of other fleets in the same market may be correlated with "own firm" adoption to the extent that "own firm" is operating in a market where exogenous characteristics of the market necessitate that firms are large on average and therefore tend to exhibit high demand for coordination. One might also expect that knowledge spillovers associated with operating in a market where other firms adopt mobile IT networks influence "own firm" adoption since "own firm" is more likely to be exposed to the benefits of mobile IT networks when their (large) competitors adopt it. Therefore, lagged average size of other firms in the same market should only be expected to have an effect on changes in "own firm" through its effect on "own firm" adoption of mobile IT networks.

6. Results and Analysis

The central tests of the first hypothesis are within-firm regressions on changes in the boundary of the firm following the adoption of mobile IT networks. Table 3 shows the results of the tests of this hypothesis. Column (1) demonstrates a strong unconditional correlation between adoption and increases in the fraction of vehicles that are fleet owned on the order of 15%. This result was replicated using firm fixed effects and a time dummy. The results are much larger (55%) when I instrument for adoption using lagged (e.g., 1992) average fleet size of other firms in the same market suggesting that true impact of mobile IT network adoption on the boundary of the firm is understated by the OLS regressions. The vastly different estimates from the OLS versus the 2SLS regressions reflect the fact that the average firm could only shift 12% of its taxi capacity toward driver ownership since the average firm owned 88% of its taxicabs in 1992 (see Table 1). Thus, the results suggests that firms would like to shift even more towards fleet ownership of vehicles, but that they are limited in their ability to do so by their initial conditions.

Column (3) includes firm and market-level controls that may influence changes in the boundary of the firm. The impact of mobile IT network adoption increases to 19% and is significant at the 1% level. IV estimates of the impact of adoption in column (4) conditional on a vector of controls are again strongly significant and three times larger suggesting that there are significant unobservable characteristics of firms that are correlated with both adoption and the boundary of the firm that are captured by lagged average fleet size of other fleets in the same market. The results are robust to alternative specifications: I tried using a number of alternative measures of firm size; a control for the average rate of change in fleet ownership rates by market; including non-respondents with a non-respondent dummy; and market-level fixed effects (not reported). Each of these alternative specifications and every combination of them yielded qualitatively similar results that continued to be statistically significant at the 5% level. The results are consistent with transaction cost economics' prediction that the adoption of mobile IT networks shifts the boundary of the firm toward vertical integration.

An alternative explanation for the pattern observed in Table 3 is that taxi drivers are budget constrained and cannot afford to invest in OBC. This might lead taxi drivers to sell their vehicles to a fleet when the fleet invests in mobile IT networks for reasons unrelated to efficiency. [9] In this view drivers may capture some of the surplus created by fleets' adoption of mobile IT networks by selling their vehicle to fleets that adopt the technology. Since our intuition, and the

[9] I thank Richard Langlois for suggesting this to us.

evidence presented in this paper, strongly suggests that vehicles with OBC are more valuable than those without, the budget constraints hypothesis is plausible. Although I use organizational form (cooperative, partnership and sole proprietorship) to proxy for budget constraints faced by the firm, the baseline tests do not account for budget constraints faced by drivers. I consider this alternative hypothesis by testing whether adopting fleets acquire more vehicles from independent drivers in markets where drivers are more likely to be financially constrained. Specifically, I use population density as a proxy for wealth constraints and then test to see if the interaction between adoption and population density impacts firm boundaries. Since permit prices should be correlated with population density, the cost of OBC should have a smaller marginal impact on a driver's resources in high density markets. To test the effect of driver budget constraints on changes in the boundary of the firm I simply add the term DENSITY x TECH to the regression in column (4). The coefficient on DENSITY x TECH operates in the direction expected but the effect is small (0.004 per 1,000 people per square mile) and insignificant (t=0.23), providing no evidence that wealth constraints have a significant impact on the change in firm boundaries.

Table 4 shows the main tests of the second hypothesis that adoption of mobile IT networks leads to improved productivity (TFPQ). Column (1) shows an economically meaningful and statistically significant correlation between adoption and changes in productivity suggesting adoption leads to a 15% improvement in productivity. I interpret changes in productivity in terms of real output per unit of input. In other words the adoption of mobile IT networks is correlated with as a 15% increase in ride-miles per taxicab. Of course, it is unlikely that firms would adopt mobile IT networks if they did not lead to increased levels of productivity so this result is hardly surprising. However, this same logic points out how difficult it is to interpret OLS coefficients as the causal effect of adoption on changes in productivity. Since unobserved heterogeneity in the usefulness of mobile IT networks to firms implies that only the firms most likely to benefit from the mobile IT networks are likely to adopt it. Therefore, I instrument for technology adoption using a 2SLS approach.

The point estimates are twice as large when I instrument for adoption in column (2), although the result is not statistically different from the OLS point estimate. Column (2) can be interpreted as showing that adoption of mobile IT networks *causes* taxicab ride-miles to increase by 33% relative to taxicabs in fleets that do not adopt mobile IT networks, although the standard error is much larger than in the univariate OLS regression in column (1).

Adding controls to the OLS regression (column 3) improves the precision of the estimate and increases the estimated magnitude of the effect to 20%. IV estimates of the effect of adoption on productivity conditional on the vector of controls are similar in magnitude to the unconditional estimates in column (2), although the result is on the margin of statistical significance. These results support the hypothesis that adoption of mobile IT networks increases firm productivity by improving asset utilization.

Taken together, Tables 3 and 4 provide evidence that adoption of mobile IT networks simultaneously leads to increased firm productivity and causes the boundary of the firm to shift toward vertical integration to allow firms to more fully capture the coordination benefits associated with the technology. I formally test for the existence of complementarities in the production function in Table 5 by interacting the change in the fraction of vehicles owned by the firm with adoption of mobile IT networks. In each of the specifications (with or without controls, on or off the common support of the distribution of firms that adopt or do not adopt mobile IT networks) I find no evidence of first-order complementarities in the production function. The point estimate on the interaction term cannot be measured reliably, and in the preferred specification the sign on the interaction term is *negative*, although it usually statistically insignificant or on the margin of significance. Alternative specifications flip the sign on the interaction term so that it operates in the direction expected but the result is never precisely estimated and (obviously) not robust to specification. Thus, I cannot reject that the adoption of mobile IT networks independently increases firm productivity and shift the boundary of the firm toward firm ownership of vehicles.

Cross-sectional results

The results of the effect of mobile IT network adoption on within-firm changes in productivity and the boundary of the firm support the hypotheses discussed above and are broadly consistent with the findings of Hubbard (2003) and Baker and Hubbard (2003). I also check whether our results change when I follow their methodology using repeated cross-sections instead of within firm changes. I report the results in appendix II. In the OLS regressions in Table A2 (columns 1 and 3) there is only a weak positive and statistically insignificant relationship between adoption and higher levels of fleet ownership of vehicles. However, the 2SLS results are large (on the order of 33-57%) and significant (columns 2 and 4) suggesting that adopters would have had substantially lower levels of fleet ownership had they not adopted mobile IT networks.

IT network adoption and TFPQ are positively correlated and strongly significant in the OLS regressions in Table A3 (columns 1 and 3). Adopters appear to be approximately 20-25% more productive than non-adopters. However, these results are not robust to 2SLS estimates (columns 2 and 4), which show similar magnitudes as the OLS regressions but with much larger standard errors.

In general, cross-sectional results should be interpreted cautiously as unobserved heterogeneity in pre-sample firm or market characteristics that are correlated with both adoption and the dependent variables of interest could bias the coefficient estimates. In this context, using lagged market-level instruments, the 2SLS cross-sectional results are broadly consistent with the 2SLS results of the regressions on within-firm changes. This implies that the effect of unobserved within-firm variation on the observed relationship between adoption and higher levels of TFPQ and fleet ownership of vehicles is not particularly important in this context, suggesting that lagged market-level instruments are sufficient to identify the effects of interest even in cross-section.

7. Conclusion

This central proposition of this paper is that the adoption of mobile IT networks leads to improved performance through improved coordination and increased vertical integration for transaction cost economizing reasons. By adopting mobile IT networks firms can better coordinate resources within the firm leading to improved asset utilization. By simultaneously vertically integrating, firms overcome haggling and hold-up costs associated with implementing mobile IT networks, which allows them to leverage the benefits of the technology across the firm. Although there is a rich theoretical basis for expecting such effects there has been little work testing these propositions empirically in the context of coordination technologies. This paper identifies within-firm effects of mobile IT network adoption on the boundary of the firm and performance rather than relying on potentially misleading results from repeated cross-sections as previous empirical work has done. The results suggest that adoption of mobile IT networks improves firm performance through improved coordination but requires the firm to shift toward an increasingly vertically integrated structure to fully capture the benefits of mobile IT networks, although I cannot formally reject the null hypothesis that the asset utilization and asset ownership effects operate independently.

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Table 1 – Descriptive Statistics

Panel A - Unbalanced Panel

Variable	N	1992 Mean	Std dev	N	1997 Mean	Std dev
TFPQ	229	0.64	1.41	409	0.26	0.82
Taxi revenue ($000)	229	1124	2713	409	1146	3147
Total taxis	229	44	93	409	51	107
Taxi capital ($000)	229	585	1355	409	634	1522
Fleet owned taxis	229	37	90	409	32	90
Driver owned taxis	229	7	30	409	19	59
TECH	229	0.00	0.00	409	0.28	0.45
Taxis in the county –i	229	129	340	409	262	512
Average 1992 fleet size - i	229	18	29	409	15	27
County population (000)	229	695	958	409	799	1322
County square miles	229	1054	1878	409	1164	1899
Sole proprietor	229	0.10	0.30	409	0.15	0.36
Partnership	229	0.01	0.09	409	0.03	0.18
Cooperative	229	0.05	0.21	409	0.03	0.17

Panel B - Balanced Panel

	N	1992 Mean	Std dev	N	1997 Mean	Std dev
TFPQ	166	0.29	0.71	166	0.39	0.76
Change in TFPQ	166	n/a	n/a	166	0.10	0.48
Taxi revenue ($000)	166	1417	3084	166	1855	4564
Total taxis	166	50	103	166	66	123
Taxi capital ($000)	166	683	1536	166	923	1995
Fleet owned taxis	166	44	103	166	50	121
Driver owned taxis	166	6	23	166	16	35
Change in fleet owned taxis (%)	166	n/a	n/a	166	-0.19	0.45
TECH	166	0.00	0.00	166	0.34	0.48
Taxis in the county -i	166	151	390	166	288	474
Average 1992 fleet size –i	166	20	31	166	20	31
County population (000)	166	711	1065	166	795	1157
County square miles	166	1100	1576	166	1094	1575
Sole proprietor	166	0.09	0.29	166	0.09	0.29
Partnership	166	0.01	0.11	166	0.02	0.13
Cooperative	166	0.04	0.20	166	0.04	0.20

63 firms of the 229 in the 1992 cross-section exited the industry after 1992 leaving 166 observations in the 1992 and 1997 panel. There are 243 entrants (between 1992 and 1997) in the 1997 Unbalanced Panel.

Table 2 – 1997 Balanced Panel Correlations (n=166)

	TFPQ	ΔTFPQ	Taxi rev.	Tot. taxis	Taxi K	FOWN%	ΔFOWN%
TFPQ	1						
ΔTFPQ	0.43	1					
Taxi rev.	0.45	0.23	1				
Tot. taxis	0.14	0.12	0.65	1			
Taxi K	0.15	0.16	0.67	0.98	1		
FOWN%	0.10	0.25	0.22	0.10	0.21	1	
ΔFOWN%	0.13	0.10	0.14	0.05	0.13	0.73	1
TECH	0.17	0.15	0.29	0.36	0.34	0.09	0.16
Fips $taxi_{-i}$	0.28	0.21	0.50	0.39	0.41	0.19	0.06
Avg. SZ_{-i}	0.09	0.12	0.19	0.18	0.21	0.21	0.22
Fips pop	0.05	0.09	0.32	0.49	0.51	0.17	0.11
Fips mi^2	0.37	0.13	0.49	0.08	0.10	0.11	0.11
Sole prop.	-0.09	-0.11	-0.10	-0.13	-0.12	-0.10	-0.13
P-ship	-0.07	-0.06	-0.04	-0.03	-0.03	0.02	-0.02
Coop.	0.10	0.07	0.02	-0.00	0.00	0.06	0.00

	TECH	Fips $taxi_{-i}$	Avg. SZ_{-i}	Fips pop	Fips mi^2	Sole prop.	P-ship
TECH	1						
Fips $taxi_{-i}$	0.00	1					
Avg. SZ_{-i}	0.38	0.11	1				
Fips pop	0.10	0.67	0.07	1			
Fips mi^2	0.04	0.40	0.06	0.23	1		
Sole prop.	-0.10	-0.09	-0.11	-0.15	0.09	1	
P-ship	-0.10	-0.05	-0.04	0.01	-0.04	-0.03	1
Coop.	0.04	0.08	0.01	0.18	0.07	-0.07	-0.03

Table 3: Adoption of mobile IT networks and the boundary of the firm
Within-firm changes 1992 – 1997

Dependent variable = Change in the fraction of fleet owned taxis (ΔFOWN)								
	(1)		(2)		(3)		(4)	
	OLS		2SLS		OLS		2SLS	
TECH	0.15	**	0.55	***	0.19	***	0.63	***
	(0.07)		(0.16)		(0.07)		(0.16)	
Change in taxis					-0.01	***	-0.01	***
					(0.00)		(0.00)	
Sole proprietor					-0.19	*	-0.15	
					(0.11)		(0.14)	
Partnership					-0.08		0.07	
					(0.17)		(0.18)	
Cooperative					-0.06		-0.11	
					(0.09)		(0.13)	
Change in log(taxis in the market -i)					0.02		0.03	
					(0.02)		(0.03)	
Log(population)					0.04		0.03	
					(0.03)		(0.03)	
Log(square miles)					0.02		0.03	
					(0.03)		(0.03)	
Constant	-0.24	***	-0.38	***	-0.81	**	-0.87	**
	(0.04)		(0.07)		(0.36)		(0.38)	
N	166		166		166		166	
R^2	0.02		n/a		0.20		n/a	

Standard errors are robust and clustered at the metropolitan statistical area level.
First-state results for regression (2) using lagged (1992) average fleet size in the same market as an instrument were: IV coefficient 0.006, standard error (0.001). F-stat = 28, Adjusted R^2 = 0.14.
First-state results for regression (4) using lagged (1992) average fleet size in the same market as an instrument were: IV coefficient 0.005, standard error (0.001). F-stat = 9, Adjusted R^2 = 0.15.
*** Significant at the 1% level, ** Significant at the 5% level, * Significant at the 10% level

Table 4: Adoption of mobile IT networks and productivity
Within-firm changes 1992 – 1997

Dependent variable = Change in TFPQ								
	(1)		(2)		(3)		(4)	
	OLS		2SLS		OLS		2SLS	
TECH	0.15	**	0.33	**	0.20	***	0.31	*
	(0.08)		(0.16)		(0.07)		(0.18)	
Change total vehicles					-0.00	***	-0.00	***
					(0.00)		(0.00)	
Change in log taxis in the market -i					0.01		0.01	
					(0.02)		(0.02)	
Log (population)					0.05	***	0.05	***
					(0.01)		(0.01)	
Log (square miles)					0.03		0.03	
					(0.03)		(0.03)	
Constant	0.05		-0.01		0.08		0.05	
	(0.05)		(0.07)		(0.05)		(0.08)	
N	166		166		166		166	
R^2	0.02		n/a		0.11		n/a	

Standard errors are robust and clustered at the metropolitan statistical area level.
First-state results for regression (2) using lagged (1992) average fleet size in the same market as an instrument were: IV coefficient 0.006, standard error (0.001). F-stat = 28, Adjusted R^2 = 0.14.
First-state results for regression (4) using lagged (1992) average fleet size in the same market as an instrument were: IV coefficient 0.005, standard error (0.001). F-stat = 9, Adjusted R^2 = 0.15.
*** Significant at the 1% level, ** Significant at the 5% level, * Significant at the 10% level

Table 5: Complementarities

Dependent variable = Change in TFPQ								
	(1)		(2)		(3)		(4)	
	OLS		Matched		OLS		Matched	
TECH	0.12	*	0.10		0.13	**	0.12	**
	(0.07)		(0.07)		(0.06)		(0.06)	
Change in the fraction of fleet owned taxis	0.10		0.09		0.05		0.05	
	(0.07)		(0.08)		(0.05)		(0.05)	
TECH x change in the fraction of fleet owned taxis	-0.10		-0.11		-0.15	*	-0.17	*
	(0.07)		(0.07)		(0.08)		(0.09)	
Change in log taxis in the market $_{-i}$					0.01		0.01	
					(0.02)		(0.02)	
Change in log (population)					0.03	**	0.02	**
					(0.01)		(0.01)	
Urban					-0.04		-0.04	
					(0.08)		(0.08)	
Constant	0.12	*	0.14	*	0.33	***	0.30	***
	(0.06)		(0.08)		(0.10)		(0.10)	
N	166		113		166		113	
R^2	0.05		0.04		0.14		0.13	

Standard errors are robust and clustered at the metropolitan statistical area level.
*** Significant at the 1% level, ** Significant at the 5% level, * Significant at the 10% level

Appendix I – Calculating total factor productivity in quantities (TFPQ)

To calculate TFPQ beginning with the information in (i):

(i) $p_m + q_{it} = \omega_{kt}k_{it} + \omega_{lt}l_{it} + TFP_{it}$

I wish to recover (1).

(1) $TFPQ_{it} = q_{it} - \alpha_{kt}k_{it} - \alpha_{lt}l_{it}$

If prices were known, I would just subtract p_m from (i). Since I do not observe p_m directly in the full data set I de-mean the data at the market level by including a market-level fixed effect, which eliminates p_m and transforms the standard TFPQ calculation in (i) into a market-adjusted measure of deviation from mean quantity produced conditional on deviation from mean input levels:

(ii) $TFP_{imt} = q_{it} - q_{mt} - \alpha_{kt}(k_{it} - k_{mt}) - \alpha_{lt}(l_{it} - l_{mt})$

Where (ii) is equivalent to (1) with the addition of market-level fixed effects.[10]

Equation (ii) generates y=TFPQ, a mean zero approximately normally distributed parameter. I show the results of these regressions in table A1 (below).

[10] Alternatively I can obtain (4) by starting with a Cobb-Douglas production function with market-level fixed effects and develop (4) directly. $P_{mt}Q_{it} = CL_{it}^{\alpha lt}K_{it}^{\alpha kt}\xi_{it}$, where $C=\exp(\alpha_{mt}m_{it})$. In logs, $p_{mt} + q_{it} = \alpha_{mt}m_{it} + \alpha_{kt}k_{it} + \alpha_{lt}l_{it} + \eta_{it}$. De-meaning at the market level, $p_{mt} + q_{it} = q_{mt} + p_{mt} + \alpha_{kt}(k_{it} - k_{mt}) + \alpha_{lt}(l_{it} - l_{mt}) + \varepsilon_{it}$. Where, $\varepsilon_{it} = \eta_{it} - \eta_{mt}$. Estimating the fitted values I find, $(p_{mt} + q_{it})$-hat $= q_{mt} + p_{mt} + \alpha_{kt}(k_{it} - k_{mt}) + \alpha_{lt}(l_{it} - l_{mt})$. I then calculate $TFP_{imt} \equiv p_{mt} + q_{it} - (p_{mt} + q_{it})$-hat $\equiv \varepsilon_{it}$. This is equivalent to (4).

Table A1 – Total factor productivity

Panel A – Total factor productivity (TFPQ) calculations				
	(1) Taxi only TFPQ		(2) Taxi only TFPQ	
Year	1992		1997	
Log capital	0.86	***	0.83	***
	(0.03)		(0.03)	
Constant	1.49	***	1.41	***
	(0.13)		(0.14)	
County fixed effects	200		223	
N	898		1106	
R^2	0.74		0.68	
Panel B – Summary statistics for TFPQ (panel A residuals)				
<u>TFPQ</u>				
Mean	0.00		0.00	
Std. deviation	0.69		0.79	

Standard errors are robust.
The results include all firms with SIC codes 412100 (taxicabs) or 411920 (limousines), taxi revenue ≥ \$10K, at least 2 taxicabs, and at least 2 taxi fleets in their market (county) in either 1992 or 1997.
*** significant at the 1% level, ** significant at the 5% level, * significant at the 10% level

Appendix II – Cross sectional results

Table A2: Adoption of mobile IT networks and the boundary of the firm 1997 cross-section

Dependent variable = % of taxis owned by the fleet

	(1)		(2)		(3)		(4)	
	OLS		2SLS		OLS		2SLS	
TECH	0.04		0.33	***	0.06		0.57	***
	(0.04)		(0.11)		(0.05)		(0.19)	
Total taxis					-0.00		-0.00	*
					(0.00)		(0.00)	
Sole proprietor					0.02		0.07	
					(0.06)		(0.06)	
Partnership					0.11	***	0.27	
					(0.03)		(0.10)	
Cooperative					0.14	***	-0.15	
					(0.03)		(0.14)	
Log(taxis in the market -i)					0.02		0.01	
					(0.01)		(0.01)	
Log(population)					-0.01		-0.03	
					(0.03)		(0.03)	
Log(square miles)					-0.01		0.04	*
					(0.02)		(0.02)	
Constant					0.60	**	0.58	**
					(0.26)		(0.28)	
N	409		409		409		409	
R^2	0.01		n/a		0.02		n/a	

Standard errors are robust.
First-state results for regression (2) using lagged (1992) average fleet size in the same market as an instrument were: IV coefficient 0.005, standard error (0.001). F-stat = 43, Adjusted R^2 = 0.10.
First-state results for regression (4) using lagged (1992) average fleet size in the same market as an instrument were: IV coefficient 0.004, standard error (0.001). F-stat = 13, Adjusted R^2 = 0.19.
*** Significant at the 1% level, ** Significant at the 5% level, * Significant at the 10% level

Table A3: Adoption of mobile IT networks and productivity
1997 cross-section

Dependent variable = TFPQ						
	(1)		(2)	(3)		(4)
	OLS		2SLS	OLS		2SLS
TECH	0.25	***	0.14	0.20	**	0.08
	(0.09)		(0.23)	(0.10)		(0.28)
Total vehicles				0.00		0.00
				(0.00)		(0.00)
Log(taxis in the market -i)				-0.02		-0.02
				(0.03)		(0.03)
Log(population)				0.06		0.07
				(0.05)		(0.05)
Log(square miles)				0.00		0.00
				(0.04)		(0.04)
Constant				-0.58		-0.62
				(0.49)		(0.48)
N	409		409	409		409
R^2	0.01		n/a	0.02		n/a

Standard errors are robust.
First-state results for regression (2) using lagged (1992) average fleet size in the same market as an instrument were: IV coefficient 0.005, standard error (0.001). F-stat = 43, Adjusted R^2 = 0.10.
First-state results for regression (4) using lagged (1992) average fleet size in the same market as an instrument were: IV coefficient 0.004, standard error (0.001). F-stat = 13, Adjusted R^2 = 0.19.
*** Significant at the 1% level, ** Significant at the 5% level, * Significant at the 10% level