WHY ARE PROCESS MONITORING TECHNOLOGIES VALUABLE? THE USE OF ON-BOARD INFORMATION TECHNOLOGY IN THE TRUCKING INDUSTRY

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ABSTRACT

Recent advances in information technology (IT) have enabled firms in many industries to give middle managers new access to timely production data. "Process monitoring" technologies give distant managers a window to production which can both lower their cost of monitoring subordinates and provide them better information toward allocating their firms' resources in the short term. This paper investigates where and why IT-based process monitoring is valuable within the trucking industry, distinguishing between its incentive- and coordination-related benefits. Using truck-level data, it examines how the use of on-board computers varies with characteristics of carriers, shippers, and hauls. It then analyzes these patterns in light of existing theory and relates them to how supply chains are organized.

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1. Introduction

Recent advances in information technology (IT) have led many firms to consider adopting "process monitoring" applications which give middle managers access to timely information about production. These can help managers make better short-run decisions concerning the allocation of their firms' resources and improve how they motivate workers.[1] Some middle managers in manufacturing now can monitor work at one or more production lines remotely and view up-to-the-minute inventory levels. Managers at package shipping companies such as Federal Express can view local demand conditions and resource utilization.[2] Process monitoring can even extend to intellectual output. Managers of research and development projects can monitor their teams' progress by using "groupware" applications such as Lotus Notes. The diffusion of these applications offers a new opportunity to investigate the role of information and the value of IT in organizations.

This paper is an empirical study of two broad questions. First, in what contexts is IT-based process monitoring valuable? Establishing this helps identify the information problems for which IT offers significant efficiencies over less IT-intensive systems, and those for which it does not. Second, where is it valuable primarily for improving workers' incentives, and where is it valuable primarily for improving managers' decisions? The distinction between the incentive- and coordination-related benefits of IT use is important because a general theme in economic theories of organizations is that whether delegation is a substitute or complement to improvements in managers' information depends on whose decision new information is used to improve.[3] Suppose delegation takes advantage of workers' better local information, but agency costs increase with the degree to which decisions are delegated. IT-based informational improvements would be complementary to delegation when they are only useful toward improving workers' incentives. They would be a substitute to delegation when they are only useful toward making managers' decisions better informed. Direct examination of

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[1]It can also improve longer-run decisions about regarding capital purchases, production planning, and the like, but that is outside of the scope of this paper.

[2]Bresnahan and Hubbard (1996) find this in interviews investigating commercial use of wide-area networking applications.

[3]See, for example, Jensen and Meckling (1992).

organizational change and tests of specific organization theories are outside the scope of this paper. But empirically distinguishing between situations where IT is mainly incentive-improving and coordination-improving can guide the application of different strands of organization theory.

I investigate these questions in the context of the trucking industry. This industry is a particularly good place to do so for two reasons. First, the recent diffusion of on-board IT is arguably the most important technological change in the industry since the 1960s, when many large carriers adopted their first computers. New process monitoring technologies offer the potential for significant efficiency gains in an economically important industry. Second, the general manner in which process monitoring can improve managers' and workers' short run decisions is conceptually simple and similar across firms. This is analytically convenient. Two important management problems trucking firms (or divisions) face are how to provide truck drivers incentives and how to coordinate hauls. Drivers can be difficult to monitor, and can potentially shirk in several ways. Among other things, they have discretion regarding how long and when they drive, how they operate their truck, and whether to report that their truck has been unloaded and is ready for another haul. Their choices may not be in the best interest of their firm or their firm's customers. Dispatchers must decide how to allocate their company's resources — trucks and drivers — to meet demand. Poor matches between trucks and hauls can mean that these resources are underutilized. Good information about trucks' location and operation can permit firms to provide drivers better incentives and allow dispatchers to allocate resources better. This can lower carriers' costs and permit them to offer shippers higher quality service.[4]

This paper examines the use of two types of on-board IT: trip recorders and electronic vehicle management systems (EVMS). Trip recorders chronicle trucks' operation. They record variables such as when drivers turn trucks on and off, how long trucks idle, trucks' speed over time, and when sudden accelerations or decelerations take place. When trucks return to their base, dispatchers can view the information trip recorders collect to verify drivers' performance. This can help carriers write more efficient contracts with drivers, shippers, and other interested parties such as insurers. Trip

[4]In this paper, "carriers" refers to firms or divisions which specialize in motor carriage and "shippers" refers to firms or divisions which send or receive cargo. When private fleets haul cargo, carriers and shippers are often divisions of the same firm.

recorders provide information which can result in improved incentives. However, the information they collect does not help dispatchers coordinate their fleets in the short run because it is only available once trucks return to their base.

EVMS are more advanced. They serve both as a data collection device and a communication terminal. Like trip recorders, they collect information about trucks' operation. Unlike trip recorders, EVMS record trucks' geographic location, and can transmit the data they collect to dispatchers via a land or satellite link in close to real time while trucks are on the road. They also permit data, and for some systems voice, communication between dispatchers and drivers while drivers are in their truck. The informational and communication capabilities of EVMS both can help align incentives and improve dispatch. Dispatchers can make better decisions when they have timely information about trucks' location and are able to contact drivers in their cab, even when they are outside of radio range.

The analytic framework is somewhat different from how others have examined the demand for technology. In most recent work, aggregate demand is derived from explicit models of potential buyers' adoption decisions.[5] This study diverges from this work because it applies an efficiency criterion, and bases economic inferences on how technologies are used in equilibrium. An efficiency-based framework takes advantage of and accommodates special features of the industry. It takes advantage of the interchangeability of truck-tractors across trailers, the presence of equipment leasing markets, and the fact that reallocating trucks across hauls involves very low adjustment costs. These features imply that in the short run, cost-minimization by individual firms and competitive output markets will promote the efficient allocation of different types of trucks across hauls and shippers, conditional on carriers' stock of trucks and carriers' and shippers' long run organizational decisions. In the medium run, competitive leasing markets and low demand uncertainty promote the efficient allocation of different types of trucks across carriers as well. An efficiency-based framework accommodates situations where truck owners do not appropriate all of the benefits from equipping their trucks with IT, and the fraction they appropriate varies across hauls, shippers, and carriers. It does so by allowing where different kinds of trucks are used to be based on the net benefits of all

[5]See, for example, Bresnahan and Greenstein (1997) and Trajtenberg (1989).

interested parties.

The empirical framework identifies factors which affect the net benefits of using IT-equipped trucks. The economic implications of trip recorder and EVMS use differ. Patterns of trip recorder use identify factors which affect the incentive-related benefits of IT-based process monitoring. Agency theory suggests that factors affecting differences in the incentive-related benefits would be related to the difficulty of measuring drivers' performance using alternative methods, the responsiveness of drivers to increases in performance incentives, and the incremental benefits (to carriers and shippers) of driver effort. This guides my interpretation of the data. I attribute patterns associated with differences in trucks' routes (for example, the length of their haul) to differences in measurement improvements. I attribute patterns associated with other variables, conditional on those associated with trucks' routes, to differences in the value of a given informational improvement.

Interpreting patterns of EVMS use is slightly different. EVMS subsumes trip recorders' informational capabilities. Thus, one would expect that factors which make trip recorders more valuable relative to using neither technology would also make EVMS more valuable. Where this is true empirically, one can conclude that part of the benefits from using EVMS are incentive-related, but one cannot determine whether these factors are also positively related to the coordination-related benefits from EVMS use. One can say more about the coordination-related benefits in other cases. Assume that any factor which affects the incentive-related benefits from using EVMS also affects those from using trip recorders.[6] Then factors which are positively related to EVMS use but not trip recorder use are those which increase the coordination-related benefits from using IT-equipped trucks. This paper uses *differences* in how and where trucks with trip recorders and EVMS are used to identify factors which affect the coordination-related benefits.

The data are from the Census' Truck Inventory and Use Survey (TIUS). The TIUS contains detailed information about the physical characteristics and use of about 40,000 truck-tractors during 1992.[7] Physical characteristics include the make, model year, and whether trip recorders and EVMS

[6]This assumption is relatively weak. It rules out cases where, for example, trip recorders offer absolutely no additional information about drivers' behavior relative to using neither trip recorders nor EVMS. It also rules out cases where information toward providing drivers better incentives is worthless unless it is obtained in real time.

[7]Truck-tractors are the front halves of tractor-trailer combinations. In this paper, I will use "truck" and "truck-tractor" interchangeably.

are installed. Variables which reflect use include how far from home trucks were generally operated, whether they were part of a private or for-hire fleet, and what products they generally hauled. The data do *not* contain variables which allow trucks' owners to be identified. This prevents the publicly-available Survey data from being merged with other data sets which contain more detailed firm-level information.

The main empirical results are from multinomial logits which explain whether trucks have trip recorders, EVMS, or neither. I find that trip recorders are more common on trucks which operate far from home than close to home. Among those which operate close to home, they are more common on trucks which tend to make fewer stops and which return to terminals only at the end of the day. Route structures which keep drivers close to home and require them to make frequent pick-ups and deliveries mean that carriers have good alternative means of evaluating drivers' performance. Even though local drivers work remotely by most standards, the incentive-related benefits from IT-based process monitoring are low. Trip recorders are more common on trucks which are refueled at trucking terminals than truck stops. This is inconsistent with the idea that relying on transaction reports from third parties is costly relative to using internal reports. Conditional on these routing variables, trip recorders are more likely to be used on trucks within private fleets than for-hire fleets, and on those used for contract rather than common carriage. They are relatively common on trucks used to haul dangerous goods, which deliver to loading docks, and which haul products for which sales/inventory ratios are high. I attribute these patterns to higher costs of delays or accidents. This may, in turn, reflect complementarities between IT-equipped trucks and the organization of logistics.

EVMS use shows similar patterns, but differs from trip recorder use in several ways. Among long-haul trucks, EVMS use increases with distance but trip recorder use does not. The benefits become increasingly coordination-related with distance. One explanation is that "backhauls" — return trips of outbound trucks — become more important and difficult to arrange. EVMS are more common on trucks in for-hire than private fleets, and on trucks used for common than contract carriage. When transactions are mediated by spot markets, the benefits are primarily coordination-related; when they are mediated by long-term contracts or internal arrangements, the benefits are more incentive-related. EVMS are relatively uncommon on trucks which haul chemicals or petroleum. The benefits from process monitoring are disproportionately incentive-related for chemical and petroleum hauls.

The outline of the rest of this paper follows. Section 2 describes the trucking industry, the internal structure of carriers, how trip recorders and EVMS can potentially provide drivers better incentives, and how EVMS can help dispatchers coordinate tasks. Section 3 presents the economic framework. Section 4 describes the empirical approach. Section 5 outlines the data. Section 6 presents estimation results and interprets them in light of the economic framework. Section 7 concludes.

2. The Trucking Industry

Industry Structure and Segmentation

The trucking industry is large and fragmented. Motor carriage accounts for about 5% of GDP. Slightly more than half of this is by trucks in private fleets — trucking divisions of firms whose main business is not in motor carriage. The rest is by trucks in for-hire trucking firms' fleets. There were more than 50,000 for-hire trucking firms in the United States in 1992.[8] These range in size from independent owner-operators with one tractor and trailer to large fleets with more than 5,000 tractors and 20,000 trailers. About 20% of for-hire trucks are driven by their owners; about half of these operate under a long term subcontracting agreement with a larger trucking firm. Nearly all geographic and product markets are served by many for-hire firms. Deregulation of interstate trucking over the past twenty years has removed entry barriers and encouraged competition. Full deregulation of intrastate for-hire carriage did not occur until 1995. Before then regulation probably created or helped maintain entry barriers and limited price or quality competition in some markets.[9]

For-hire carriers tend to specialize in the size of the loads they carry. One prominent segmentation of the industry is between truckload (TL) and less-than-truckload (LTL) carriage.[10] TL and LTL carriers are organized differently. LTL carriers use a hub and spoke system which resembles those used by most airlines. Pick up and delivery trucks haul cargo between shippers and terminals. Line haul trucks transport cargo between terminals. These operate on regular schedules. TL carriage

[8] Standards and Poor's Industry Reports, 1993.

[9] See Swan (1996) for background on the industry.

[10] "Truckload" refers to freight which weights more than 10,000 pounds. The capacity of most heavy duty tractor trailers is at least four times this.

is point-to-point. Trucks haul cargo directly from their origin to their destination. Schedules are usually irregular, particularly for long hauls. Short-haul TL trucks tend to make fewer stops at shippers per day than short-haul LTL trucks, in part because larger quantities are loaded and unloaded. Long-haul TL trucks' destinations are generally shippers; long-haul LTL trucks' are terminals. Efficiencies of consolidation lead to scale economies for LTL carriers. LTL carriers tend to be more highly unionized than TL carriers.

The terms of trade between for-hire carriers and shippers take two forms: contract and common carriage. Common carriage refers to situations where transactions between carriers and their shippers are mediated by short-term agreements or spot markets. Contract carriage refers to circumstances where transactions are mediated by longer-term agreements. These agreements often require carriers to dedicate part of their fleet to serve shippers' needs. The terms of trade offered by carriers within common carriage are available to all shippers; those within contract carriage are not.

The terms of trade implicitly or explicitly govern pickup and delivery times and stipulate what happens which such times are not met. Picking up and delivering on time is an important dimension of service quality. In some circumstances, late arrivals are costly. Loading docks are sometimes tightly scheduled — particularly when single loading docks are used to receive deliveries from several trucks during the day.[11] Late deliveries can disrupt logistics and production when supply chains maintain small inventories. In such circumstances, the terms of trade may impose financial penalties for late deliveries or require deliveries to be rescheduled at a time convenient to the shipper. Timing is less important when there is more slack, such as when loading docks receive goods from only a single truck per day, when deliveries are not made to a loading dock, or when inventories are large relative to sales.

Trucks and Technology

Although there are many other kinds of trucks (straight trucks, pick-ups, delivery vans, etc.) used for motor carriage, this study focuses on heavy duty truck-tractors. These may be attached to many different types of trailers. The most common is the familiar enclosed, non-refrigerated van. Others include flatbeds, refrigerated vans ("reefers"), open top vans, tank trucks, and car carriers.

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[11]Some warehouses require carriers to deliver within time windows as small as one-half hour.

Tractors are generally not specific to individual trailer types in the sense that there are standard interfaces.[12]

Active and competitive leasing markets exist for truck-tractors and various types of trailers in all but the smallest geographic markets. The length of these arrangements ranges from daily rentals to multiple year leases. A substantial fraction of trucks on the road are leased.[13] More than 25% of the truck-tractors in my sample were leased at some point during 1992. More than 80% of these were long-term leases covering at least one year.

Trip recorders and EVMS are aftermarket equipment which can be installed or removed from a truck in two hours or less, usually by a carrier's mechanic or an equipment dealer. These devices are not standard equipment on new truck-tractors. Low-end trip recorders cost roughly $500. EVMS hardware costs $3000-4500 per truck to buy or about $150/month for a long term lease. Trucks with these devices preinstalled are generally not available for short-term rental. They are widely available under long-term leases.

Although most of the discussion in this paper concerns the incentive- and coordination-related benefits of on-board IT, it also can simply reduce paperwork. Truck owners pay state highway taxes on a per-mile basis. Some trip recorders and EVMS enable electronic recording of when trucks cross state lines, and report miles driven within each state. This is a concern because trucks used for interstate carriage tend to operate farther from home than those used for intrastate carriage. IT may be more common on long-haul trucks than short-haul ones for reasons other than incentives or coordination. I investigate this by comparing the relationship between IT use and distance from home for trucks used exclusively for interstate and intrastate hauls. I find no evidence that the relationship differs.[14]

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[12]There are efficiencies in matching tractors to loads of appropriate weight. Some loads are too heavy for some tractors, and using a heavy duty tractor for a light haul sacrifices fuel efficiency. (Nickerson and Silverman (1996))

[13]Harrington (1995) states that during 1994, about 40% of all medium and heavy duty trucks were leased. Wittekind (1996) reports that almost half of motor carriers lease equipment without drivers and over 60% lease equipment with drivers.

[14]Using specifications analogous to those reported in section 6, I cannot reject the null that the parameters on interactions between the distance dummies and "interstate" and the interactions between the distance dummies and "intrastate" are statistically different from each other at any conventional significance level.

Internal Organization

In all but the smallest carriers, production-related tasks are divided between dispatchers and drivers. Dispatchers take orders from shippers, schedule pick ups and deliveries, assign drivers and trucks to hauls, and motivate drivers. When trucks' destination is far from home and return trips are not prearranged, dispatchers actively search for "backhauls" which prevent trucks from making long, empty return trips. Drivers operate trucks.

Incentives Within Carriers

Carriers provide dispatchers incentives to set schedules and assignments and motivate drivers so that the fleet's resources are utilized efficiently. Incentive conflicts between carriers and dispatchers are relatively unimportant. It is relatively easy to oversee and evaluate dispatchers because they work closely with their supervisors, often in the same room.

Incentive conflicts between carriers and drivers are more difficult to resolve. Drivers can be hard to evaluate because they work remotely. Drivers choose how long, when, and where they drive to maximize utility. Utility is in part a function of their income and effort, where effort is defined as acting in ways that carriers desire. Carriers' preferences are reflected by standards or guidelines which cover such things as how long drivers are expected to drive per day, the length and frequency of breaks, maximum highway speed, and what they should do with equipment while off duty. They also state when these guidelines may be breached. Drivers privately bear the cost of effort, but absent performance incentives they do not reap its benefits. They may thus choose to take long breaks, speed, not notify dispatchers when they finish a haul, or use equipment in unauthorized ways. One example of the latter is making unauthorized hauls ("milk runs"). This is costly to carriers even if done in off duty hours because it adds wear and tear to trucks and may require drivers to detach their trailer and store it temporarily, thus exposing the trailer and cargo to theft. It may also make drivers more fatigued while on duty.

Carriers provide drivers performance incentives through piece rates and job assignments. Generally, long haul drivers are paid piece rates; short haul drivers are not. Payment by the mile or by the haul encourages drivers to finish hauls quickly and to call in for new ones when they are finished. Dispatchers use job assignments to motivate drivers when using pecuniary incentives would be complicated or when union contracts or custom restricts their use. Drivers earn rents when they are assigned to desirable hauls. Hauls which take drivers into unsafe neighborhoods, force them to make many stops, take them far from home for long periods, or require them to carry heavy objects are undesirable. Firing drivers is more extreme and sometimes costly to carriers, but is used when departures from guidelines are particularly egregious.

Carriers base incentives on variables which reflect drivers' effort and decisions. These include the length and number of hauls, whether trucks reach their destination late, the number and severity of accidents, fuel consumption, trucks' physical condition, and so on. Dispatchers obtain information about drivers' effort from several sources other than drivers themselves. When trucks arrive at terminals, they can directly observe their arrival time, physical condition, and odometer reading. They can obtain information about how and when drivers operate trucks from trip recorders and EVMS, and where they operate them from EVMS. They may learn delivery times from shippers, particularly when drivers are unexpectedly late. They may learn when and where trucks refuel from internal records when they refuel at terminals, and from receipts or transaction reports when they refuel at truck stops.[15]

Coordination and Scheduling

Dispatchers arrange schedules and job assignments in a changing environment in which they are imperfectly informed. New orders come in throughout the day and unanticipated delays from traffic, crowded loading docks, mechanical problems, etc., can disrupt schedules. Dispatchers respond to changing conditions by adjusting schedules and rearranging assignments. Doing so is difficult when they have imprecise information about individual trucks' location and availability, and find it hard to communicate new assignments to drivers.

Obtaining good information about drivers' location and communicating new assignments has traditionally been much easier and less costly for local trucks than long distance trucks. Most local trucks make many stops during the day, and their approximate location is revealed by where they have and have not been. Drivers and dispatchers can communicate over private channels using two-way radios. The range of two-way radio communication is about 25 miles. When drivers are outside two-way radio range, carriers have traditionally relied on a check and call system in which drivers call in

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[15]Several debit card providers offer a popular service whereby carriers receive an itemized daily report of their drivers' transactions.

periodically from pay phones. Two important drawbacks of this system are that drivers have to stop trucks to communicate and dispatchers cannot initiate communication. This makes it difficult to quickly determine where individual trucks are and change drivers' schedules.

Recently, new means of communication have become available. Some firms use cellular telephones or paging systems for local communication as substitutes for radios. However, they are rarely used for long distance communication because of high "roaming charges." EVMS is another alternative, and may be particularly valuable for long-distance trucks, both because they inform dispatchers of trucks' location and because they allow dispatchers to communicate with drivers while they are in their truck.

Carriers' backoffice technology — computer hardware and software — helps dispatchers schedule and assign hauls. The systems used by different carriers to support dispatch differ widely. Many small firms still rely on paper-based systems. Larger fleets are more sophisticated. Many have systems which are PC-based; some of the largest ones have mainframes. Programs help dispatchers assign jobs and keep track of individual shipments' progress. Software and communications hardware can integrate EVMS with backoffice systems so dispatchers can have access to data in close to real time. EVMS and certain elements of backoffice technology may thus be complementary.

3. Economic Framework

The first part of this section outlines a model where the allocation of differently-equipped truck-tractors across hauls is efficient in the short run. The second part discusses how agency theory and decision theory suggest a similar classification toward interpreting differences in the value of information-improving devices.

The Use and Allocation of Trip Recorders and EVMS

Carriers make long-, medium-, and short-run decisions. What distinguishes these categories is the size of the adjustment costs involved in making changes. Long-run decisions include firms' hierarchies, investments in immovable physical capital such as terminals, investments in backoffice IT, and whether they pay drivers by the hour or by the mile. These decisions are fixed over long periods because adjustment costs from changing them are high. Carriers make medium- and short-run decisions taking them as given. Medium-run decisions are those for which adjustment costs are high enough so that firms do not change them from day to day, but may do so over the course of several months. These include how many trucks to own or lease long-term and how to equip them. Carriers make these decisions based on demand forecasts and anticipating how in expectation subsequent short-run decisions will be made. Short-run decisions are those which are made on a day-to-day basis. Each day, demand is realized and carriers choose (i) the quantities they supply for internal purposes and to outside shippers, and (ii) their input mix, taking their organizational characteristics and the composition of their owned fleet as given. Short-run "input mix" decisions include how many trucks (with or without drivers) to rent, and assignments of trucks and drivers to hauls.

Suppose trucks are homogeneous except in whether they have trip recorders or EVMS installed. There are therefore three types of trucks. Suppose carriers choose output levels and assign trucks to hauls to maximize profits. Profit maximization and the assumption that carriers are price-takers together imply that given each carrier's stock of trucks, the allocation of trucks across hauls and shippers will be efficient. If trucks could be costlessly reallocated across carriers or competitive rental markets existed for each type of truck and carriers rented their marginal trucks, one would obtain the stronger result that the allocation of trucks across carriers, hauls, and shippers in the short run would be efficient. However, neither of these conditions holds. Adjustment costs mean that there may be circumstances where an IT-equipped truck would be more valuable if it were used by a different carrier than the one actually using it.

From a medium-run perspective, the conditions necessary for the allocation of trucks across carriers to be efficient (conditional on the costs of adding or reallocating IT-equipped trucks in the short run) are more reasonable. Suppose carriers are price takers in the market for each of these different types of trucks. They anticipate how each truck in their fleet will be used and the net benefits of equipping individual trucks with trip recorders or EVMS from their forecasts of demand. If carriers correctly anticipate how each truck will be used, then the allocation of different types of trucks will be efficient from an *ex post* perspective. That is, given adjustment costs and knowing the realization of demand, there is no way of reallocating the different types of trucks across carriers, shippers, and hauls (at the time they decided) that would have produced as much value at lower cost.

Under these assumptions, trucks with trip recorders and EVMS will be used where their net benefits are highest. By specifying net benefits as a function of characteristics of carriers, hauls, and shippers, one can identify what factors make trip recorders and EVMS more or less valuable. These facts can be then used to explain what makes IT-based process monitoring valuable in trucking and why.

While these assumptions do not hold exactly in the present context, they are a fairly close approximation of what actually happens. Demand is realized each day, and carriers do dispatch trucks to fulfill each day's demand taking virtually all organizational decisions as fixed. Truck-tractors are heterogeneous in ways other than whether they have trip recorders or EVMS. But by restricting the study to heavy-duty truck-tractors, I am only examining the use of trip recorders and EVMS on vehicles which are largely interchangeable across hauls, trailers, carriers, and shippers. Adjustment costs from adding or subtracting IT-equipped trucks are positive, but do not differ much across carriers. Adjustment costs from reallocating different types of trucks across hauls or shippers are negligible. Although carriers may not correctly anticipate how individual trucks will be used, forecast errors are probably not large. Apart from daily fluctuations and (anticipated) seasonal variation, most firms face fairly consistent demand. They haul similar products similar distances from week to week and month to month.

The Value of Informational Improvements

There is a large literature on the theory of organizations. Theories within this literature seek to explain institutional characteristics such as contractual features, hierarchies, and the allocation of decision or property rights. They speak indirectly to the value of improved information within institutions. In general, informational improvements bring about more efficient decisions. The link between informational and decision improvements differs according to whether incentive conflicts are at the heart of the theory. However, one can classify the factors which affect the value of informational improvements similarly. This classification provides a useful guide when interpreting the data, regardless of whether on-board IT is valuable because it improves incentives or coordination.

Organization theories in which incentive conflicts are not an issue include "team theory" and many models used in operations research. Analysis of the value of information follows from decision theory.[16] In decision-theoretic models, individuals have incentives to make efficient decisions, but are uncertain about the true state of the world. Obtaining additional information can decrease or

[16]See Marschak and Radner (1972) for team theory; see Raiffa and Schlaifer (1961), Raiffa (1968), and DeGroot (1970) for expositions of basic decision theory.

eliminate uncertainty, but is costly. Differences in the benefits of additional information reflect (i) differences in how it changes individuals' beliefs about the state of the world, and (ii) holding constant changes in beliefs, differences in the value of any consequent changes in decisions.

Organization theories in which incentive conflicts are important draw from agency theory and contract theory. The link between informational and decision improvements is more subtle because information is used by individuals to improve others' decisions. Standard agency models illuminate this link.[17] In this class of models, a single risk-neutral principal observes a variable which is imperfectly correlated with a single risk-averse agent's choice of effort. Effort is costly to the agent, but increases the principal's welfare. In one version, the principal observes a performance measure which is the sum of the agent's effort and a random variable, neither of which are separately observable by the principal. The principal offers the agent a contract which is linear in the performance measure. Informational improvements allow the principal to construct a performance measure which has a higher correlation with the agent's effort. It then becomes efficient to provide the agent stronger performance incentives which, in turn, elicit more effort. The benefits of using a device which improves the principal's information are higher, the greater the informational improvement, the greater the responsiveness of agents' effort to changes in incentives, and the greater the incremental value of agents' effort. A similar logic applies to models in which agents allocate effort across different dimensions or tasks, and to situations where improved information increases the scope of variables upon which agents can contract.

This suggests a simple taxonomy of factors which affect the benefits of using information-improving devices. Regardless of the link between information and incentives, holding long run organizational features constant, the differences should reflect (i) the informational change the devices afford, (ii) the decision-maker's responsiveness to informational or contractual changes, and (iii) the magnitude of the efficiency improvement from changes in decisions. (i) is largely determined by the availability of information without the device. (ii) and (iii) together determine the incremental value of a given informational improvement. Applying this to the present context, I will attribute

[17]See, for example, Holmstrom (1979) and Grossman and Hart (1983). Milgrom and Roberts (1992) provide a simple textbook version which is closest to this discussion. See Holmstrom and Milgrom (1987) for the optimality of linear performance incentives, Holmstrom and Milgrom (1991, 1994) for analyses of multitask agency problems, and Baker (1992) for the effect of increasing the scope of contractible variables.

differences in the use of trip recorders and EVMS associated with some variables — mainly those associated with differences in trucks' routes — to differences in the informational improvement they bring about. I will attribute differences associated with other variables — variables unlikely to be associated with differences in informational improvements, given the routing variables — to differences in the incremental value of a given informational improvement.

4. Empirical Framework

The empirical framework consists of a system which describes the equilibrium use of trip recorders and EVMS. Let y_1* be the net benefit of using a truck with a trip recorder; let y_2* be the net benefit of using one with EVMS. Let y_0* be the net benefit of using a truck without either. These net benefits are calculated across all interested parties: carriers, shippers, and drivers. Let:

$$y_i^* = X\beta_i + \varepsilon_i$$

In the basic specification, X includes organizational characteristics of the carrier and shipper and variables which describe the use of the truck. Normalizing β_0 to zero and assuming that ε_i are independently and identically distributed and orthogonal to X, one can estimate the parameter vectors β_1 and β_2 with a multinomial logit.

Assuming that the error terms are i.i.d. implies that the impact of unobserved (to the econometrician) factors is uncorrelated across choices. This may not be true. Such factors may make using both trip recorders and EVMS more likely relative to using neither; or may make using neither and using trip recorders both more likely than using EVMS. One can relax this assumption by allowing the error terms to be correlated across choices in nested logit models. To date, I have found no evidence that such models would fit the data better.[18]

This specification implicitly restricts trucks to be homogeneous except with respect to their information technology. However, the value of certain other characteristics, such as reliability, may

[18]I have attempted to estimate versions of this model which nest the trip recorder and EVMS branches. Using maximum likelihood, I have been unable to improve the likelihood function over the multinomial logit. Using results from two-step methods, one cannot reject the multinomial logit model in favor of the nested version in specifications like those reported here.

differ across hauls as well. This can present problems if vehicle age is correlated with whether trucks are IT-equipped. Patterns in where IT-equipped trucks are used may reflect differences in the value of using newer, more reliable, trucks rather than the value of the IT itself. One way of addressing this would be to permit the data to jointly explain where new and IT-equipped trucks tend to be used. I take a simpler approach. I run the basic specification above on subsamples of old and new trucks. If the results using the full sample reflect differences in the value of using more reliable trucks, patterns in the use of IT-equipped trucks should differ across the subsamples. If similar patterns appear within the old and new subsamples, this supports the interpretation that the patterns reflect differences in the value of the IT.

The orthogonality restriction implies that conditional on the included right hand side variables, carrier characteristics which affect the value of using IT-equipped trucks are independent of the included variables. One important unobserved firm characteristic is their investment in backoffice IT. This restriction implies that differences in backoffice IT investments among carriers of similar size are uncorrelated with what their fleets haul. I check whether unobserved firm characteristics of this sort are affecting the results in the following manner. I run the basic specification including and excluding the fleet size dummies. If bias results because of differences in backoffice IT investments within fleet size categories, omitting the fleet size dummies should induce bias as well. The patterns in the coefficients should change. Finding that they do not implies that it is unlikely that any unobserved firm characteristic which is strongly correlated with fleet size is inducing bias in the basic specification.

Differences in the benefits of using on-board IT reflect differences in the informational improvement they offer and differences in the value of driver effort or improved coordination. Substitute methods for measuring drivers' effort are generally based on carriers' direct observation of drivers and their trucks, and possibly also information obtained from transaction reports and shippers. The effectiveness of substitute methods may thus vary with how frequently trucks stop at terminals, and if information from third parties is of value, how frequently they make pick-ups and deliveries. If information from shippers is not valuable for evaluating drivers (perhaps because it is not verifiable or is costly to process), the informational improvement trip recorders offer would not differ between short-haul TL and LTL trucks, and would grow more rapidly with distance for TL than

LTL trucks. Similarly, if information from transaction reports is less valuable than internal reports, trip recorders use should be higher for trucks refueled at truck stops than terminals. Substitute methods may be less effective for coordinating long-haul trucks than short-haul trucks because two way radios and pagers are feasible and economical when trucks are close to terminals, but not when they are far. Patterns in EVMS use may reflect this.

Holding constant where trucks operate and how frequently and where they stop, other variables are unlikely to be associated with differences in informational improvements. If the data indicate that they are associated with differences in the benefits of using on-board IT, conditional on the routing variables, this indicates differences in the value of driver effort (or, equivalently, the cost of driver shirking) or differences in the value of improved coordination. These, in turn, may be attributable to differences in the costs associated with delays, accidents, or miscommunication. Delays or accidents may be more costly when cargo is dangerous or perishable. Along with miscommunication, they may be more costly when shippers organize logistics or production in ways that are sensitive to the timing of shipments or deliveries.

The empirical framework aims to identify which factors matter, and why. Unfortunately, it provides far less power in identifying factors which influence the coordination-related benefits than those which influence the incentive-related benefits. It cannot identify factors which correspond to differences in the coordination-related benefits if they push the incentive-related benefits in the same direction.

5. Data

The data are taken from the Census Bureau's 1992 Truck Inventory and Use Survey (TIUS). This is a mail survey sent to about 150,000 truck owners; these are selected at random from truck, van, and truck-tractor registrations from state motor vehicle departments. Truck owners are required by law to respond. This paper uses only observations of truck-tractors (N=39,850).

The Survey collects data on the attributes of individual truck-tractors — both their characteristics as they were built and any after-market equipment. These include the make, model year, engine size, number of axles, gross vehicle weight, and many other variables. It also collects variables which reflect how they are used. These include miles driven, what type of trailers are commonly attached, what commodities they haul, how far from home they commonly operate, whether they are used for contract or common carriage, and where they are refueled and maintained. It contains some information about trucks' owners, including the size of the fleet of which they are part. Due to confidentiality restrictions, however, one cannot identify individual trucks' owners.

The Survey also asks whether trucks have trip recorders and EVMS installed. In some cases, respondents recorded that both were installed. This paper assumes that EVMS contain all of the capabilities of trip recorders. In what follows, I treat circumstances where respondents indicate "both" the same as where they indicate "EVMS only."

Sample Means and Cross-Tabulations

From Table 1, 7.5% of trucks in my sample have trip recorders installed; 10.5% have EVMS installed.[19] The fraction of trucks with on-board IT installed is much higher for recent vintages than earlier ones. In 1992, nearly 50% of model year 1992-3 tractor-trailers had some form of IT installed. This IT was disproportionately EVMS. In contrast, only 8% of pre-1987 trucks had some form of IT installed, and it was disproportionately trip recorders. IT is more common on trucks in large fleets than small ones, and the IT is disproportionately EVMS in large fleets. IT is more common on trucks used for long hauls than short ones. The relationship between length of haul and EVMS use is particularly strong. Trip recorder use is actually lower for trucks used for hauls greater than 500 miles than those used for hauls between 100-500 miles. Both devices are more common on trucks used for TL carriage than LTL carriage. The difference is larger for EVMS. Both are more common on trucks which are refueled at private fueling facilities than truck stops. The difference is larger for trip recorders.

Table 2 presents cross-tabulations with respect to variables which, conditional on those in Table 1, are unlikely to be associated with differences in the information that systems which do not rely on on-board IT provide dispatchers. Trip recorders are more common on trucks in private than for-hire fleets. Within for-hire fleets, they are much more common on trucks driven by company drivers than owner-operators working as subcontractors or as independents. They are more common on trucks used for contract than common carriage. EVMS are more common on trucks operated by company drivers than owner-operators. This is the same as with trip recorders. However, EVMS are

[19]All sample means, cross-tabulations, and estimation results use the expansion factors provided by the census as weights. The Survey oversamples trucks in small states and undersamples them in large ones.

more common on trucks within for-hire firms' fleets than private fleets, and are more common on trucks used for common carriage than contract carriage. This suggests that the benefits of process monitoring are disproportionately coordination-related when relationships between carriers and shippers are more arm's-length.

Trip recorders are most common on trucks with tank trucks or refrigerated vans as trailers. They are relatively common on trucks which haul processed food, chemicals, and petroleum, and relatively uncommon on trucks which haul farm products, logs, animals, and machinery. EVMS are most common on trucks trailing refrigerated and non-refrigerated vans. Like trip recorders, they are relatively common on trucks hauling processed food, but they are also common on those hauling paper products and transportation equipment. In general, they are more common on trucks hauling manufactured outputs (food, wood, paper, mixed cargo, transportation equipment) than inputs (raw agricultural products, building materials, logs).

6. Estimation Results

Table 3 contains results from the basic specification. The dependent variable is whether the truck has a trip recorder, EVMS, or neither installed. The left side of the panel contains the estimates for the trip recorder branch; the right side contains those for the EVMS branch. The "neither" branch is normalized to zero. The omitted product type dummy is "mixed cargo."

Routing Variables

The distance from home coefficients and probability derivatives tell the same story as Table 1, except trip recorder use flattens out rather than declines after 100 miles. Holding all other variables at their sample means, moving from a local to a long distance truck increases the probability trucks have trip recorders from .03 to about .07 — more than double. Process monitoring improves carriers' ability to evaluate long-haul drivers more than short-haul drivers. Moving from a local to a long-distance truck increases the probability trucks have EVMS even more dramatically. Trucks which operate more than 500 miles from home are 13.5 percentage points more likely to have EVMS than those which operate less than 50 miles from home. They are 9.4 percentage points more likely to have them than those which operate 100-200 miles from home. Combined with the result that trip recorder use flattens out after 100 miles, this implies the benefits of process monitoring become increasingly coordination-related with distance among trucks which tend not to return home at the end of the day.

The results do not indicate that information obtained via third parties is not reliable for the purposes of evaluating drivers. Several patterns provide evidence. One is that both trip recorders and EVMS are more common on trucks which are refueled at private facilities than at truck stops. This is inconsistent with the hypothesis that incentive-related benefits are higher when trucks refuel at places other than terminals. This pattern may reflect that the benefits from trip recorder use are highest when the data can be collected and processed quickly. Timeliness may enhance the value of using trip recorders to motivate drivers, or enable carriers to analyze and repair engines at early stages. Other patterns suggest that how frequently trucks stop at shippers affects the value of using trip recorders. Table 4 contains selected coefficients and estimated use probabilities from a specification which interacts "long haul" with LTL, TL, and private dummies. "Long haul" equals one for trucks which operate more than 100 miles from home, and zero otherwise. Among trucks which operate close to home, trip recorders are much more common on TL trucks than LTL trucks. As distance from home increases, trip recorder use increases for LTL trucks much more than TL trucks.[20] Combined, this is inconsistent with the hypothesis that only the frequency of stops at terminals, not at shippers, affects the incentive-related benefits.

Integration Variables

From Table 3, trip recorders and EVMS are more common on trucks in private than for hire fleets, controlling for fleet size, area of operation, and fueling site. That EVMS are more common was not apparent in the cross-tabulations. They are uncommon on trucks driven by owner-operators. Trip recorders are more common on trucks used for contract carriage or to haul "exempt" goods than common carriage, but EVMS are less common. Moving from common to contract carriage increases the probability trucks have trip recorders by about one percentage point and decreases the probability they have EVMS by about one percentage point, holding all other variables at their sample means. Applying the overall use rates of 7.5% and 10.5% as a base, trip recorders are 16% more common and EVMS are 11% less common on trucks used for contract carriage than common carriage. A similar pattern appears in Table 4. Most hauls by private fleets are truckload-sized. Among both long and

[20]The probability derivative for TL trucks is .006, and not significantly different from zero using a two-tailed t-test of size .05. That for LTL trucks is .052, and significantly different from zero.

short haul trucks, EVMS are more valuable on TL trucks than on those in private fleets, but trip recorders are not.

The incentive-related benefits from process monitoring are higher for trucks in private fleets than for-hire fleets and for trucks used in contract rather than common carriage. One interpretation of this has to do with differences in the cost of driver shirking. Longer-term or vertical relationships between carriers and shippers may be associated with other differences in organizational structure which make driver shirking (or shipping delays in general) particularly costly. One possibility is that it reflects lower inventory levels, but it could reflect any practices or organizational features which tend to make shipments more time-sensitive. The nature of the benefits from IT-based process monitoring differ according to how transactions between carriers and shippers are mediated. They are disproportionately incentive-related for internal transactions, and disproportionately coordination-related for market transactions. Similarly, among market transactions, the benefits are disproportionately coordination-related within common carriage relative to contract carriage. One interpretation of these patterns is that they reflect differences in the regularity or consistency of transactions. When transactions are regular and consistent, carriers and shippers may be able to anticipate when trucks will arrive fairly well and assign trucks to hauls relatively efficiently without IT-based process monitoring. When they are irregular, IT-based process monitoring offers greater coordination improvements. Such improvements may take place both within and between transacting firms.

Product Dummies

Trip recorders are more common on trucks used to haul processed food, paper products, chemicals, and petroleum than on those used to haul mixed cargo. The incentive-related benefits from using on-board IT are high for trucks hauling these goods. Accidents involving trucks hauling chemicals or petroleum can be particularly costly. Trip recorders both serve to improve drivers' incentives and help determine who is at fault if an accident occurs. The high use for trucks hauling processed food and paper products compared to that for trucks hauling farm products, live animals, logs, and wood products implies that the incentive-related benefits of process monitoring may be systematically higher for trucks which haul goods further down these supply chains. This may be because of differences in goods' value, or differences in how deliveries and inventories are managed.

EVMS are more common on trucks hauling processed food, wood, paper products, petroleum, and transportation equipment than on trucks hauling mixed cargo. Transportation equipment includes vehicles and parts. This indicates that the gains from process monitoring are disproportionately incentive-related for trucks hauling chemicals and petroleum. They are disproportionately coordination-related for trucks hauling transportation equipment. This may reflect how transactions between auto assemblers and shippers are organized. Assemblers maintain low inventories and logistics are managed tightly. Late deliveries are very disruptive. Shippers and carriers face large fines — reportedly as large as $15,000 per minute — for late deliveries. This provides them very strong incentives to deliver on time. Long-run decisions concerning the organization and incentives within these transactions make the coordination-related benefits from using EVMS high in the short run.

Cross-product patterns thus suggest that differences in goods' value or how logistics are organized affect the benefits of process monitoring. However, the TIUS data do not contain information on the value of goods hauled by individual trucks or organizational characteristics of individual shippers or receivers. In a later section, I incorporate outside data to provide further evidence regarding what the cross-product patterns mean.

Robustness Checks

Table 5 contains results for recent and non-recent vintages of trucks.[21] This investigates whether the results from the basic specification reflect vintage effects. Use patterns associated with variables other than the product dummies are similar. Some of the cross-product patterns do differ. The most striking difference is that trip recorder and EVMS use is high for paper-hauling trucks of recent vintages but not older ones. The high use rate of these devices on paper-hauling trucks may reflect the value of using new trucks rather than IT-equipped trucks. EVMS use on petroleum-hauling trucks generally only extends to newer vintages. This strengthens the result that the benefits of process monitoring on these trucks are primarily incentive-related. EVMS use is only relatively high for transportation equipment-hauling trucks of older vintages. High EVMS use on such trucks in the full sample does not reflect higher valuation of using new trucks.

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[21]Similar results appear when one simply includes model year in the specification as a reduced form, and when one includes both model year and the number of weeks in the year trucks were in operation.

Table 6 reports results from specifications which include and omit the fleet size dummies. The trip recorder patterns are very similar. The coefficients on the product dummies on the EVMS branch change substantially relative to the omitted category "mixed cargo." They do not change much relative to each other. This suggests that if a bias arises from not being able to distinguish among carriers with different backoffice technology within fleetsize categories, it tends to make all of the coefficients smaller. Mixed cargo tends to be handled by large, technologically sophisticated carriers. This may be for reasons having nothing to do with on-board IT, such as scale economies or shippers' valuation of the services provided by these firms' backoffice IT. When interpreting the coefficients on the EVMS branch in the basic specification in terms of differences in value of on-board IT, the difference between mixed cargo and products with positive coefficients (food, paper, transportation equipment) may be understated and that between mixed cargo and those with negative coefficients may be overstated.

What Might the Product Coefficients Mean?

This section explores several explanations for differences in the product coefficients. One hypothesis is that they reflect differences in the value of the goods themselves. The incentive-related benefits may be higher when trucks haul more valuable cargo if unauthorized breaks or unauthorized use of trucks raise the risk of theft or hijacking. EVMS may also be more valuable because it makes it easier for drivers to request help when their truck breaks down or they are in danger, and for firms to locate stolen or abandoned equipment or cargo. Another hypothesis is that the benefits of process monitoring vary across products because logistics are organized differently. Goods which are delivered to loading docks must be unloaded from trucks. This presents more complicated logistical issues than delivering goods which can be dumped or poured. Scheduling is more important because unloading takes longer and is more labor-intensive. Unexpectedly late deliveries may be more disruptive both to carriers (because trucks may have to wait longer to be unloaded) and shippers (because they may have to rearrange workers' schedules). These issues may be of particular concern when goods are temperature-sensitive. A third explanation is that the flexibility of delivery schedules and the sophistication of logistics varies across supply chains. Differences in sales/inventory ratios for different goods may reflect this. When sales/inventory ratios are low, late or ill-timed deliveries may be particularly disruptive because they cause stock-outs or because the capital used to handle inbound and outbound shipments is used more intensively and is more tightly-scheduled. IT-equipped trucks may be complementary to more sophisticated but less flexible business processes used by manufacturers, wholesalers, or retailers to handle goods.

I examine these issues in several ways. One is by using the trailer type variables in the TIUS. Trailer type reflects differences in how deliveries are organized. Tractors which are attached to refrigerated or non-refrigerated vans deliver to loading docks. Tractors which are attached to platforms, tank trucks, open top vans, and other specialized trailers such as grain body vans or car carriers generally do not. Another is by incorporating outside data into the analysis. Using data from several different Census surveys, I construct series which reflect (i) the average value/weight of private and for-hire truck shipments, by TIUS product class, (ii) volume-weighted sales/inventory ratios of wholesale firms, by TIUS product class, and (iii) the value-weighted fraction of manufacturers' shipments shipped to wholesalers and retailers, by TIUS product class. Details are in the Appendix; Table A1 contains these series.

Including the first of these series controls for the value of the shipments. In specifications where the product dummies are not included, they pick up differences in value within and across product categories; when the product dummies are included, they pick up differences within product categories. I include the other two Census series in specifications in place of the product dummies. I interpret sales/inventory levels at wholesale firms as a proxy for differences in how product inventories are managed in general. The underlying assumption is that high stock turns for the product class at wholesalers imply high stock turns with respect to other places products within the class are shipped.[22] The value-weighted fraction of manufacturers' shipments to wholesalers and retailers tracks differences in how supply chains are organized.

Results are in Table 7. The top of the table contains coefficients on the series computed from Census data. The middle contains those on the trailer dummies. The bottom are dummy variables which equal one when the principal product hauled by the truck corresponds to a missing value in the

[22]A better measure of cross-product differences in inventory management would also incorporate inventory levels of inputs at manufacturers. However, I have been unable to find a data series which has this information at the product input level. One might also consider incorporating information about retailers' inventories. However, single classes of retailers often sell products of multiple TIUS product classes, and inventories are not reported by product class. Linking the retail inventory data collected by the Census to data concerning the trucks that haul different types of goods is far more tenuous than linking the wholesale inventory data.

Census series (for example, this is always the case for "mixed cargo"). Looking at the trailer dummies, the tank truck coefficient is positive and significant on the trip recorder branch, and negative and significant on the EVMS branch. This reflects the same phenomena as the chemical and petroleum coefficients reported earlier. Trip recorders and EVMS are more common on trucks attached to refrigerated vans than enclosed, non-refrigerated vans, and more common on trucks attached to non-refrigerated vans than platforms.

From the coefficients on ln(value/weight) in the left panel, there is no evidence that the cross-product differences in IT use reflect differences in the value of cargo.[23] This is also true in specifications not shown which include product dummies. Both trip recorders and EVMS are more common for trucks which haul products for which sales/inventory ratios are high. Increasing the sales inventory ratio by 10 units (approximately one standard deviation in my series) is associated with a 3 percentage point increase in the probability trucks have trip recorders, and a similar increase in the probability they have EVMS. From the right panel, EVMS are less common on trucks which haul products which tend to be shipped to wholesalers and retailers than those which are shipped to the omitted category, "other manufacturers." For example, increasing the fraction to wholesale by 20 percentage points (approximately one standard deviation) is associated with a 1.8 percentage point decrease in the probability a truck has EVMS.

Both TIUS product categories and the Census data used to construct the variables used in Table 6 are highly aggregated. The analysis in this subsection provides weaker evidence than that in the rest of the paper. That said, there is some evidence that the cross product differences in Table 3 reflect differences in how logistics are organized. Controlling for a host of other factors, IT appears to be more common on trucks which deliver to loading docks than those which do not, those which haul goods for which inventories tend to be low relative to sales, and those which haul goods which tend to be shipped between manufacturing firms or divisions rather than to wholesalers or retailers.

7. Conclusion

Monitoring and coordinating production is inherently difficult in motor carriage because production is geographically dispersed. On-board IT offers a means by which dispatchers can better

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[23]The negative coefficient on the trip recorder branch in the right panel is due to the fact that "missing fraction to wholesale, retail" is picking up all of the low value/weight products except petroleum and chemicals.

evaluate drivers and arrange schedules. The results provide three broad themes with respect to where and why it is valuable in the trucking industry. First, on-board IT is particularly valuable for evaluating drivers who operate far from home and do not return home at the end of the day. It is not generally valuable for evaluating those who work close to home, especially those who make many stops. Relying on information from shippers and knowing when drivers return to terminals is an effective monitoring substitute in most circumstances. Exceptions may include when trucks haul dangerous cargo. As trucks operate farther from home, the coordination-related benefits grow. Scheduling backhauls becomes more difficult and important. Second, the nature of on-board IT's benefits differs systematically with the transactional relationship between carriers and shippers. They are disproportionately coordination-related when spot markets mediate trade, and are disproportionately incentive-related when long term contracts or vertical arrangements do. This may be attributable to differences in how logistics are organized as well as in the contractual arrangements themselves. Third, on-board IT is particularly valuable on trucks which deliver to loading docks, and which haul goods for which sales/inventory ratios tend to be low. Deliveries tend to be more time-sensitive. This makes driver shirking and coordination lapses particularly costly.

A wide range of theories has been proposed to understand relationships between the adoption of information and communication technology and long-run organizational change. These theories differ both in the environment they model and in the role information plays. This paper's results suggest where certain classes of theories are particularly applicable. Theories in which, in the short run, IT improves incentives may model circumstances where there are regular, stable transactional relationships well. One might label such relationships as those in which decisions are "routinized." In contrast, theories in which, in the short run, IT improves coordination may model those in which transactions within or between firms are irregular well.

Although this paper has concentrated more on differences in use rates than levels, the levels suggest that situations where IT-based process monitoring provides large incentive-related benefits may be rare. Local drivers work remotely by most standards. Trip recorders are inexpensive, well-understood technologies with which carriers can obtain fairly detailed information about drivers' activities. However, they are rare on local trucks. This may reflect factors such as information processing costs, but probably instead indicates that less technologically-sophisticated means of obtaining information to evaluate drivers — relying on shippers to verify arrival times, noting when drivers return to terminals — generally work well. The trucking industry is a valuable laboratory to examine how IT can ameliorate incentive and coordination difficulties, but the geographic dispersion of production exaggerates the informational problems faced by most firms. One of the central themes in this paper has been how IT can be used to improve incentives in the trucking industry. But as of 1992, IT-based process monitoring provided relatively small incentive-related benefits in circumstances where the informational difficulties carriers faced with respect to their drivers was most similar to those faced by firms in most other industries.

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Appendix

This Appendix describes the process whereby I obtain the value/weight, sales/inventory ratio, and distribution of manufacturers' shipments series used in this paper. The main complication is that the product and business establishment categories used in other surveys do not correspond exactly to the product categories used in the TIUS. In several cases (for example, "mixed cargo"), it is impossible to link TIUS product codes to categories used in these other surveys.

Details regarding how the codes used in these other series were assigned to TIUS product codes are available from the author upon request. Table A1 reports the series used in the paper.

Value/Weight.

The 1993 Commodity Flow Survey contains data on the value and weight of shipments by product category. The scope of the survey is shipments from most establishments in SIC codes 10, 12, and 14 (metal, coal, and non-metallic mineral mining); SIC codes 20-39 (manufacturing); SIC codes 50 and 51 (wholesale trade); SIC code 596 (catalog and mail order houses); and SIC code 782 (motion picture and video tape distribution). It does not include shipments of agricultural products originating at farmers; it does include those originating at grain elevators and other distribution or wholesale outlets. Shipments are classified using the Standard Transportation Commodity Classification, a coding system maintained by the railroads. In many cases, 2-digit STCC codes map closely to 2-digit SIC codes.

The Commodity Flow Survey contains value and weight by commodity for shipments according to the size of shipments and mode of transport at the 2-digit STCC level (Table 10). It contains value and weight by commodity by mode of transport at the 3-digit STCC level (Table 6b).

I create value/weight series for TIUS product categories in the following manner. First, I associate STCC categories with TIUS categories. Many 2-digit STCC categories for manufactured goods map directly into TIUS categories. ("primary metal products," "petroleum or coal products") In other cases, multiple 2-digit STCC categories map to the same TIUS category. (The TIUS "processed food" category includes STCC categories "food or kindred products" and "tobacco products," for example.) When all products within a 2-digit STCC code fall in the same TIUS product category, value/weight series are formed using data from Table 10: the value and tonnage of shipments weighing between 10,000 and 40,000 pounds. This weight category represents truckload-sized shipments. Separate series are available for shipments which use private and for-hire trucks. In other cases, 2-digit STCC categories map into multiple TIUS product categories. For example, "clay, concrete and glass products" includes building materials and bottles. When this is the case, analogous data from Table 6b is used. The only difference in the data from Tables 6b and 10 is that Table 6b includes shipments of all sizes, not just those of truckload-sized shipments.

Sales/Inventory Ratios

The 1992 Census of Wholesale Trade Geographic Area Series contains sales and inventory data for wholesalers, by the type of commodity they generally handle (4-digit SIC codes 50xx and 51xx). The scope of the data includes wholesale establishments only; it does not include warehouses of manufacturers or retailers unless they are considered separate establishments.

The wholesale SIC codes are linked to TIUS product categories where possible. For each TIUS product category for which such a calculation is possible, I obtain figures for total 1992 sales by wholesalers and end-of-year 1992 inventories at wholesalers by aggregating across the SIC codes within that product category. I then obtain sales/inventory ratios for wholesalers handling products in each TIUS product category from these aggregates.

Upon calculating the series, the calculated sales/inventory ratio for wholesalers handling live animals was approximately 190: over five times that in any other product category. Handling and managing inventories of live animals at stockyards is fundamentally different than those handling other (non-living) goods. I handle this outlier by dropping it from the series and treating the value as missing.

Distribution of Manufacturers' Shipments

The 1987 Census of Manufactures Subject Series contains data on manufacturers' distribution of sales by class of customer. No such data are available in the 1992 Census of Manufactures. These data are available for all 2-digit SIC categories, and many 4-digit SIC categories. The data report the proportion of shipments, by value, which are to internal and external customers. They also report the proportion which are to wholesalers, retailers, manufacturers, and governments.

Series are obtained for TIUS product categories in a similar fashion to above. SIC codes are matched to TIUS product categories where possible. Proportions shipped to wholesalers and retailers by TIUS category are calculated after aggregating across the individual SIC categories which make up each TIUS product category.

Table 1

Trip Recorder and EVMS Use Rates

Category	% of Sample	Variable	Percent of Trucks w/Device: Trip Recorder	Percent of Trucks w/Device: EVMS
	100.00	All Truck-tractors	7.51	10.54
Model Year	52.31	pre-1987	5.46	2.63
	7.81	1987	8.75	4.93
	8.25	1988	9.55	9.22
	8.98	1989	10.04	13.38
	7.35	1990	11.12	16.93
	6.57	1991	10.03	26.32
	8.72	1992-3	8.44	40.54
Fleet Size (Tractors plus Trailers)	34.82	<10	2.40	3.45
	34.12	10-99	7.05	7.42
	18.83	100-999	15.23	15.91
	6.21	1000-4999	14.29	27.44
	6.03	5000+	8.95	25.28
Distance From Home (miles)	26.55	<50	3.94	2.33
	17.47	50-100	6.92	4.35
	13.78	100-200	11.28	7.67
	17.83	200-500	10.82	13.54
	24.38	500+	6.96	21.98
Size of Haul/Org. of Carrier (for hire only)	72.69	TL	6.82	17.18
	20.08	LTL	5.16	10.14
	7.23	Missing/Not Noted	5.46	7.95
Refueling Site	46.27	Company-Owned or Contracted	11.74	11.12
	47.21	Public Fueling Stations	3.88	9.96
	6.51	Other	3.92	9.87

Table 2

Trip Recorder and EVMS Use Rates

Category	% of Sample	Variable	Percent of Trucks w/Device: Trip Recorder	Percent of Trucks w/Device: EVMS
	100.00	All Truck-tractors	7.51	10.54
Primary Business	50.06	Non-trucking	8.83	5.84
	47.64	For-Hire Trucking Firm	6.38	15.07
	2.30	Daily Rental/Not Motor Carrier, Other	4.40	5.46
Owner of Truck (for hire only)	73.93	Motor Carrier	7.63	18.37
	10.23	Independent Owner-Operator	2.20	4.29
	11.49	Owner-Operator, Leased to MC	1.90	5.42
	4.34	Missing/Not Noted	6.82	8.39
Type of Carriage (for hire only)	39.88	Contract	7.44	13.35
	47.14	Common	5.92	18.36
	5.85	Exempt	4.13	5.60
	7.13	Missing/Not Noted	5.41	7.93
Type of Trailer	8.93	Tank Truck	14.23	7.49
	11.40	Refrigerated Van	13.46	20.88
	32.70	Enclosed Non-Refrigerated Van	7.78	14.27
	22.43	Platform (e.g., Flatbed)	4.46	5.57
	5.17	Open Top	3.56	3.70
	19.36	All Others	4.64	5.60
Principal Product Hauled	16.20	Processed Food	14.46	17.12
	3.25	Chemicals	14.24	8.15
	4.04	Petroleum	11.95	7.76
	4.22	Paper Products	8.91	29.10
	3.92	Transportation Equipment	6.92	15.14
	3.29	Primary Metal Products	5.98	7.29
	8.41	Mixed Cargo	5.79	11.67
	9.11	Building Materials	5.48	4.73
	4.17	Lumber and Wood Products	5.23	9.05
	9.19	Farm Products	4.37	6.54
	4.55	Logs	3.96	3.94
	2.92	Live Animals	3.52	6.48
	5.40	Machinery	2.18	4.72
	21.34	Other	6.00	8.30

Table 3

Multinomial Logit Results

Area of Operation, Fuel Site, TL/LTL

Branch	Trip Recorder			EVMS		
	Estimate	Std. Err.	Prob. Der.	Estimate	Std. Err.	Prob. Der.
C	**-5.04**	**0.11**		**-4.86**	**0.10**	
50-100 mi.	**0.43**	**0.07**	**0.014**	**0.61**	**0.09**	**0.019**
100-200 mi.	**0.91**	**0.07**	**0.038**	**1.09**	**0.09**	**0.041**
200-500 mi.	**1.04**	**0.07**	**0.043**	**1.64**	**0.08**	**0.083**
500+ mi.	**1.05**	**0.07**	**0.039**	**2.09**	**0.08**	**0.135**
Private Fueling	**0.92**	**0.05**	**0.053**	**0.43**	**0.04**	**0.040**
TL	**0.52**	**0.08**	**0.023**	**1.03**	**0.07**	**0.071**
Private	**0.98**	**0.08**	**0.052**	**0.34**	**0.07**	**0.020**
Indy	**-0.81**	**0.12**	**-0.019**	**-1.03**	**0.08**	**-0.042**
Contract	**0.29**	**0.07**	**0.012**	**-0.18**	**0.05**	**-0.011**
Exempt	**0.33**	**0.17**	**0.014**	**-0.30**	**0.15**	**-0.018**
Farm	-0.21	0.12	-0.010	0.08	0.10	0.005
Animal	**-0.52**	**0.20**	**-0.022**	0.11	0.16	0.009
Food	**0.48**	**0.10**	**0.027**	**0.59**	**0.08**	**0.042**
Building	-0.21	0.12	-0.009	-0.21	0.11	0.011
Logs	-0.19	0.17	-0.009	0.16	0.16	0.011
Wood	-0.20	0.15	-0.010	0.14	0.12	0.010
Paper	**0.29**	**0.12**	**0.014**	**0.57**	**0.09**	**0.041**
Chemicals	0.47	0.12	0.031	**-0.31**	**0.13**	**-0.017**
Petroleum	**0.52**	**0.13**	**0.033**	**0.26**	**0.13**	0.014
Primary Metals	-0.19	0.14	-0.008	**-0.52**	**0.12**	**-0.024**
Machinery	**-1.03**	**0.18**	**-0.035**	-0.25	0.13	-0.011
Transportation	-0.20	0.13	-0.011	**0.32**	**0.10**	**0.022**
Other	-0.17	0.10	-0.008	-0.14	0.08	-0.008
Fleet 25-99	**0.67**	**0.06**	**0.027**	**0.42**	**0.06**	**0.018**
Fleet 100-499	**1.31**	**0.06**	**0.070**	**0.88**	**0.06**	**0.046**
Fleet 500-999	**1.46**	**0.08**	**0.080**	**1.28**	**0.07**	**0.080**
Fleet 1,000-4,999	**1.61**	**0.08**	**0.092**	**1.49**	**0.07**	**0.103**
Fleet 5,000-9,999	**1.26**	**0.13**	**0.054**	**1.85**	**0.09**	**0.159**
Fleet 10,000+	**0.56**	**0.11**	**0.015**	**1.49**	**0.08**	**0.114**

Note:
Omitted product category is "mixed cargo."

Table 4

Area Interactions

Selected Coefficients, Estimated Use Probabilities

Branch	Trip Recorder			EVMS		
	Estimate	Std. Err.	Use Prob.	Estimate	Std. Err.	Use Prob.
LTL	-	-	0.025	-	-	0.016
TL	**1.18**	**0.16**	0.073	**1.79**	**0.18**	0.086
Private	**1.23**	**0.15**	0.078	**1.30**	**0.17**	0.054
LTL*Long Haul	**1.18**	**0.15**	0.069	**2.26**	**0.16**	0.123
TL*Long Haul	**0.36**	**0.09**	0.079	**1.47**	**0.10**	0.283
Private*Long Haul	**0.87**	**0.06**	0.155	**1.03**	**0.07**	0.126

Notes:
-LogL equals 19604.2.
Long haul" refers to trucks which principally operate more than 100 miles from home.
Specification includes full set of variables from Table 3, not shown here.
Use probabilities are calculated using mean values of all other variables.

Table 5

Multinomial Logit Results

New and Old Trucks

Branch	Model Year <1988 (N=23,806)				Model Year >=1988 (N=16,044)			
	Trip Recorder		EVMS		Trip Recorder		EVMS	
	Estimate	Std. Err.	Estimate	Std. Err.	Estimate	Std. Err.	Estimate	Std. Err.
C	**-5.30**	**0.16**	**-5.76**	**0.21**	**-4.69**	**0.17**	**-3.50**	**0.12**
50-100 mi.	**0.35**	**0.09**	**0.63**	**0.16**	**0.48**	**0.13**	**0.30**	**0.11**
100-200 mi.	**0.74**	**0.09**	**1.24**	**0.15**	**1.04**	**0.12**	**0.57**	**0.11**
200-500 mi.	**1.06**	**0.09**	**1.81**	**0.14**	**0.98**	**0.12**	**1.01**	**0.10**
500+ mi.	**0.85**	**0.11**	**1.50**	**0.16**	**1.03**	**0.12**	**1.38**	**0.10**
Private Fueling	**0.98**	**0.08**	**0.77**	**0.11**	**0.81**	**0.07**	**0.28**	**0.05**
TL	**0.70**	**0.14**	**0.72**	**0.16**	**0.40**	**0.11**	**1.02**	**0.07**
Private	**1.15**	**0.13**	0.07	0.16	**0.87**	**0.10**	**0.35**	**0.08**
Indy	**-0.83**	**0.16**	**-0.95**	**0.18**	**-0.63**	**0.17**	**-0.63**	**0.09**
Contract	**0.36**	**0.10**	-0.05	0.12	**0.20**	**0.09**	**-0.32**	**0.06**
Exempt	-0.03	0.27	-0.18	0.29	**0.70**	**0.23**	-0.33	0.18
Farm	-0.07	0.19	**0.57**	**0.22**	-0.31	0.17	-0.05	0.12
Animal	-0.53	0.29	0.41	0.31	-0.47	0.30	0.07	0.19
Food	**0.63**	**0.16**	**0.63**	**0.19**	**0.36**	**0.12**	**0.55**	**0.09**
Building	-0.24	0.18	-0.02	0.24	-0.12	0.17	-0.18	0.13
Logs	-0.28	0.24	0.39	0.30	0.00	0.25	0.27	0.20
Wood	-0.02	0.22	-0.05	0.30	-0.36	0.23	**0.33**	**0.14**
Paper	0.01	0.20	0.02	0.25	**0.52**	**0.15**	**0.82**	**0.10**
Chemicals	**0.39**	**0.19**	-0.39	0.31	**0.55**	**0.16**	-0.17	0.14
Petroleum	**0.44**	**0.20**	**-0.94**	**0.46**	**0.60**	**0.17**	**0.33**	**0.14**
Primary Metals	**-0.52**	**0.24**	**-1.12**	**0.38**	0.06	0.17	**-0.28**	**0.13**
Machinery	**-0.89**	**0.24**	-0.66	0.37	**-1.10**	**0.30**	0.08	0.15
Transportation	-0.27	0.20	**1.09**	**0.20**	0.06	0.18	-0.05	0.14
Other	-0.22	0.16	-0.25	0.19	-0.09	0.13	-0.05	0.09
Fleet 25-99	**0.55**	**0.09**	-0.10	0.15	**0.73**	**0.09**	**0.37**	**0.07**
Fleet 100-499	**1.33**	**0.09**	**0.73**	**0.14**	**1.17**	**0.09**	**0.56**	**0.07**
Fleet 500-999	**1.79**	**0.13**	**0.99**	**0.21**	**1.17**	**0.12**	**0.90**	**0.08**
Fleet 1,000-4,999	**1.63**	**0.12**	**1.89**	**0.15**	**1.46**	**0.10**	**0.90**	**0.08**
Fleet 5,000-9,999	**1.59**	**0.19**	**1.89**	**0.23**	**0.91**	**0.19**	**1.49**	**0.11**
Fleet 10,000+	**1.03**	**0.19**	**2.02**	**0.19**	0.21	0.14	**0.86**	**0.09**

Table 6

Multinomial Logit Results

Including and Omitting Fleet Size
All Trucks

-LogL	19462.9				20206.7			
Branch	Trip Recorder		EVMS		Trip Recorder		EVMS	
	Estimate	Std. Err.	Estimate	Std. Err.	Estimate	Std. Err.	Estimate	Std. Err.
C	**-5.04**	**0.11**	**-4.86**	**0.10**	**-4.42**	**0.10**	**-4.01**	**0.09**
50-100 mi.	**0.43**	**0.07**	**0.61**	**0.09**	**0.52**	**0.07**	**0.64**	**0.09**
100-200 mi.	**0.91**	**0.07**	**1.09**	**0.09**	**1.04**	**0.07**	**1.16**	**0.09**
200-500 mi.	**1.04**	**0.07**	**1.64**	**0.08**	**1.19**	**0.07**	**1.76**	**0.08**
500+ mi.	**1.05**	**0.07**	**2.09**	**0.08**	**1.34**	**0.07**	**2.45**	**0.08**
Private Fueling	**0.92**	**0.05**	**0.43**	**0.04**	**1.21**	**0.05**	**0.74**	**0.04**
TL	**0.52**	**0.08**	**1.03**	**0.07**	**0.61**	**0.08**	**1.08**	**0.06**
Private	**0.98**	**0.08**	**0.34**	**0.07**	**0.75**	**0.08**	0.07	0.07
Indy	**-0.81**	**0.12**	**-1.03**	**0.08**	**-1.17**	**0.11**	**-1.38**	**0.08**
Contract	**0.29**	**0.07**	**-0.18**	**0.05**	**0.19**	**0.07**	**-0.48**	**0.05**
Exempt	**0.33**	**0.17**	**-0.30**	**0.15**	0.03	0.17	**-0.66**	**0.15**
Farm	-0.21	0.12	0.08	0.10	**-0.55**	**0.12**	**-0.57**	**0.10**
Animal	**-0.52**	**0.20**	0.11	0.16	**-0.85**	**0.20**	**-0.58**	**0.16**
Food	**0.48**	**0.10**	**0.59**	**0.08**	**0.55**	**0.09**	**0.29**	**0.07**
Building	-0.21	0.12	-0.21	0.11	**-0.43**	**0.12**	**-0.68**	**0.11**
Logs	-0.19	0.17	0.16	0.16	**-0.59**	**0.17**	**-0.47**	**0.16**
Wood	-0.20	0.15	0.14	0.12	**-0.49**	**0.15**	**-0.40**	**0.12**
Paper	**0.29**	**0.12**	**0.57**	**0.09**	0.21	0.12	**0.39**	**0.09**
Chemicals	**0.47**	**0.12**	**-0.31**	**0.13**	**0.43**	**0.12**	**-0.62**	**0.12**
Petroleum	**0.52**	**0.13**	**0.26**	**0.13**	**0.27**	**0.11**	**-0.28**	**0.12**
Primary Metals	-0.19	0.14	**-0.52**	**0.12**	-0.25	0.14	**-0.85**	**0.12**
Machinery	**-1.03**	**0.18**	-0.25	0.13	**-1.21**	**0.18**	**-0.67**	**0.13**
Transportation	-0.20	0.13	**0.32**	**0.10**	-0.13	0.13	0.15	0.10
Other	-0.17	0.10	-0.14	0.08	**-0.27**	**0.10**	**-0.50**	**0.07**
Fleet 25-99	**0.67**	**0.06**	**0.42**	**0.06**				
Fleet 100-499	**1.31**	**0.06**	**0.88**	**0.06**				
Fleet 500-999	**1.46**	**0.08**	**1.28**	**0.07**				
Fleet 1,000-4,999	**1.61**	**0.08**	**1.49**	**0.07**				
Fleet 5,000-9,999	**1.26**	**0.13**	**1.85**	**0.09**				
Fleet 10,000+	**0.56**	**0.11**	**1.49**	**0.08**				

Note: -LogL for full specification, holding non-fleet size coefficients at the estimates in the right panel equals 19527.1.

Table 7

Multinomial Logit Results

Census Variables, Trailer Dummies
Selected Coefficients

-LogL	19438.4				19399.9			
Branch	Trip Recorder		EVMS		Trip Recorder		EVMS	
	Estimate	Std. Err.	Estimate	Std. Err.	Estimate	Std. Err.	Estimate	Std. Err.
Ln(value/weight)	0.009	0.019	0.031	0.018	**-0.101**	**0.032**	0.009	0.029
Sales/Inventory	**0.034**	**0.004**	**0.026**	**0.004**	**0.035**	**0.004**	**0.032**	**0.004**
Fraction to Wholesale					-0.000	0.002	**-0.006**	**-0.002**
Fraction to Retail					-0.006	0.003	**-0.009**	**0.003**
Platform	**-0.17**	**0.07**	**-0.22**	**0.06**	**-0.22**	**0.07**	**-0.26**	**0.06**
Refrigerated Van	**0.44**	**0.06**	**0.50**	**0.06**	**0.45**	**0.07**	**0.60**	**0.06**
Open Top Van	-0.20	0.14	-0.05	0.14	-0.04	0.14	0.00	0.01
Tank Truck	**0.45**	**0.07**	**-0.33**	**0.08**	**0.53**	**0.07**	**-0.34**	**0.08**
Specialized Trailer	**-0.29**	**0.07**	-0.09	0.06	**-0.23**	**0.07**	-0.05	0.07
Miss. Ln(value/weight)	0.009	0.019	**0.194**	**0.081**	**0.354**	**0.115**	**0.468**	**0.103**
Miss. Sales/Inventory	**0.758**	**0.103**	**0.221**	**0.095**	**0.764**	**0.115**	0.185	0.105
Miss. Frac. to Wholesale, Retail					**-0.645**	**0.137**	**-0.568**	**0.119**

Notes:
Omitted trailer type is enclosed, non-refrigerated van.
Specification includes distance from home, contract, exempt, private fuel, fleet size, TL, independent, and private fleet variables, not shown.

Table A1

Value, Sales/Inventory Ratios, and Distribution of Manufacturers' Shipment

by TIUS Product Category

	Value/Weight ($000/ton)		Sales/Inventory Ratio (Wholesalers)	Value Share of Manufacturers' Shipments	
	Private	For-hire		To Wholesalers	To Retailers
Farm Products	0.36	0.23	19.73	-	-
Live Animals	1.30	1.44	-	-	-
Processed Food	0.96	1.25	27.12	56.1%	23.8%
Mining Products	0.07	0.08	24.85	-	-
Building Materials	0.03	0.06	13.44	-	-
Logs and other Forest Products	0.03	0.11	26.53	-	-
Lumber and Fabricated Wood Products	0.21	0.31	13.44	47.3%	13.8%
Paper Products	0.68	0.86	20.09	19.8%	15.8%
Chemicals	0.50	1.25	17.50	29.6%	12.2%
Petroleum	0.22	0.18	32.41	75.7%	7.6%
Plastics and/or Rubber	2.02	2.63	24.11	26.5%	11.5%
Primary Metal Products	0.61	0.77	-	19.7%	1.5%
Fabricated Metal Products	1.22	1.76	11.57	24.2%	5.1%
Machinery	3.85	7.25	5.98	28.3%	8.9%
Transportation Equipment	2.97	4.42	17.50	12.5%	32.9%
Furniture or Hardware	3.06	3.13	12.18	28.4%	51.6%
Textile Mill Products	5.32	8.67	10.60	18.1%	40.8%
Glass Products	1.72	1.04	-	26.3%	7.7%
Misc products	4.44	7.25	-	27.9%	13.1%

Note: See Appendix for sources and calculation of series. All TIUS categories not listed (e.g., mixed cargo) have missing values for each series.