PRODUCTIVITY GROWTH IN THE U.S. TRUCKING INDUSTRY

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

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ABSTRACT

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The performance of the trucking industry is very important to the economy given that it moves nearly 70 percent of the nation's freight (Tarr et al. 2005). The more efficient and productive trucking firms are, the less the shipping costs are for the trucking firm managers and the end consumers or businesses. Consequently, it has become vital to keep the trucking industry running efficiently and continuing to improve productivity.

Productivity change of 115 of the largest firms in the United States was determined for the years 1999 and 2003. The Malmquist Productivity Index was decomposed into technical efficiency change and technical change. Results showed that the trucking industry, on average, was technically inefficient in years 1999 and 2003, even though the trucking industry experienced productivity improvement during that period. There was evidence that, on average, technical change, instead of technical efficiency, contributed more to productivity growth in the U.S. trucking industry.

The findings in this study point to technological innovation as the reason for positive productivity change. It has also been found that the industry has been rather technically inefficient. Trucking firms should embrace innovation and technology, and develop new strategies for delivery to improve productivity.

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INTRODUCTION

In the United States, the trucking industry plays a vital role in the movement of freight. In fact, the trucking industry moves nearly 70 percent of the nation's freight (Tarr et al. 2005). Nearly every U.S. citizen is affected by the cost of delivery in some way, shape, or form. The performance of the trucking industry is very important to the economy. Studies on productivity and efficiency are important to trucking firm managers, regulators, and customers. The more efficient and productive a trucking firm is, the less the shipping cost to the end consumer or business.

Many different factors affect trucking performance, including state and federal regulatory environments, sub-contracting, intermodal transport, regional/geographic characteristics, and firm characteristics. High costs can result in failure for such a competitive industry, and as competition in a market increases, the pressure on less efficient firms to exit increases. This has been the case since the deregulation of the trucking industry in 1980.

Although the main objective of individual trucking firms is to make a profit, high productivity levels should be sought to achieve this objective. As a result, it is imperative to investigate productivity and productivity change differences in the U.S. trucking industry. The Malmquist Productivity Index is one method used to measure total factor productivity change between two time periods. The Malmquist Productivity Index allows for observation of productivity change over time. Solving productivity indices when a single input produces a single output may be simple, but for multiple inputs and outputs, it is much more complex.

The first goal of this research is to analyze the productivity change of U.S. trucking firms with the Malmquist Productivity Index. The analysis is accomplished with data from 115 trucking firms between the years of 1999 and 2003. This time period was selected because of a growing national security concern which started in 2001. In response to the terrorist acts that took place on September 11, 2001, and other threats that affected the transportation industry, including the trucking industry, the Federal Motor Carrier Safety Administration implemented programs to protect motor carriers. In addition to these safety programs, the Performance and Registration Information Systems Management Program (PRISM) was implemented in more and more states, beginning in 1998. This is a federal-state partnership program established to identify unsafe motor carriers and hold them responsible for the safety of their operation by imposing registration sanctions. Under this program, all carriers' safety performance evaluation reports are made available not only to state agencies but to the general public (Federal Motor Carrier Safety Administration). This increased safety requirement could restrain or put pressure on unsafe carriers that might otherwise look "productive" at the cost of public safety.

A major advantage of the Malmquist Productivity Index is that it can be broken down into two parts: technical efficiency change and technical change. This division is helpful because it allows for the trucking firm managers and regulators to identify potential areas in need of productivity improvement. The second goal of this research is to find the causes of productivity change, whether it is from a more efficient use of existing technology or from technological advancement.

Objective

The main objective for this study is to estimate productivity ratios, and technical and technical efficiency change for the United States trucking industry. Research goals in this paper are to

(1) Analyze the productivity change of U.S. trucking firms between 1999 and 2003.

> Hypothesis 1: Productivity for the industry will increase for the five-year span covered for this study.

(2) Find the reasons for productivity change based on Malmquist productivity components: technical change and technical efficiency change.

> Hypothesis 2: Any increase in productivity for the U.S. trucking industry will be a result of technical change.

Structure

The paper is organized into six chapters. Chapter two provides a review of previous literature on the U.S. trucking industry and topics that affect it. The next chapter presents the model, the calculation of Malmquist Productivity Index, and a decomposition of the index. Chapter four contains a description of the Data and Variables. Chapter five provides a review of the Results and the answers to the hypotheses. Chapter six ends this paper with some Concluding Remarks on our findings along with ideas for future research.

LITERATURE REVIEW

The U.S. trucking industry is a vital aspect of the U.S. economy and many, if not all, businesses deal with motor carriers directly or indirectly. The more efficient and cost effective the motor companies are, the lower the cost to the businesses that interact with them. The market structure of the trucking industry is relatively competitive with many buyers and sellers. Therefore, cost savings obtained by trucking firms may be passed down to the end consumers in an effort to gain market share. Many factors and changes that affect the efficiency in trucking will be discussed in this literature review. One of these changes is deregulation, specifically the removal of government rate regulations and restrictions on entry. Deregulation has been one of the major economic policy changes in recent years.

The U.S. motor carrier industry moved towards deregulation in 1978 with administrative changes of the Interstate Commerce Commission (ICC); the transformation was completed and instituted with the Motor Carrier Act of 1980. Before deregulation, the ICC regulated the industry by requiring a motor carrier to have a certificate to haul certain routes and by limiting the number of certificates issued. Through deregulation, obtaining a certificate was much easier and the rules that restricted certificate holders were relaxed (Boyer 1993).

As the barriers to entry started to fall, many new competitors entered the market and competition increased. The new entrants increased pressure on less efficient firms to exit the market (Silverman and Nickerson 1997). Silverman and Nickerson found different characteristics of trucking firms accounted for mortality or failure due to low profitability in the industry. Two of the more important characteristics were the age of the firm at the time of deregulation and post deregulation as well as the profitability of the firm. Another reason that strong firms failed after deregulation was that most of the new firms in the market were non-unionized, with cost minimization as a major goal. Therefore, the unionized incumbent firms who were obligated to pay high labor costs could not compete with these low-priced, efficient firms.

The remainder of this literature review will provide more detail on studies completed on the trucking industry after deregulation, the new entrants into the deregulated market, the labor force available to the deregulated trucking industry, advances in technology, and the cost and efficiency aspects of operating a motor carrier.

Deregulation of the Trucking Industry

Boyer (1993) points out the reason for regulation was not to promote economic efficiency, rather to provide a safe, reliable, and fair system of transportation, which does not give an advantage to one shipper or another. Deregulation allowed the introduction of operating procedures that made important productivity improvements in the industry. Boyer states that the greatest efficiency enhancements came from better location decisions, technology improvements, lower transaction costs for users, different inventory policies, and more efficient types of transport (private or for-hire). These efficiency enhancements implemented after deregulation reduced shippers' trucking expenses by more than $12 billion annually and led to reductions of 12-25 percent in trucking rates or costs.

Boyer (1993) continues his discussion on deregulation by explaining how a hub-and-spoke system improves load factor. The system for collecting, transporting, and delivering freight for a large group of shippers increases the capacity of carriers making deliveries. This means truckers can constantly run their trucks at the load capacity, and shippers can operate the just-in-time inventory method that not only increases efficiency for the truckers but for the shippers as well.

Ying (1990) found that after deregulation, the rates for shipping were reduced, monopoly rents by unions had fallen, and in some areas, service quality improved. Before deregulation, cartel-like bureaus controlled prices. Existing carriers did not experience competition from entrants because the ICC limited entry, and restricted the operating licenses that were granted. This policy allowed carriers to be lax in their cost-minimization efforts that created inefficiency.

Soon after the regulatory reform, Ying's study indicates substantial productivity growth in the trucking industry. As a result of regulatory reform, trucking companies were able to fill more backhauls, make use of more efficient routes, and experiment with cost-cutting techniques. Ying demonstrates that cost savings were up over 9 percent after two years. He concludes that regulatory reform has encouraged truckers to be more efficient and more aggressive in order to cut costs drastically. The aggressive nature of the firm and attempts to have the lowest costs are most likely the reasons for the service quality improvement. If the costs are reduced to a minimum, a firm can differentiate itself from other firms by guaranteed on-time deliveries and the use of well-trained and experienced drivers. This hypothesis is confirmed by a study done by Allen and Liu (1995) who found shippers are very sensitive to service quality factors. High quality carriers also receive significant competitive advantages with competitive or lower costs.

Types of Carriage

To better understand the trucking industry, knowledge of the two major types of carriage is needed. The first, known as less-than-truckload (LTL) carriage, involves the movement of shipments of less than 10,000 pounds. Silverman and Nickerson (1997) point out the United Postal Service as a familiar example of this type of transport. The second, known as truckload (TL) carriage, involves the movement of shipments of 10,000 pounds or more. In addition to weight differences, TL carriages are full truckloads going from pick-up point to destination, whereas LTL freight carries multiple shipments to many destinations most often through a hub and spoke system. Because of these multiple shipments, LTL carriage demands on-time arrivals and departures at the hubs, called break-bulk facilities. At these facilities, the freight arrives, transfers to other carriers, and is shipped out to particular destinations accordingly. The LTL network is considerably intertwined; therefore, a late arrival at a hub can cause holdups throughout the system (Nickerson and Silverman 2003).

New Entrants into the Deregulated Market

After deregulation, barriers were lowered which allowed many new entrants into the market. Boyer (1993) states that almost all of the new trucking firms in the newly deregulated environment were owner-operators who operated on a much smaller scale and who acted as sub-contractors to private carriers or large, for-hire trucking companies. It is generally less expensive for a firm to hire trucking services from an owner-operator than to provide the services itself. The for-hire companies are usually more successful at filling vehicles on their return trips than are private truckers. Another advantage of a for-hire trucker, in addition to filling backhauls, is that a for-hire carrier should be able to achieve higher load average factors than a larger carrier, because the larger carrier needs to keep a reserve margin to assure availability for its shippers.

Through sub-contractors, larger carriers are able to expand their network. Nickerson and Silverman (2003) figure the extent that a carrier invests in its reputation and the proportion of the carrier's hauls that are LTL, affects the choice of driver employment. Carriers will use for-hire truckers when hauls are not time-sensitive and when investments are not at a high risk of devaluation by the driver. A company driver will likely be monitored during his/her hauls via on-board computers; the results of this oversight will be discussed in the technology section. However, a sub-contractor usually can't be monitored, and will not have customer service training to better represent the trucking company. Company drivers are preferred mainly because trucking companies can provide performance guarantees. These guarantees are necessary for the just-in-time delivery method under which many shippers operate and which provides major efficiency gains in the market due to reduced inventory.

Owner-Operators vs. Company Drivers

He and Nickerson (2006) investigated the decision by most trucking firms to use company drivers for hauls or to outsource these hauls to owner-operators or other trucking companies. Their results showed that hauls that are outsourced had higher revenue per mile, were unlikely to be LTL, were not time-sensitive, and did not have multiple pick-ups or drop-offs. Most importantly, He and Nickerson found that carriers outsource hauls when the origin or destination is outside its normal carrying area and when there is no backhaul available. This allows the carrier to maintain strong relationships with shippers and achieve greater efficiency by outsourcing the haul.

In their 2003 study, Nickerson and Silverman state that 35 percent of 353 interstate carriers observed, engaged in both modes of organization, using company drivers and owner-operators. They also discovered that taking into account capital, maintenance, and fuel costs, owner-operators typically cost less per mile than company drivers. However, there are other factors that nullify the initial cost savings. In their article, Nickerson and Silverman argue that when the outcome of one haul imposes externalities, such as late hauls or damaged freight, on other hauls or on the carrier's reputation, it is best to avoid hiring an owner-operator because he/she will not internalize all costs associated with poor outcomes.

Owner-operators own their own equipment, which provides an incentive to expend more effort and resources in vehicle maintenance and careful driving. Company drivers might not realize this incentive. Therefore, in the absence of externalities, a carrier might prefer to contract with an owner-operator to haul its shipment instead of a company driver, which causes wear and tear on company equipment. On the other hand, because externalities are so frequent and sometimes expensive, a carrier may prefer to use a company truck, one that is operated by a trained company driver. Besides, since success or failure of one haul inflicts externalities on the rest of the carrier's business, an owner-operator who does not maintain his/her truck to the carrier's standards could cause costly externalities. The most prevalent area of trucking for externalities is for LTL carriage because of its time sensitive deliveries and important investments in reputation (Nickerson and Silverman 2003). He and Nickerson (2006) back this claim by stating "an LTL haul is less likely to be outsourced since it demands more coordination efforts and also is more lucrative; a hazardous haul may be less likely to be outsourced since it may require special training for the drivers."

Nickerson and Silverman (2003) continue to explain the reason for investments in reputation by noting some carriers invest for a reputation of quality service because they are looking for a price premium over other carriers. Nickerson and Silverman interviewed truckers who stated: "Quality service in trucking pertains to on-time delivery, low freight damage, and a high level of driver professionalism when dealing with a customer to whom freight is delivered. Poor performance by a driver can tarnish a carrier's reputation, imposing costs well beyond those borne directly by the driver."

Labor Makeup After Deregulation

Following deregulation, the trucking industry gained 586,000 jobs between 1980 and 1994, and trucking jobs were projected to increase by nearly 300,000 between 1994 and 2005. These new carriers, who were primarily non-union, easily won business based on price competition due to of lower labor costs, causing union representation in the trucking industry to decline sharply. In 1973, 62 percent of for-hire truckers were unionized; this number fell by half to 30 percent by 1984. In 1996, only 23 percent of truckers were unionized (Engel 1998). Belman et al. (2005, p. 191) found that union membership for the overall population of drivers was only 10 percent in 2005.

These trends have been studied recently. Peoples (1998) claims deregulation causes a decline in unionization. Regulation that restricts the entry of potential competition, which the trucking industry had through a limited number of operating licenses, allowed for relative ease of unionization. Organizing a large proportion of the labor force increases the bargaining power of unions. With the ability to slow down, or even stop operations with a labor strike, the unions can become very powerful. The unions did use their power in the trucking industry to negotiate wages which were at least 14 percent higher than the wages received by their counterparts in other industries.

After deregulation, competition greatly increased, and the unions started to lose their bargaining advantage as new, non-union firms entered the industry with ease. A large number of new, non-union carriers grew rapidly, at the expense of unionized carriers that had much higher costs (Boyer 1993). In fact, contracting out transportation services by the larger carriers often prevented the unionization of the workforces. These examples show how a firm that has unionized drivers with higher wages and benefits hurts the firm's ability to survive in a deregulated environment (Zingales 1998). As the competition increased, companies decided to change the compensation methods for their workers. They decided to pay their truckers based on output rather than paying them by time needed to complete the shipment. This change led to increased workloads but less pay, which increased the labor turnover rate and resulted in persistent driver shortages. This competition also allowed carriers to bid down their unionized truckers' wage premiums (Engel 1998). Simply put, wage decreases have led to a significant shortage of well-trained and experienced drivers available under regulation (Allen and Liu 1995). Many agree that regulation allowed for-hire carriers to receive better wages, but there is also some argument that better quality service in the form of very little cargo damage and on-time deliveries came from shippers paying somewhat higher costs. These non-price competition factors demand better-qualified drivers who demand higher wages (Peoples 1998).

In a deregulated industry, such as trucking, there is much more emphasis on cost savings. Since the unions were losing control over the labor supply, many cuts were made in the form of lower wages to drivers. These lower wages turned into lower per worker labor costs for firms, which are passed on to the consumer in the form of welfare gains.

The decline in unionization was mourned by some firms who played a positive economic role by helping carriers find and fix workers' concerns over working conditions, job security, promotional practices and labor compensation issues. A good relationship between employers and unions can lead to a stronger work environment that can increase service quality and productivity, while a bad relationship can lead to poor treatment of equipment or even labor strikes. After deregulation, the bargaining power of unionized drivers in the trucking industry has been reduced, as expected (Peoples 1998).

Advantages of Technology

Significant advancements in technology have boosted performance in the trucking industry. The utilization of the Internet through e-commerce, load matching services, and even on-board computers, has allowed carriers to acquire more freight services and be more efficient in their shipments. Ying (1990) credits deregulation as a significant factor in accelerating technological progress because firms have been required to become more efficient and cut costs.

A growing trend in the trucking industry is the impact of e-commerce. Trucking firms are participating in the new economy by expanding existing resources, by adopting new technologies to enable Internet-based communication with their customers, and by improving processes to improve service and efficiency. Nagarajan et al. (2000)

investigated the direct and indirect influences of the Internet on the trucking industry. Nagarajan et al. found utilization of the Internet allows for better management of the flow of shipment information in the fragmented trucking industry. This information provides the trucking industry with greater efficiency in everyday transportation activities and it also creates demand for new and diverse types of transportation activities. However, this dual demand for greater efficiency and innovative services, an indirect influence of the Internet, is causing substantial pressure on the capabilities of trucking companies. Nagarajan et al. fear that firms trying to adapt to these new skills may lose track of their own abilities. Firms looking to expand with new technologies should follow a plan in order to handle the growth effectively.

In the trucking industry, productivity gains come mainly from two sources: the first is fewer empty miles (deadheading) and the second is less time waiting to get loaded at the hub. The Internet can help the carriers by using load-matching services, which provide information that matches available shipments with trucks that have available cargo space to avoid costly deadheading. This information is very valuable to small firms and owner-operators who avoid using costly freight brokers who have previously provided these services (Nagarajan et al. 2000).

Employees of trucking companies must acquire new skills due to the Internet demand, which is why many company trucks now have on-board computers, cellular communications, or specialized mobile radios. Baker and Hubbard (2004) studied the use of on-board computers in trucking firms and found they were beneficial to capacity utilization. They found that trip recorders, which record speed, idle time, and other variables, are most valuable when trucks have infrequent scheduled stops, haul goods for which inventories tend to be low, or haul dangerous or hazardous cargo. Another on-board computer is the electronic vehicle management system (EVMS). The EVMS is much more expensive but does all that a trip recorder can do, and also tracks the truck's geographic location, sends information to dispatchers in real time, and gives dispatchers a means of contacting drivers. Baker and Hubbard found the EVMS to be most valuable when spot arrangements mediate trade. These advancements by on-board computers have enabled a 3 percent increase in capacity utilization for the industry even though a few carriers use them. Boyer (1993) also recognizes that the increased use of computers for dispatching and load matching increases the advantage of large networks over smaller ones. This advantage is a result of evidence showing that shippers would rather deal with a smaller number of motor carriers.

Baker and Hubbard (2004) studied how truck ownership has changed with the diffusion of on-board computers. They also tested whether on-board computers changed how drivers drive by assessing the fuel economy of trucks driven by company drivers and owner-operators with and without on-board computers. They found that while fuel economy is better for trucks with on-board computers than for those without them, there is a difference between company drivers and owner-operators. Company drivers tend to have a larger gap in fuel economy from using on-board computers than not. This difference reflects the improved incentives for company drivers to drive more efficiently which started with the adoption of on-board computers. Baker and Hubbard (2004) also show that driver ownership of trucks decreases with on-board computer adoption. Therefore, they suggest that through the use of on-board computers, improved contracting has led to more integrated asset ownership. The increased use of informational capabilities leads to less subcontracting. From studies done on the influence of technology on the trucking industry, advantages not only come in the form of cost-minimizing benefits but also coordination-enhancing capabilities which affect a shipper's make-or-buy decision. This decision is whether to use company drivers or outsource it and use owner-operators to fill shipments.

Technology has also increased security in the trucking industry following the September 11, 2001, terrorist attacks on the U.S. One major area of concern, post 9-11, was the transportation of hazardous materials (hazmat). On any given day in the U.S., there are approximately 800,000 loads of hazardous materials in transit (Harvey 2004). In addition to the danger of a hazmat truck being hijacked and used as a weapon, there is speculation that the proceeds from cargo theft may be used to fund terrorist activity. In order to lessen these threats, carriers have begun to use the Secure Networked Truck, which has been developed to provide additional security. The Secure Networked Truck has safety features such as a vehicle immobilizer, door locks, smart values, and other security devices that can either operate automatically, based on certain local conditions, such as a door being opened, or be activated from a distance by a dispatcher (Harvey 2004)

Tarr et al. (2005) point out that although trucks haul nearly 70 percent of the nation's freight, the federal government spends significantly more on airplane safety than it does on truck safety. The most likely reason is that airplanes carry humans and trucks carry freight. However, according to Julian (2003), the U.S. economy was able to continue operations following the events of September 11, 2001, even with the airlines out of service. She does not believe this would be the case if the U.S. truck fleet were immobilized. The use of technology to secure trucks will obviously help protect against terrorism but the real advantage from a Secure Networked Truck will come from cargo theft prevention. The trucking industry loses as much as $10 billon a year due to cargo theft. Harvey (2004) also reports that 85 percent of all business security losses are attributed to the theft or loss of products in transit. Therefore, carriers using location-based services or global positioning services often realize a return on investment in their first year of purchase, as a result of a decrease in security losses and an increase in efficiency gains. Along with efficiency gains, these systems have also proved to be invaluable in case of a medical emergency or an accident where the driver needs to summon help immediately. Likely, carriers carrying hazmat will soon be required to have mobile communications systems, but in addition, other carriers could also benefit from the Secure Networked Truck systems.

Since deregulation, competition in the trucking industry has increased significantly and each firm's goal has been cost minimization. Each firm tries different methods to lower its costs such as using technology, outsourcing hauls, employing different inventory methods, and location decisions. With cost savings being passed on to consumers, this minimization enables more efficient firms to drive out their less efficient competitors. Eventually, more efficient firms will find the most beneficial cost minimization methods.

Cost and Efficiency in the Trucking Industry

Trucking companies have sought to discover and implement strategies that yield cost reductions and increase efficiency. Better and faster service, on-the-dot delivery and pickup times, and better tracking of shipments are the services demanded from carriers and transportation buyers. They have responded by improving their time and asset management during their deliveries. This strategy relies on infrequent handling of goods and new technologies to try to achieve greater efficiency and lower costs (Engel 1998).

Before deregulation, efficient operation wasn't realized for several reasons. Inefficiency resulted because firms simply did not minimize costs, due to regulation protection. Firms faced various factors during regulation including: incentives for uses of inputs, input biases due to required service levels or restrictions on purchases of inputs, or inefficient structuring of the industry. For example, the distribution of output and/or costs over firms is different than that which would emerge from unregulated competition. However, Daughety and Nelson (1988) do not find that all the reasons affected industry, but some do. They believe a couple reasons did in fact cause distortions of carriers' operation during regulation. The first roadblock was the restrictions on network structure, or operating rights. Certain carriers were only allowed to use specific routes and serve particular markets. This restriction meant increased competition for other established carriers. The other barrier was that carriers, during regulation, faced incentives allowing for an inefficient variation of carrier types to develop. These variations were most evident in costs the firms endured. Daughety and Nelson found that costs would have been lower in the 1950s without regulation.

As soon as regulation ended, carriers found new ways to improve efficiency. The just-in-time inventory method became more popular as customers began to demand quicker and more flexible service from the motor carriers. In 1990, 18 percent of production was just-in-time, compared with 28 percent by 1995, and inventory sales ratios declined sharply over that 5-year period. Improvements in the way inventory is processed decrease the amount of time warehouses take to fill orders. By 2003, this time was expected to be reduced 15 to 20 percent, and transit times were to be cut 5 to 10 percent. As world trade grows and the business environment becomes even more time sensitive, demands for efficiency are expected to increase (Engel 1998).

Technology in the trucking industry is advancing daily. Electronic data interchange, new vehicle location detection systems, voice and data communication along with the technologies listed above in the Advantages of Technology section, have helped increase efficiency in firms' distribution methods. Firms are also able to easily track mileage of specific vehicles, fuel efficiency, best fueling stations, location, and speeds of vehicles, as well as other helpful information because of technology advancements. Delivery costs can also be lowered with a combination of these new technologies and the use of transportation brokers, who help firms avoid deadheading and low load size, to increase revenue of trips (Engel 1998).

Grimm et al. (1989) identified a group of trucking firms called the Advanced Truckload Firms (ALTFs) who used computer software to match the areas of consumer demand with their equipment availabilities in congested areas of operation. They found the ALTFs had the best load size. Grimm et al. state, "Load size is based on the relation of a firm's total ton-miles to its total miles." The reason for the ALTF's superior performance was that their computer software allowed them to minimize backhauls, maximizing the ratio of ton-miles to total miles. Grimm et al. found there is strong evidence of economies of load size in the trucking industry and recommend that other firms study the success of the ALTFs because economies of load size exist all over the U.S. In their study, Grimm et al. found that great rewards could also come from creative policies to increase average loads and lower costs.

According to Engel (1998), larger and more fuel-efficient trucks have led to a 20 percent increase in the average tonnage of freight hauled between 1975 and 1995. Increased fuel efficiency of the trucking firms' trucks and the move to larger trucks has reduced gains from using labor. The emphasis on using larger equipment has increased the capital-to-labor ratio in the trucking industry in recent decades. As a result, the increase of the capital-to-labor ratio has allowed trucking companies to spread average variable costs over a larger volume of freight. Now, more and more freight is being diverted from slow moving modes, such as rail, to faster moving ones such as air and truck.

In addition to assessing increased vehicle size, researchers have studied the benefits of intermodal transportation, which is growing as an antidote to deadheading on the return trip and helping save on labor costs. In the trucking industry, intermodal transportation became widespread in the 1980's. For example, trailers are lifted and placed onto a rail flatcar, and containers hauled by trucks can also be stacked or double-stacked on rail flatcars. The linkage of different modes of transportation by intermodal firms provides a more efficient route from ports to railroads and highways. Between 1988 and 1995, the use of containerization in the intermodal industry has grown an average annual rate of 6 percent (Engel 1998). Engel defines containerization as "the movement of commodities in large containers or trailers rather than as smaller units." Containerization, along with larger, more fuel-efficient trucks, signals a shift to more capital-intensive operations. Engel argues that using containers reduces handling costs, costs of damage or theft, and most importantly time required to transfer cargo. Deregulation and intense competition have caused firms to change their method of service. These changes have led to cost savings that have been passed on to the customers (Engel 1998).

Summary of Literature Reviewed

Many researchers have argued their opinions on how carriers can and have become more efficient and why others have not. They cite the deregulation of the trucking industry, a more competitive market, a new labor market, advances in technology, and other cost minimization methods as the reasons for cost savings and increased efficiency. As researchers try to find the reason for a specific firm's success and another's failure, the market continues to change and adapt to an influx of new entrants and different varied methods.

CONCEPTUAL FRAMEWORK

Consider a firm using N inputs represented by the input quantity vector $X = (x_1, \ldots, x_N)$ to produce M outputs represented by the output quantity vector $Q = (q_1, \ldots, q_M)$. Inputs are the resources being used for the production of goods or services output. Output is the good or service provided by the firm using the input resources. The firm pays input prices $W = (w_1, \ldots, w_N)$ and the output prices are $P = (p_1, \ldots, p_M)$. The production set is the set of output quantity vectors and input quantity vectors that is feasible, and is defined as

$$S = \{(Q, X) : Q \text{ is producible with } X\}. \quad (1)$$

An output set is the set of all output quantity vectors that are producible with a given input quantity vector, and is defined as

$$Z(X) = \{Q : (Q, X) \in S\}. \quad (2)$$

An output set is assumed to be closed and convex and to satisfy strong disposability of outputs. Its outer boundary is known as an output isoquant

$$O(X) = \{Q, Q \in Z(X), \lambda Q \notin Z(X), \lambda > 1\}. \quad (3)$$

An output quantity vector *Q* must be within its output set *Z(X)* but need not be located on its output isoquant *O(X)*.

The Farrell output distance function is defined as [1]

$$f_0(Q, X) = \max\{\varphi = \varphi Q \in Z(X)\}. \quad (4)$$

If *Q* belongs to production set *Z(X)*, $Q \in Z(X)$, then $f_0\ (Q, X) \geq 1$. If q belongs to the output isoquant or the frontier of the production set, then $f_0\ (Q, X) = 1$.

[1] Distance functions are function representations of multiple-output, multiple-input technology that require data only on input and output quantities (Coelli et al. 2005, p. 47).

An input set is the set of all input quantity vectors capable of producing a given output quantity vector. It is defined as

$$L(Q) = \{X: (X \text{ can produce } Q)\}. \tag{5}$$

This is assumed to be closed and convex, and to satisfy strong disposability of inputs.

The lower bound of the input set is the input isoquant given by

$$I(Q) = \{X : X \in L(Q), \lambda X \notin L(Q), \lambda < 1\}. \tag{6}$$

An input quantity vector, X, must be within its input set, $L(Q)$. However, it does not need to belong to its input isoquant, $I(Q)$.

The input distance function is defined as

$$f_i(Q, X) = \min\{\theta = \theta X \in L(Q)\}. \tag{7}$$

If X belongs to the input set, $L(Q)$, then $fi(Q, X) \leq 1$. If X belongs to the input isoquant, $I(Q)$, then $fi(Q, X) = 1$.

Efficiency Measures

Efficiency of a firm consists of two components: technical efficiency and allocative efficiency. Technical efficiency refers to the ability of a firm to obtain maximal output from a given set of inputs. Allocative efficiency refers to the ability of a firm to use the inputs in optimal proportions, given prices and technology. Together, these two measures provide a measure of total economic efficiency. The output-oriented technical efficiency measures are equivalent to the output distance functions by Shephard (1970). This is important when discussing the use of Data Envelopment Analysis (DEA) methods calculating Malmquist indices of total factor productivity change.

Productivity Measures

Productivity is a level concept which, when measured, we can compare performance of firms at specific times. In other words, the goal in productivity, as well as efficiency analysis, is to examine and assess the performance of firms that convert inputs into outputs. Productivity is the efficiency in the use of inputs, measured in output in relation to these inputs. When productivity change is measured, a specific firm's performance over time is observed. When measuring a firm's change in productivity that has multiple outputs and multiple inputs, the change of productivity is shown by total factor productivity. To measure productivity change for a firm from period *s* to period *t*, the firm's outputs q_s and q_t using inputs x_s and x_t are used. With this data for a firm, productivity change can be measured in a number of ways. For this study, the approach utilized was that made popular by Caves, Christensen, and Diewert (1982) who measured productivity by comparing the observed outputs in period *s* and *t* with the maximum level of outputs that could be produced using x_s and x_t, producing under a reference technology. For example, using period *s* technology as the reference technology, a firm produces 75 percent of the maximum output for the given input vector, x_s, in period *s*. Then in period *t*, the firm produces 25 percent above the maximum output of the input vector x_t in comparison to the reference technology, which is period *s*. The firm would have a measure of productivity change between the two periods of 1.25/0.75 = 1.667. This 1.667 is the ratio of productivity change or the Malmquist Productivity Index (Coelli et al. 2005, p. 65).

Malmquist Productivity Index (MPI)

The Malmquist Productivity Index (MPI) is a measurement of the change in total factor productivity in two data points by calculating the ratio of the distances of the specified data compared to a common technology with panel data. The Malmquist Productivity Index is named after Professor Sten Malmquist, on whose ideas it is based. The Malmquist index was introduced by Caves et al. (1982); they named it to recognize Sten Malmquist who proposed constructing quantity indexes as ratios of distance functions (Fare et al. 1994). The MPI is not based on specific assumptions about the returns-to-scale properties of the production technologies that underpin the observed output and input quantity vectors.

When the technology shows constant or variable returns-to-scale, all distances involved in both input-oriented and output-oriented Malmquist indices can be calculated (Coelli et al. 2005, p. 72). However, Grifell-Tatjé and Lovell (1995) use a simple one-input, one-output example to show that the MPI may not accurately measure total factor productivity when variable returns-to-scale (VRS) is the assumed technology. Constant returns-to-scale (CRS) must be imposed on the technology used to accurately estimate distance functions or adjustments must be made to correct for this omission. If the CRS assumption is not made, the measures may not reflect gains or losses in total factor productivity resulting from scale effects (Ray and Desli 1997). Therefore, Grifell-Tatjé and Lovell (1995) state that MPI should be estimated using CRS distance functions. Productivity change estimates are biased when they are based on VRS distance functions and this bias is systematic. Therefore, in the presence of decreasing returns to scale productivity, change is overstated when there is input growth. In the presence of increasing returns to scale, productivity change is understated when there is input growth.

Constant returns-to-scale in the model are assumed because of the aforementioned reasons and also all firms are expected to operate at an optimal scale, using output-oriented productivity measures. The output-oriented productivity measures will use an output distance function. This function will identify the maximum expansion possible without changing the input quantities. The decision to choose output-oriented productivity measures over input-oriented is an arbitrary process. One rule is to utilize with input-oriented distance functions when the firms have more control over inputs rather than outputs, and vice versa (Coelli et al. 2005, p. 264). However, when the production technology exhibits CRS like this one, then input-oriented and output-oriented Malmquist indices correspond (Coelli et al. 2005, p. 69).

In the case of two periods, base period s and a subsequent period t, if technology used for period t is used as the reference technology, the productivity change over period s and period t is can be written as

$$m_o^t(q_s, x_s, q_t, x_t) = \frac{d_o^t(q_t, x_t)}{d_o^t(q_s, x_s)}. \tag{8}$$

Period s can be the reference technology and be defined as

$$m_o^s(q_s, x_s, q_t, x_t) = \frac{d_o^s(q_t, x_t)}{d_o^s(q_s, x_s)}. \tag{9}$$

An output-oriented MPI value greater than one indicates positive total factor productivity change (TFP) or technology progress; a value less than one indicates a TFP decline. In the case of two periods s and t, the Malmquist calculation requires two single-period and two mixed period measures, defined as follows (Chen and Ali 2004).

The Malmquist Index is often defined as the geometric mean of two indices to avoid choosing one technology (or time period) over the other,

$$m_o(q_s, x_s, q_t, x_t) = \left[\frac{d_o^s(q_t, x_t)}{d_o^s(q_s, x_s)} \times \frac{d_o^t(q_t, x_t)}{d_o^t(q_s, x_s)} \right]^{1/2}. \quad (10)$$

With the Malmquist Index, more information can be found through decomposition. The Malmquist index can be decomposed into two components, one measuring the change in efficiency and the other measuring the change in the frontier technology (Chen and Ali 2004). The distance functions in this Malmquist Index can be rearranged to show the product of technical efficiency change index and an index of technical change,

$$m_o(q_s, x_s, q_t, x_t) = \frac{d_o^t(q_t, x_t)}{d_o^s(q_s, x_s)} \left[\frac{d_o^s(q_t, x_t)}{d_o^t(q_t, x_t)} \times \frac{d_o^s(q_s, x_s)}{d_o^t(q_s, x_s)} \right]^{1/2}. \quad (11)$$

Technical efficiency change of an observed pair of inputs and outputs from an output-orientated measure is the extent to which the observed output vector could be radially expanded to be on the frontier of the production possibility set associated with the input vector. This term is the ratio outside the brackets in equation (11). If the value of technical efficiency is less than, equal to, or greater than one, then that firm is below, on, or above the production frontier, respectively. This is shown graphically in Figure 1. There, Firm A is producing below the frontier in period s and, thus, is deviating from the frontier and is technically inefficient.

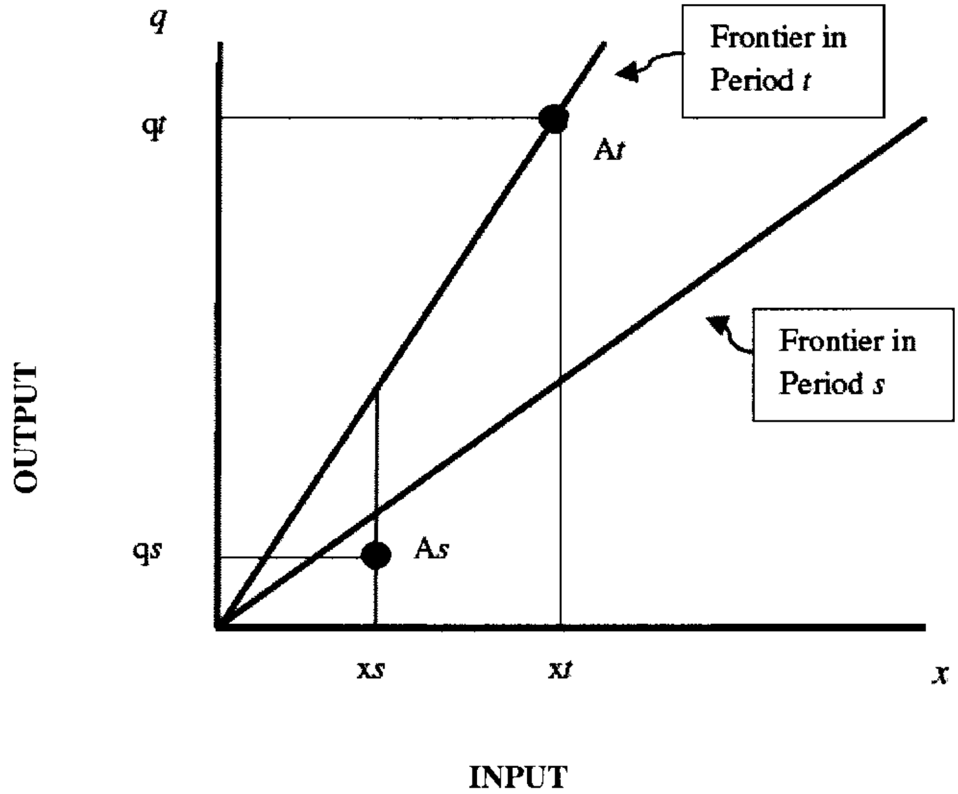

Figure 1. *The Malmquist Productivity Indices Illustrated* (Source: Coelli et al. 2005, p. 71).

The remainder of equation (11) is technical change. Technical change experienced by a firm can be measured through its ability to produce more or less with a given vector of input quantities in period *t* in comparison to the levels feasible in period *s* in regards to production technology. Technical change can be measured relative to a given input and output vector. If this measure is less than, equal to or greater than one, the technological best practice is deteriorating, unchanged or improving respectively. In the same Figure 1, technical change can easily be seen by comparing the two periods' frontiers. Compared to the first period, if it is below, technical change is deteriorating. However, if it appears as in Figure 1, technical change is improving for the specified firm (Coelli et al. 2005, p. 76-77).

The relationship found in equation (11) is shown in Figure 1. In this diagram, a single output q is produced from one input x. CRS technology in this example is assumed. If firm A were to produce at point As in the first period and at point At in the second period, both its technical efficiency change and technical change can be analyzed. With firm A producing below the CRS frontier in period s as noted before, it is determined that A is technically inefficient. However, in period t, A is producing at point At that is on the frontier for that period and thus, is technically efficient. The upward shift in the CRS production frontier from period s to period t demonstrates that there has been an improvement in technology. This explains technical change for firm A (Kirikal 2005, p. 27).

There are a number of different methods that could be used to estimate a production technology and therefore are able to measure distance functions that form the Malmquist index. The most popular method has been the data envelopment analysis (DEA) linear programming methods. For the i-th firm, five distance functions must be calculated to measure the productivity change between two periods (Coelli et al. 2005, p. 294). The five necessary linear programming problems are (12), (13), (14), and (15) along with (16).

$$\begin{aligned}
&\left[d_o^t(q_t, x_t)\right]^{-1} = \max_{\phi,\lambda} \phi, \\
\text{st} \quad & -\phi q_{it} + Q_t\lambda \geq 0, \\
& x_{it} - X_t\lambda \geq 0, \\
& \lambda \geq 0, \qquad (12)
\end{aligned}$$

$$
\begin{aligned}
&\left[d_o^s(q_s, x_s)\right]^{-1} = \max_{\phi,\lambda} \phi, \\
\text{st} \quad & -\phi q_{is} + Q_s\lambda \geq 0, \\
& x_{is} - X_s\lambda \geq 0, \\
& \lambda \geq 0,
\end{aligned} \tag{13}
$$

$$
\begin{aligned}
&\left[d_o^t(q_s, x_t)\right]^{-1} = \max_{\phi,\lambda} \phi, \\
\text{st} \quad & -\phi q_{is} + Q_t\lambda \geq 0, \\
& x_{is} - X_t\lambda \geq 0, \\
& \lambda \geq 0,
\end{aligned} \tag{14}
$$

$$
\begin{aligned}
&\left[d_o^s(q_t, x_t)\right]^{-1} = \max_{\phi,\lambda} \phi, \\
\text{st} \quad & -\phi q_{it} + Q_s\lambda \geq 0, \\
& x_{it} - X_s\lambda \geq 0, \\
& \lambda \geq 0,
\end{aligned} \tag{15}
$$

$$
\begin{aligned}
&\left[d_o^t(q_s, x_s)\right]^{-1} = \max_{\phi,\lambda} \phi, \\
\text{st} \quad & -\phi q_{is} + Q_t\lambda \geq 0, \\
& x_{is} - X_t\lambda \geq 0, \\
& \lambda \geq 0,
\end{aligned} \tag{16}
$$

$s = 1999$
$t = 2003$

DATA AND VARIABLES

Data available on the trucking industry is abundant due to reporting demands by the Interstate Commerce Commission (ICC). Large motor carriers, both public and private, are required to file Form M's. These detailed annual reports give pertinent information on each carrier's operations. For over 60 years, firms have been filing Form M's annually that detail their financial instruments such as the balance sheet and income statement, as well as a description of operations and organizational structure (Silverman and Nickerson 1997).

This study used the Form M's to gather information on Class I and Class II[2] carriers that were in operation during the years from 1999 to 2003. With a goal to measure productivity change among the large motor carriers in this period, it was required that the firm's data was available annually for the sample years. After deleting firms with noticeable errors or omissions, a sample of 115 firms remained. The data used has some areas of caution despite being so detailed. First, there is a size bias with the data. After deregulation, the ICC required only carriers with annual revenues above $3 million to file Form M. Since Form M supplied data, it cannot be presumed that the small carrier population has had the same productivity change as its larger competitors. Second, the Bureau of Transportation Statistics (BTS) notes that users of the data should use caution because all data elements are not annual. Some observations are reported for close of year, beginning of year, actual full year, and as averages for a year of data (Bureau of Transportation Statistics). However, the data variables used in this study take this into account and are capable of providing concise results of productivity change, technical efficiency change, and technical change.

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[2] Class I carriers have annual carrier operating revenues of $10 million or more. Class II carriers have annual carrier operating revenues of at least $3 million but less than $10 million.

To properly analyze productivity change, technical efficiency change, and technical change in this study, six inputs and three outputs were chosen. The vector of inputs is composed of variables that give an idea of how much input and time are incorporated into operation. The inputs chosen are total insurance payments, fuel quantity, total wages, equipment rentals with drivers, equipment rentals without drivers, and total revenue equipment. The inputs were used because they are key inputs to trucking and give insight into each carrier's operation. Each figure is determined differently according to ICC guidelines and is listed in Table 1, except for fuel quantity. This variable was determined by using Form M's variable fuel expense and dividing it by the average national price of diesel for the corresponding year according to the Energy Information Administration. For 1999, the average price of diesel was $1.12 per gallon and $1.51 for 2003 (Energy Information Administration). Output is measured by intercity miles, intercity tons and intercity shipments. Revenue ton-miles (RTM) is the preferred output measure, however erroneous and questionable RTM values required the use of the three listed output variables. These output variables are defined and explained in Table 2.

Table 1. *Definition and Derivation of Input Variables*[3]

Variable	Label	Description	Construction
Total Insurance Expenses	tot_ins	All insurance premiums and expenses	Sum of Acct lines 219 – 221 in form M
Fuel Quantity	fuelqty	Fuel and lubricants plus taxes divided by average price of diesel	Sum of Acct213 and Acct223 in form M divided by average price of diesel
Total Wages	tot_wages	Total wages, salaries and fringe benefits	Sum of Acct lines 206 – 211 in form M
Equipment Rentals with Drivers	equip_dr	Amounts payable for use of rev. vehicles and drivers	Acct226 of form M
Equipment Rentals without Drivers	equip_nodr	Amounts payable for use of rev. vehicles only	Acct227 of form M
Total Revenue Equipment	eq1	Equipment at start of year plus equipment at end of year divided by 2	(Acct408a + Acct 408e)/2 in form M

[3] Based on Form M database done by the Bureau of Transportation Statistics, 2003.

Table 2. Definition and Derivation of Output Variables[4]

Variable	Label	Description	Construction
Total Intercity Miles	ic_mile	Total miles, loaded and empty in intercity service	Acct301c in form M
Total Intercity Tons	ic_ton	Total tons - intercity	Acct304c in form M
Total Intercity Shipments Carried	ic_ship	Total shipments carried - intercity	Acct305c in form M

*Any missing values in these data were replaced by LTL and TL totals.

The descriptive statistics for these variables are compiled from the annual data of the 115 firms included in this data from 1999 and 2003. Table 3 provides general statistical information on the variables used. Nearly all the variables; total insurance expenses, fuel quantity, total wages, equipment rentals with drivers, equipment rentals without drivers, total intercity miles, total intercity tons, and total intercity shipments carried, increased between 1999 and 2003. The largest increase was equipment rentals with drivers (101%). Nickerson and Silverman (2003) stated that in the absence of externalities, a carrier would prefer to contract with an owner-operator rather than to hire a driver to operate a company-owned truck. Two externalities they identify as the most important are coordination and carrier reputation problems. However, increased use of cell phones and the availability of logistical software could help reduce some of the coordination problems when renting an owner-operator for certain shipments where it is more economical to do so. As for the reputation concerns of the carrier, simple background checks on the Federal Motor Carrier Safety Administration's website (fmcsa.dot.gov) can verify whether or not an owner-operator can be trusted hauling its freight. Whether these reasons were the cause for

[4] Based on Form M database done by the Bureau of Transportation Statistics, 2003.

Table 3. Descriptive Statistics of the Variables

Variable	Year	Mean	Change	Median	Standard Deviation	Minimum	Maximum
tot_ins	1999	3432038		449759	9548716	53197	61534482
	2003	5309511	55%	697700	14047218	140351	94684000
fuelqty	1999	8730380		1414836	22355581	29313	153502900
	2003	10598366	21%	1329547	28814912	20477	217981846
tot_wages	1999	70163941		5781512	220799910	910294	1760000000
	2003	87203036	24%	6090571	257926604	688033	1860000000
equip_dr	1999	3739166		262133	13966069	0	146209000
	2003	7519401	101%	869523	33986888	0	354208000
equip_nodr	1999	2261420		346762	7385644	0	49260100
	2003	3321688	47%	283558	12780380	0	97694037
eq1	1999	5248		357	26669	52	277069
	2003	3586	-32%	401	10104	52	63003
ic_mile	1999	65672327		10850000	199391440	21300	1700000000
	2003	79077111	20%	10500000	257050894	217000	1930000000
ic_ton	1999	1571993		338198	4689794	21	36000000
	2003	1872010	19%	333121	6481470	1125	57500000
ic_ship	1999	775965		26254	2901570	2077	24800000
	2003	850117	10%	30655	3044113	2059	26300000

increased use of owner-operators, the bottom line is that they are cheaper to use than company drivers as noted in the Literature Review, which is most likely the primary reason.

As noted earlier, the reason this time frame was selected is because of numerous changes in safety programs and security. One of the more notable programs, the Performance and Registration Information Systems Management, or PRISM, was being implemented in states across the United States during this time. PRISM was implemented by the Federal Motor Carrier Safety Administration (FMCSA) at no cost to state government. It proved to be cost effective and feasible, with many benefits for each state. It provided accountability with a performance-based system for safety management in order to hold carriers liable for unsafe drivers. It also developed Safestat, an algorithm that used trucking data to identify potentially dangerous drivers. PRISM improved the efforts of the FMCSA in identifying high-risk drivers and sending warning letters for minor safety problems. However, the greatest benefit from PRISM for analyzing the trucking industry is that it improved data quality by developing systems for identification accuracy, developing a procedure for correcting errors in data, and by funding bar-code technology for registration documents (Federal Motor Carrier Safety Administration).

The smallest increase shown in Table 3 was the total intercity shipments carried (10%). Although this is a small percentage compared to the rest, it is still, on average, a 74,000 increase in shipments per carrier as seen in Table 3. The reason that it is the smallest of the three outputs may be that the trucks are now bigger and more efficient. Being able to haul more freight per shipment would keep the increase in the number of shipments down.

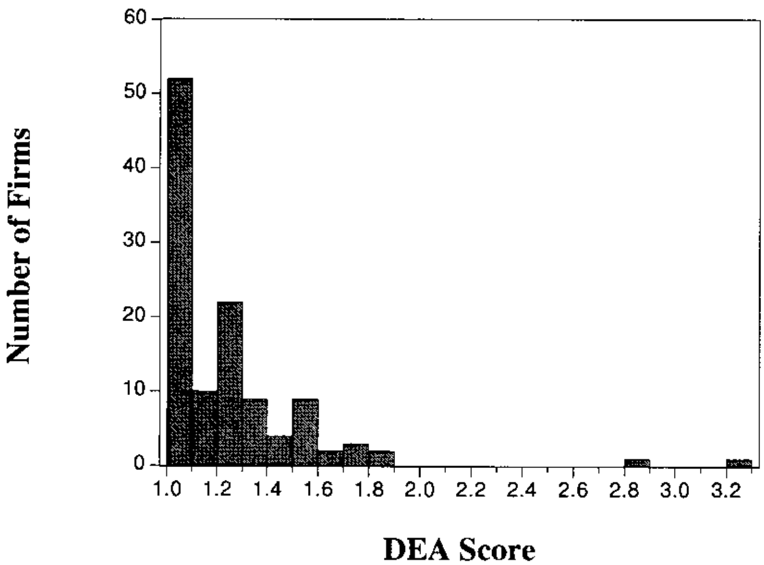
Total revenue equipment (-32%) did not increase like every other variable. However, if equipment rentals were increasing and a smaller number of trucks were needed to haul the same amount of freight, it would seem logical that the amount of equipment owned would decrease.

High standard deviations seen in Table 3 suggest that although only the larger firms were sampled, they vary greatly in size and composition. Median values are also much smaller than the means; this difference shows large gaps between the smallest and largest firms in the sample.

RESULTS

The Malmquist Productivity Index was calculated, and decomposed into efficiency change and technical change for 115 Class I and II motor carriers. This paper had two goals and two hypotheses that were presented in the beginning. This chapter presents the results as well as provides the findings to the hypotheses.

In order to solve for the Malmquist Productivity Index, linear programs shown previously in equations (12) through (16) were used. For every firm, distance functions were calculated to measure the productivity change between two periods, 1999 and 2003. Let s represent year 1999 and let t represent year 2003. Figures 2 and 3 present the DEA efficiency scores for years 1999 and 2003, respectively.



Series: _11_10	
Sample 1 115	
Observations 115	
Mean	1.229852
Median	1.147180
Maximum	3.244496
Minimum	1.000000
Std. Dev.	0.331794
Skewness	3.230307
Kurtosis	17.99200
Jarque-Bera	1276.977
Probability	0.000000

Figure 2. *Histogram of DEA Scores for Year 1999.*

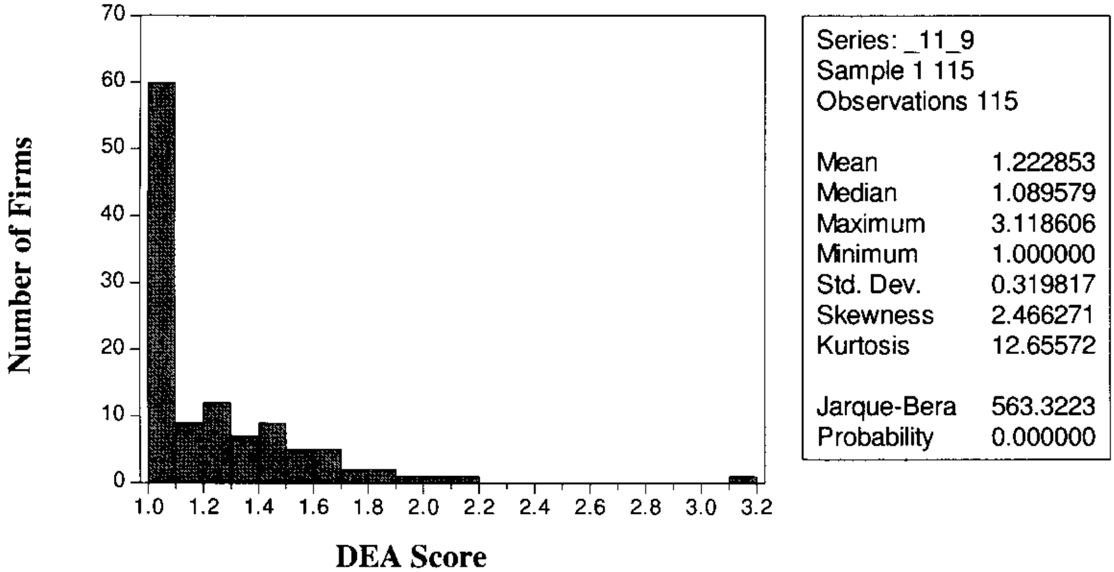


Figure 3. *Histogram of DEA Scores for Year 2003.*

The two years have similar means of 1.2299 for 1999 and 1.2229 for 2003. A t-test is used to find if the means are statistically different from 1.0 or not (Table 4). The median was lower in 2003, which can be seen on the histogram as well with more firms closer to one. A lower median is a positive indicator that most firms are efficient. There is an outlier in each histogram that has the maximum 3.2445 in 1999 and 3.1186 in 2003.

The goal in equations (12) and (13) was to find out how efficient the industry was on average for a single period. For equation (12), 2003 was noted as period t and found a mean of 1.2229 and a standard error of 0.0298. The t – statistic for this period was 7.4725. For equation (13), 1999 was noted as period s and found a mean of 1.2299 and a standard error of 0.0309. The t – statistic for period s was 7.429. Hence, the averages of 1.2229 and

Table 4. *Hypothesis Test for DEA Scores*

Period	(1999)	(2003)
Mean	1.2299	1.2229
Standard Error	(0.0309)	(0.0298)
t - Statistic	7.429*	7.4725*
Number of firms = 1	44	49
Number of firms > 1	71	66

* Significant at the 1% level

1.2299 are significantly different from 1. Therefore, the U.S. trucking industry on average was technically inefficient in years 1999 and 2003.

The first goal was to analyze the productivity change of U.S. trucking firms between 1999 and 2003. This goal was the primary motivator for this study and was chosen because of the need to find productivity change in the U.S. trucking industry. One of the most important aspects of management is productivity.

Hypothesis 1: Productivity for the industry will increase for the five-year span covered for this study.

This hypothesis was supported in this study. Figure 4 shows the Malmquist productivity change scores by the U.S. trucking firms in a histogram. Improvements in productivity result in Malmquist indices greater than one, and deterioration in performance throughout the sample period yield a Malmquist index less than one. Figure 4 shows the median of 1.13, a maximum of 4.03 and a minimum of 0.248. However, a Malmquist Productivity Index of 1.1825 for the industry is much greater than one. Furthermore, 75.7 percent of the 115 firms have a score of greater than one. This finding proves that the trucking industry was experiencing productivity improvement from 1999 to 2003.

However, the trucking industry was found to be inefficient during this time period. This motivates decomposition of the Malmquist Productivity Index.

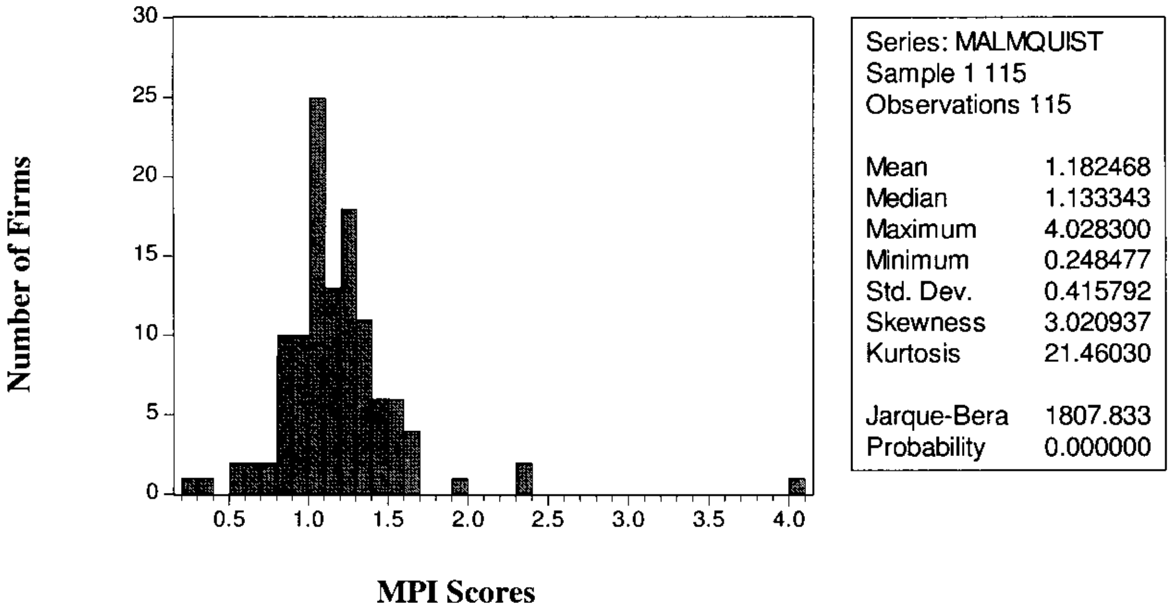


Figure 4. *Histogram of MPI from Equation (10).*

The second goal was to find the reasons for productivity improvement over time based on Malmquist Productivity Index components: technical change and technical efficiency change. It is beneficial to use the Malmquist Productivity Index approach for a few reasons. First, it can handle examples with multiple inputs and multiple outputs. It can also be decomposed into two components: technical change and technical efficiency change. This division allows the analysis of the U.S. trucking industry to determine whether it has improved its productivity and to examine the reasons for this productivity change.

Hypothesis 2: Any increased in productivity for the U.S. trucking industry will be a result of technical change.

The second hypothesis was also confirmed in this study. The results gathered from the study suggest that, in most of the trucking firms, productivity growth has mainly been fueled by technical change rather than improvements in technical efficiency. Since the deregulation of the trucking industry, trucking has become a highly competitive arena. If a trucking firm is not efficient at its conception, it most likely will not succeed.

Figures 5 and 6 show the histograms for the decomposition of the Malmquist Productivity Index. The histograms show industry average scores of 0.98105 and 1.17838 for technical efficiency change and technical change, respectively. While the Malmquist Productivity Index and technical change had higher scores, they also had higher standard deviations, .4158 and .3888, respectively. Technical efficiency change had a lower score but with a lower standard deviation of .2470. This low standard deviation for technical efficiency demonstrates that the whole industry operates at a similar efficiency level. Also, only 52.2 percent of the firms had technical efficiency scores of one or greater while 74.8 percent of the firms had technical change scores of one or greater.

To see which component is greater, the technical efficiency change component was divided by the technical change component for each of the 115 firms. If the ratio was greater than one, on average, technical efficiency change would be greater than technical change. A ratio of one would mean they are equal. The ratio was 0.86. Therefore, the technical change component is greater than the technical efficiency component. However, to confirm this, a t-test was run and a t-statistic of -6.348 was found. The t-stat is

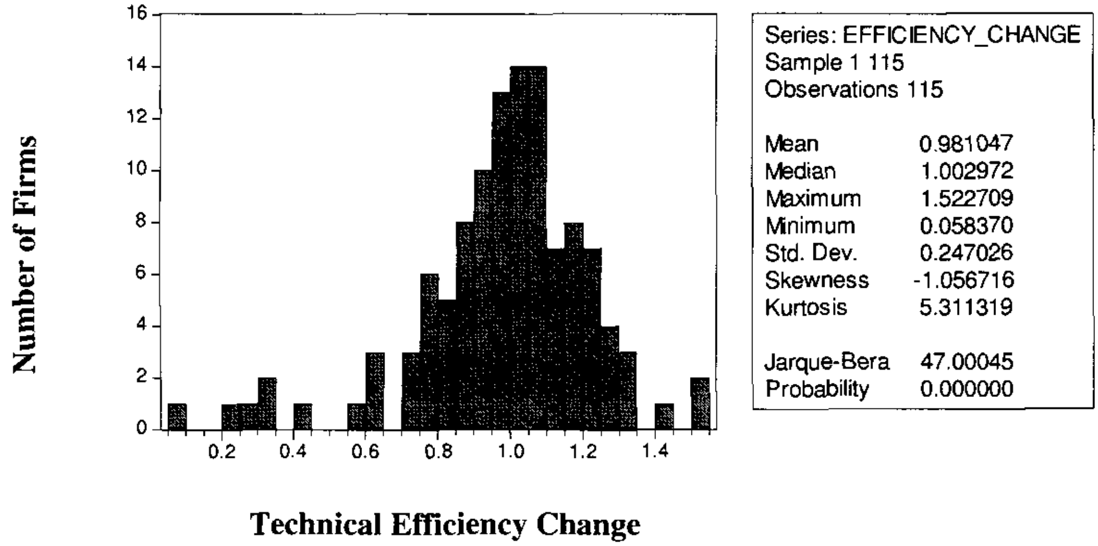


Figure 5. *Histogram of Technical Efficiency Change.*

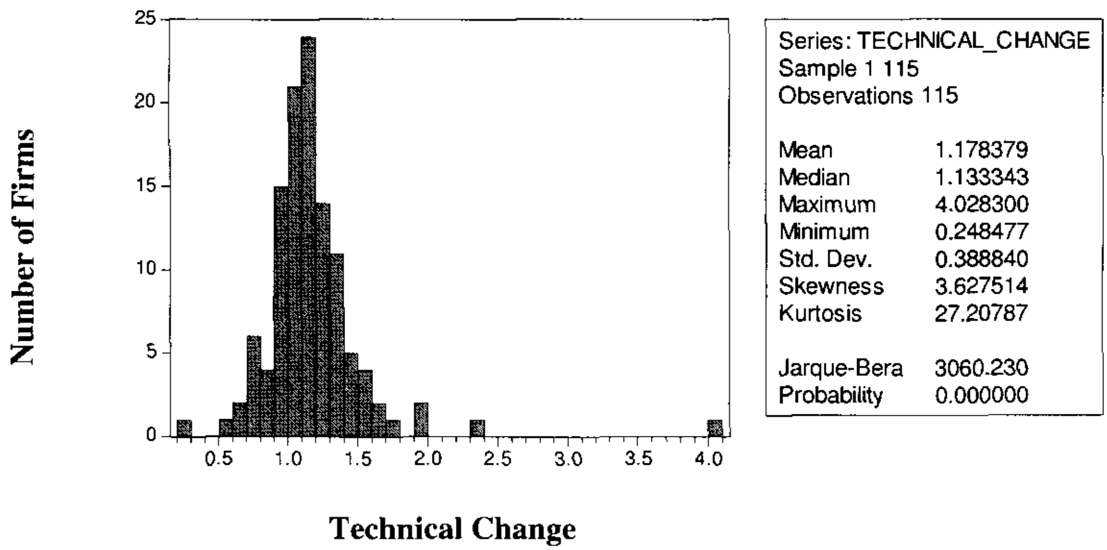


Figure 6. *Histogram of Technical Change.*

negative and significant at the 1 percent level. Therefore, on average, the effect of technical change is greater than that of technical efficiency for the productivity growth of the trucking industry between the period 1999 and 2003.

The findings confirm that technical efficiency change is at a statistical standstill for the industry and technical change is nearly equal to the Malmquist Productivity Index on average. Improvements in the technical efficiency change are to be interpreted as getting closer or "catching up" to the frontier. For technical efficiency in each year, the mean is to be statistically greater than 1.0 and therefore, the industry has been inefficient. Methods such as the just-in-time method mentioned in the literature review may be outdated and inefficient. New strategies should be developed to get shipments from point A to point B in order to increase efficiency. Meanwhile, improvements in the technical change score are evidence of innovation. This evidence is supported by the literature review through an explanation of how productivity improvements are made, either through fewer empty miles or less time waiting to be loaded (Nagarajan et al. 2000). Load matching services that use the Internet, on-board computers, and other forms of e-commerce, help decrease empty miles and wait time (Baker and Hubbard 2004). Also, bigger and better trucks have helped increase productivity by hauling more freight. A technical change score of 1.18 for the trucking industry signals it is fair to say, they have had technological advancements that have led to increased productivity.

CONCLUDING REMARKS

The U.S. trucking industry is a dynamic part of the U.S. economy, affected by numerous factors. Many variables affect its efficiency and productivity. To determine what variables most directly affect the industry, the Malmquist Productivity Index was decomposed to analyze technical efficiency scores and technical change scores. The findings in this study point to technological innovation as the reason for productivity improvement and to inefficiency in the industry. The competitive nature of the industry, coupled with deregulation, require trucking firms to embrace technology to increase productivity. Extensive growth in efficiency change is needed as well to increase productivity. The U.S. trucking industry would benefit from this study by acknowledging shortfalls in efficiency and by initiating new programs to improve it. For individual firms, especially those with an MPI lower than one, an awareness that technology increases productivity, coupled with investments in technology would be productive for the firms.

It is positive to see improvements in productivity and interesting to find those improvements are coming from technological advancements. This topic would be interesting to study again for the next five-year period to see whether or not the industry will continue to improve productivity or if efficiency scores would increase. Technical change was important for firms in this time period and hopefully they will continue to invest in technology since it improves productivity. Other interesting variables to include for a future study are negative inputs such as pollution, congestion and delays, or safety ratings as an input, since this information is available.

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