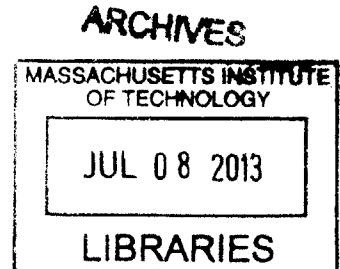


Productivity and Competition in the U.S. Trucking Industry since Deregulation

by

Veiko Paul Parming

BASc. Civil Engineering
University of Toronto, 2011



Submitted to the Department of Civil and Environmental Engineering in partial fulfillment of the requirements for the degree of

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Abstract

In 1980 Congress passed the Motor Carrier Act, substantially liberating trucking carriers from a federal regulatory structure that had exercised broad economic control over the industry for over four decades. Changes in the industry were swift and extensive.

This thesis returns to the transformational period encompassing the deregulatory and post-deregulatory years. Using the Motor Carrier Annual Reports (Form M) dataset, the thesis sets its focus as physical productivity at the firm level, and analyzes the truckload (TL) and less-than-truckload (LTL) sectors separately. The Form M dataset covers the years 1977-1992; the baseline for cumulative analysis is set as 1979, the eve of the Motor Carrier Act. The productivity analysis is contextualized within a wider account of industry changes, including substantial declines in unit costs. The thesis goes on to present a framework for understanding how deregulation engendered changes in competition and productivity.

Physical multifactor productivity (MFP) growth in the years 1979-1992 is found to average 1.6% p.a. for TL and 1.0% p.a. for LTL. After initial productivity stagnation, MFP growth from 1983 on was 2.0% and 1.7% p.a. for TL and LTL, respectively. This is suggestive of steady improvement in efficiency, if not a productivity revolution.

Although productivity growth was modest, it played a significant role in cutting unit costs. Between 1979-1992 real unit costs declined by 39% for the truckload sector; productivity factors were associated with a 17% reduction while input price factors were responsible for a 20% reduction. For the LTL sector, the decline in unit costs was 17%, with productivity responsible for a 7% drop and input price factors, an 11% drop. The unit cost savings enabled carriers to offer lower real output prices to shippers.

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Glossary

Carrier: Motor carrier; the company providing the transportation of freight.

Common vs. Contract Carrier: A distinction between carriers from the regulatory era. Common carriers offered service to the general public, while contract carriers could engage a limited number of shippers in contracts. The distinction became largely irrelevant after deregulation.

Deregulation: Used in this thesis to refer to the major liberalization of U.S. trucking regulation in the late 1970s. In some contexts “deregulation” specifically designates the passage of the 1980 Motor Carrier Act, but for the most part it refers to the general loosening of regulations taking place over the period, beginning internally at the Interstate Commerce Commission in the mid-late 1970s.

For-Hire vs. Private Carrier: For-hire carriers are companies that offer trucking services to the public; they include truckload and less-than-truckload carriers. Private carriers transport goods owned by the carrier itself.

Hybrid or Mixed Carrier: Both terms are used in this thesis to refer to carriers that performed a considerable amount of both TL and LTL operations (20-80% of revenues from each). This segment dominated the industry before deregulation but virtually disappeared after.

Interstate Commerce Commission (ICC): the federal agency tasked with regulating the interstate trucking industry from 1935 until its abolition in 1995.

Less-than-Truckload (LTL): A segment of the trucking industry involving small shipment sizes (usually under 10,000 pounds). The LTL carrier operates a regional or national network of terminals where it aggregates and sorts freight shipments. *Compare: Truckload.*

Private Carrier: see *For-Hire vs. Private Carrier*

Sector/Segment: Typically a sector is broader than an industry, but this thesis uses both sector and segment to refer to subsets of the trucking industry.

Shipper: The customer of freight transportation; a company that seeks to ship or receive freight.

Ton-mile: The basic unit of physical output in freight transportation. One ton-mile equals one ton of freight moved over a distance of one mile.

Truckload (TL): A segment of the trucking industry involving dock-to-dock transportation of full loads, with no intermediate stops to pick up additional freight. *Compare: Less-than-truckload.*

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Outline of Thesis

Chapter One gives a brief overview of the history of U.S. transportation regulation, especially as affects the trucking industry. Attention is paid to the key features of the regulatory structure and how they changed.

Chapter Two motivates the thesis and summarizes several studies on trucking productivity. It also introduces the data sources used in this thesis, principally the Motor Carrier Annual Report ("Form M").

Chapter Three is a portrait of the trucking industry. The chapter presents an overview of the major industry changes following deregulation, using a combination of Form M and other data.

Chapter Four introduces the concept of productivity and discusses mathematical formulations and general issues with productivity measurement.

Chapter Five presents multifactor productivity findings for the trucking industry since deregulation, based on analysis of Form M data.

Chapter Six examines what portion of unit cost savings were attributable to physical productivity factors, and what portion to input price factors. The chapter first presents the mathematical basis for such analysis, and then the findings based on Form M data.

Chapter Seven ties together the concepts of productivity, competition and regulation. The objective is to demonstrate how regulation had both direct and indirect effects. The first part of the chapter is a theoretical discussion of the concepts; this is followed by an application of the concepts to the deregulated trucking industry.

Chapter Eight concludes the thesis. It includes a conclusion on regulation and a brief discussion of directions for future research. The final part is a summary of the thesis in the form of "Ten Observations about Post-Deregulation Trucking."

Appendices A and B are supplements to Chapters 5 (Productivity) and 6 (Unit Cost Decomposition), respectively.

Chapter 1 – Regulation and Deregulation in Trucking

In 1980, Congress undertook deregulation of the interstate motor carrier industry, as part of a wider movement of deregulation and regulatory reform across the domestic transportation industries. The Motor Carrier Act of 1980 (MCA) transformed core aspects of carrier operations, including entry and ratemaking, leading to substantial changes in industry structure and competition. Notable contemporary regulatory acts affecting the other transportation industries include the Railroad Revitalization and Regulatory Reform Act (1976) and the Staggers Rail Act (1980) in railroads; the Air Cargo Deregulation Act (1977) and the Airline Deregulation Act (1978) in airlines; the Household Goods Act (1980); and the Bus Regulatory Reform Act (1982).

If it has been a central economic doctrine in America that competition tends to produce the best compromise between the short-run objectives of consumers and the long-run needs of firms, then many analysts of the transportation industry had come to believe that its regulatory structure was more of a hindrance than a support to competition. As Meyer et al wrote in 1959:

[T]he ideal of regulation is to achieve, at least roughly, the results of competition in situations that are not entirely competitive. There are, however, increasing signs that regulation as it is practiced in the United States has resulted in the actual organization of transportation services departing from that which would result under competitive circumstances.

The Motor Carrier Act of 1980 was the product of three years of Congressional hearings and reflected substantial compromise among the stakeholders. Although research had not indicated substantial shipper dissatisfaction with trucking service, economists and academicians contended that the regulatory structure in place obstructed entry into the market and encouraged inefficiency. Moreover, they asserted that the motor carrier industry was particularly well suited to reliance upon market forces (Lieb, 1994).

The MCA itself was not total “deregulation” of the kind economists had championed, but it unleashed competitive forces that rapidly transformed the trucking industry into something approaching the perfect competition ideal.

1.1. History of US Transportation Regulation

Transportation regulation was born in the post-Civil War period, as rail outpaced water and wagons and as agricultural shippers successfully lobbied for protection from rail price discrimination. Supreme Court rulings in the late 19th century established the constitutionality of regulating interstate business and paved the way for passage of the Interstate Commerce Act (ICA), which created the Interstate Commerce Commission (ICC) to regulate the railroads.

Early transportation regulation generally sought to cultivate competition while promoting equity and accessibility for the shipping public. Railroads were the quintessential “big business” of the day. Transportation regulation very much followed the spirit of the Sherman Antitrust Act (1890) and the Clayton Act (1914), landmark statutes that became the foundation of US competition law. The experience with early rail regulation was mixed. Blatant discrimination was eliminated, but the ICC, tasked with responsibility for determining whether rail rates were “reasonable and just,” steadfastly rejected rate increases in the inflationary 1910s, leading to severe financial and service deterioration in the industry (Lieb, 1994). Furthermore, the miserable economic climate of the 1930s sparked rate wars in the nascent, federally unregulated motor carrier industry.

Over the first half of the 20th century, Congressional philosophy shifted from enforcing competition toward strengthening and stabilizing the several modes. In 1920 the ICC gained authority over minimum and actual rail rates, and between 1935 and 1940 ICC control was extended over motor carriers, water carriers, and freight forwarders. (Air carriage, too, became federally regulated, but under its own authority.) In this period, Congress also began to invest heavily in road, water, and air infrastructure.

The construction of the Interstate Highway System in the postwar period helped spur a growing attractiveness of trucking relative to rail. Congress attempted to revitalize the railroads in 1958, directing the ICC to arrest its perceived policy of “umbrella ratemaking,” which had inflated rail rates to

protect the traffic of other modes, and issuing guaranteed loans to cover investments and outlays. However, railroads continued to realize low earnings and indeed experienced losses on mandated passenger service (Lieb, 1994). The bankruptcy of seven major railroads in the early 1970s compelled Congress to re-examine its regulatory philosophy. Critics alleged that the entire transportation regulatory structure discouraged efficiency, inflated rates, and depressed service quality. Lawmakers came to believe that a fundamental overhaul of the regulatory structure was due.

Within a span of five years, the regulatory structures of the major domestic transportation industries were substantially reformed. The new guiding philosophy was that competition should flourish within and between the modes. The ramifications for individual modes were not uniform. In the rail industry, consolidation was promoted so as to enable railroads to earn rates congruous with their capital-intensive cost structure. Trucking witnessed a bifurcation into *truckload (TL)* and *less-than-truckload (LTL)* sectors, with low concentration in the former and high concentration in the latter.

General Congressional satisfaction with the outcomes of deregulation led to continued reforms into the 1990s, when the ICC was abolished and trucking deregulation was extended to the state level.

1.1. The Nature of Motor Carrier Deregulation

In the years preceding 1980, the ICC, cognizant of evolving Congressional sentiment, had already begun to liberalize entry and operating policies, leading to a rapid increase in ICC-regulated motor carriers. Building on this momentum, the Motor Carrier Act of 1980 (MCA) further opened the industry to the forces of competition. Although initially vehemently opposed to regulatory reform, the American Trucking Association, the industry interest group, came to support the final bill (Lieb, 1994).

This subsection details three central components of deregulation: relaxation of pricing controls, greater entry/operational freedom, and easing of restrictions on firm classification.

1.1.1. Pricing Controls (Ratemaking)

Prior to deregulation, the ICC commanded considerable control over trucking rates. In principle, its mandate was to ensure rates did not violate its standards of fairness and reflected a reasonable balance between the interests of the various parties. Upon finding a rate unreasonable or unjust, the ICC could variously prescribe minimum, maximum, and/or actual rates depending on the category of

carriage. The justification for minimum and maximum rates was, respectively, the avoidance of “cutthroat” or ruinous competition and the protection of small, remote, or otherwise disadvantaged shippers (Lieb, 1994).

In practice, the ICC’s regulation of individual carrier rates was not aggressive, as most common carriers belonged to rate bureaus and thereby set rates collectively. Exempted from antitrust laws by the Reed-Bulwinkle Act of 1948, rate bureaus were regional groups that developed freight classifications and corresponding rates, taking into account changes in carrier costs and needs. The ICC’s disposition was to provide little resistance to decisions reached by rate bureaus (Teske, 1995).

Deregulation had the effect of liberalizing pricing, in an incremental manner. Although deregulation did not dispossess rate bureaus of their antitrust exemption, it diminished their power. Rate bureaus were forbidden from voting on single line rates. A zone of pricing freedom was established, within which rates were to be free of ICC interference and rate bureau involvement. Rates were still required to be filed with the ICC, but tariff discounts became increasingly common as carriers sought to compete with one another. Trucking firms often failed to notify the ICC of rate reductions and the increasingly marginalized ICC did not aggressively pursue the matter (Teske, 1995). With the abolition of the ICC in 1995, rate regulations and tariff filing were finally eliminated, with small exceptions.

1.1.2. Entry and Operational Freedom

Entry questions were, according to Rothenberg (1994), the ICC’s most time-consuming issue, demanding 80%-85% of the commission’s time. The 1935 Motor Carrier Act (not to be confused with the 1980 MCA) had mandated that common carriers hold operating certificates, to be issued according to a test of “public convenience and necessity.” In practice, prospective entrants found it very difficult to prove public necessity where existing markets were already served by incumbents (Teske, 1995). The result was a long-term decline in the number of ICC-regulated motor carriers.

The certificate system controlled not only entry into the industry but also entry into particular markets. Operating certificates specifically enumerated the particular commodities that could be carried and the routes that had to be followed. The certificates were sellable, and by some estimates the aggregate market value of the certificates had reached \$2-4 billion in 1977 (Teske, 1995).

Along with the ICC initiatives preceding it, the 1980 MCA substantially loosened entry controls. The common carriers’ “public necessity and convenience” standard was replaced with a test of “useful

public purpose,” and the burden of proof was transferred to opponents to demonstrate that a new proposed service would not be beneficial. The ICC began to consider competition and rate levels in approving entry applications. Congress directed the commission to reduce operating burdens, such as unreasonable or narrow territorial limitations and restrictions on round-trip authority and service to intermediate points on routes (Lieb, 1994).

With the ICC Termination Act of 1995, requirements for operating authority were eliminated and the states were pre-empted from imposing economic control over the industry. Carriers could now transport virtually any commodities; their only entry requirements were to register with the Federal Motor Carrier Safety Administration and to furnish proof of insurance (Coyle, 2006).

1.1.3. Firm Classification

One of the most apparent changes in the trucking industry has been the way that carriers are classified. The pre-deregulatory period had spawned a very particular segmentation scheme. To simplify, carriers could be for-hire (providing services to the public) or private (moving the owner’s own freight). Among for-hire carriers there were “common” carriers, providing service upon demand; and “contract” carriers, engaging shippers in continuing contracts. Private carriers were not under the control of the ICC; most for-hire carriers were, but there were also some “exempt” carriers that for one reason or another had managed to obtain freedom from ICC influence: for example, agricultural lobbyists had secured an exemption for farm commodities as early as 1935 (Lieb, 1994).

Understood within the context of a regulated market, such a classification scheme appeared to be supported by reason, but it also necessitated a bureaucratic web of restrictions. For example, common carriers had incentives to sign low-rate contracts with favored shippers (to the detriment of disadvantaged shippers), so carriers were forbidden from offering both common and contract service. Contract carriers, then, might have poached all the favored shippers from common carriers, so contract carriers were restricted to a maximum of eight customers (the “Rule of Eight.”)

While the regulatory system distorted the industry, it proved unable to suspend the basic laws of economics. Private carriers, unencumbered by economic regulation, rose to become the fastest growing sector of the trucking industry before deregulation (Teske, 1995). The cumulative effects of regulation on efficiency, prices, and quality in the for-hire sector had prompted many shippers to start their own private trucking operations and transport their own freight.

With the acceptance that Congress no longer needed to protect small and remote shippers from the forces of competition, the rationale for many of the restrictions disappeared. Through the ICC's late-1970s initiatives and the MCA, dual common-contract carriers became lawful, the Rule of Eight was eliminated, private trucking firms were permitted to operate for-hire services, and truckers were authorized to carry regulated and exempt commodities simultaneously in the same vehicle.

During the 1980s, economic rationale replaced bureaucratic rationale in the categorization of industry sectors. As the distinction between common and contract carriers became increasingly anachronistic, motor carriers began to be classified more logically as truckload (TL) or less-than-truckload (LTL). Truckload operations entail transporting full truckload shipments between shippers' docks, with the shipper paying for the entire movement. In contrast, customers wishing to transport smaller shipments rely on LTL carriers to secure many shipments from diverse shippers and aggregate them for the intercity haul. Naturally, LTL operations require nontrivial physical infrastructure, including consolidation terminals and pickup and delivery operations.

Up until deregulation, it was very common for carriers to offer both TL and LTL services. However, the trend since that time has been a clear bifurcation into firms that specialize in one or the other. This trend is further investigated in Chapter 3.

1.2. Intrastate Deregulation

It is important to note that even after federal deregulation in 1980, states continued to exercise regulatory authority over motor carriers well into the 1990s. In 1994, 41 states continued to regulate intrastate trucking, and 31 states had rate bureaus operating under antitrust immunity. In fact, in 1994 30 states regulated rates not only for common carriers but also for contract carriers, often to protect the former from price-cutting (Teske, 1995).

The large disconnect between federal and state regulatory structures created inefficiencies and perverse incentives for shippers. One notable example was the city of Reno, NV becoming a distribution capital of California because trips between Reno and California enjoyed the benefit of interstate status. Unexpectedly, it was the deregulation of airlines that led to congressional pre-emption of state regulation. Air freight carriers (such as FedEx) had been freed of state air regulation but became

increasingly frustrated with state trucking restrictions that impeded their burgeoning ground parcel operations. Fearful of losing ground to the parcel carriers, LTL carriers too became supporters of state deregulation. In 1994, Congress directed states' regulations to be no more stringent than ICC rules. The restrictions on state power were retained after the ICC was abolished a year later (Teske, 1995).

Chapter 2 – Motivation of Thesis and Introduction to Data Sources

This short chapter motivates the thesis, summarizes other recent studies of trucking productivity, and introduces the data sources used in this thesis, principally the Motor Carrier Annual Reports (Form M).

The objective of this thesis is to examine how deregulation changed the trucking industry, and specifically how productivity changed. The thesis seeks to answer such questions as:

- What has been the level of productivity growth since deregulation?
- How important were productivity factors in bringing down unit costs?
- How did the regulatory changes affect the structure of the industry?

It has now been more than 30 years since deregulation, and this paper takes a multi-decade perspective of some of the major shifts in the industry. However, the core part of the analysis is for the years 1977-1992, the years for which I have Form M data. Although it would be ideal to examine productivity performance over a longer time period, the availability of detailed firm-level data decreased substantially over the years. Still, the period for which I have data is the most important one because it represents a “pattern break” – a period where the industry underwent transformative changes.

The original data analysis in this thesis is chiefly of multifactor productivity, and of the relationship between productivity, input prices and unit costs. There is also original analysis of data relating to the bifurcation of the industry and changes in unit revenues, costs and profits. This is supplemented with quantitative findings from other sources, consisting of minor manipulations of other authors’ analyses.

This thesis is also distinguished from others on the subject in that it segments the industry into truckload and less-than-truckload sectors and analyzes both separately. As well, all of the original analysis is at the firm level. Finally, this thesis strives to measure productivity strictly as physical

productivity, i.e. unaffected by price factors. Unfortunately, the nature of the data source is such as to not support extensive analysis of the underlying sources of productivity changes. Also, this thesis includes some analysis of labor price changes, but the labor aspect is not the focus.

2.1. A Summary of Other Studies of Trucking Productivity

One recent analysis of multifactor productivity (MFP) in the U.S. trucking industry was performed by Apostolides (2009). He estimated MFP for the period 1987-2003 using primarily Bureau of Economic Analysis data based on the North America Industrial Classification System (NAICS). These MFP findings are presented in Figure 2-1, along with an extension to 2010 based on the same data source and methodology (he also uses various other methods that reach similar conclusions – the reader is referred to the original study).

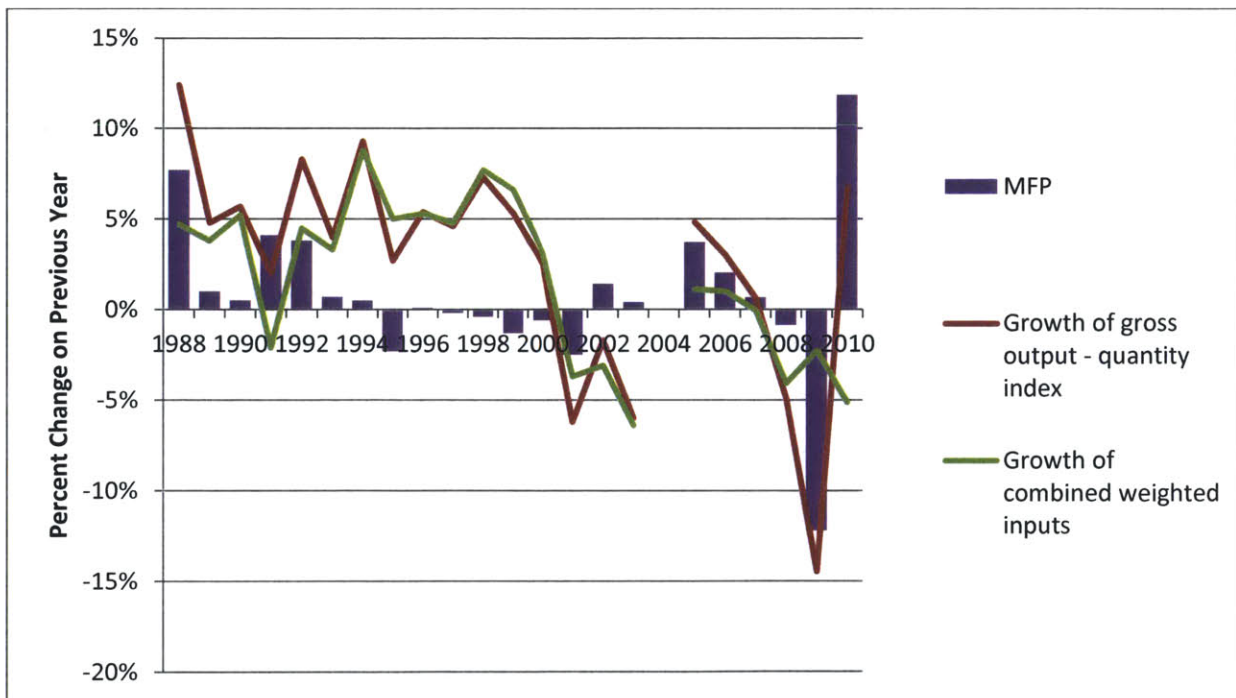


Figure 2-1: Multifactor Productivity for Trucking Industry – Using Apostolides Approach

Note: Data were not found for the year 2004.

Sources: Apostolides (2009 – see Table 2) for 1987-2003; author’s calculations for 2005-2010

Original Data Source: Bureau of Economic Analysis

Apostolides identified three periods with regard to productivity growth: 1987-1995, 1995-2001, and 2001-2003. Trucking MFP increased by 2% p.a. in the first period, declined at -0.8% p.a. in the second period, and increased again at 1.1% p.a. in the third period. Cumulatively, trucking productivity increased by 0.8% per annum over the 16-year period. Through 2000, trucking MFP growth outpaced the general economy's MFP growth, but after that trucking MFP grew more slowly.

If the analysis is extended to later years, productivity appears to grow in the mid-2000s, plummet after the 2008 recession, and recover some of the losses in 2010. Due to the unavailability of compatible data, extending the analysis to earlier years is not feasible.

A strength of the Apostolides study is its comparability with other transportation industries and with the general private business sector. Apostolides observes that rail achieves more than twice the productivity gains of air and trucking between 1987 and the early 2000s. However, although both studies are based on classical growth accounting formulas, there are several important reasons why the Apostolides results cannot be compared directly to the results from this thesis:

- Apostolides constructs inputs and outputs using a variety of physical quantities, quantity indexes, and constant-dollar (real) costs and revenues. In this thesis, productivity is based almost exclusively on directly observed physical quantities – only the fuel quantities are approximated. There are strengths and weaknesses to both approaches. Apostolides, by including a catch-all “intermediate inputs” input, potentially accounts for a larger breadth of company activity. However, the lack of physical quantities (aside from employees for labor) inhibits interpretation and makes it unclear to what extent MFP is measuring physical productivity and to what extent it captures other aspects of value
- The Apostolides study is aggregate at the industry level, while this thesis is disaggregate at the industry level, measuring the performance of individual firms
- The Apostolides study does not segment the trucking industry into TL and LTL sectors
- The Apostolides dataset overlaps only partly with the Form M set; the former only goes as far back as 1987-88

Another recent study of trucking productivity was that of Boyer and Burks (2006). They measured productivity not at the firm or industry level, but at the vehicle level, using data from the U.S.

Census Bureau's Vehicle Inventory and Use Survey (VIUS). Collected every five years, the VIUS dataset constitutes a random sample of the nation's trucks, and the authors restrict the analysis to the most common vehicle type, a heavy truck tractor pulling a standard enclosed van.

The objective of the Boyer-Burks study is to disentangle "true" physical productivity advances from shifts in the composition of traffic. They do this by controlling for three factors representative of the latter category: length of haul, sector, and commodity carried. The authors note that most productivity analyses of the trucking industry are not able to control for the heterogeneity in output and consequently overstate true productivity gains. The VIUS dataset does not include a good measure of output, but the authors construct an approximation for ton-miles from three components: the number of miles driven per year, the average tons hauled, and the proportion of trips that are loaded. They then perform regressions using the VIUS data to estimate how the three components of productivity are affected by traffic composition (the reader is referred to the study for details on how they do this). The authors hold the traffic composition steady and estimate how productivity would have changed under such a hypothetical scenario.

The authors find that productivity, defined as ton-miles per truck (per year), increased by 39% over the 15 year period, or 2.2% per year. Had there been no traffic shifts, this would have been 1.6% per year. Hence the traffic composition "bias" is around 30%. Most of the traffic mix distortion was from miles per truck, reflecting perhaps the most obvious bias: trucks that tend to perform long hauls travel the most miles per year, and the frequency of long hauls increased after deregulation.

The Boyer-Burks study is a reminder that endogenous factors impact productivity. The strict focus on vehicles necessitates ignoring other sources of productivity, such as labor (especially non-driver) productivity and fuel productivity; these would seem to be less affected by composition mix. On the other hand, further segmentation in long hauls (inhibited by data unavailability) might identify an even larger composition bias. In conclusion, it clearly seems productivity growth was positive following deregulation, but controlling for the length of haul, sector and commodities carried may adjust productivity downward by somewhere around 30%.

Fernald (1997) seeks to determine whether reduced public spending on infrastructure helped lead to the general productivity slowdown since 1973. He concludes that it did, since vehicle-intensive industries saw above-average productivity gains during periods of high road investment. However, the

road-building of the 1950s and 1960s offered a one-time productivity boost to transportation productivity; once the network is built out, roads do not offer an above-average return at the margin.

Ying (1990) estimates a translog cost function on 61 LTL companies covering the period 1975 to 1984. He finds that deregulation was associated with major gains in trucking productivity, exceeding 16% over just 5 years. In this econometric approach, a deregulation “dummy” variable is interacted with a variety of operating characteristics; in principle, deregulation-induced effects can then be aggregated and isolated from other impacts related to firms’ operations, input prices, and macroeconomic factors. For the most part, the estimated parameters are of the expected sign, but the very large faith implicitly placed in the deregulation dummy variable seems troublesome. The effective assumption is that deregulation was a single event, rather than a gradual transition. In reality, as Ying himself concedes, regulatory reform began internally at the ICC as early as 1975, and the Motor Carrier Act of 1980 was simply a culmination of sorts.

2.2. Introduction to Form M

The primary data source for this thesis is the Motor Carrier Annual Report (Form M), which was submitted annually by the largest trucking firms to the Interstate Commerce Commission. The dataset contains a wealth of financial and operating statistics at the firm level.

The Annual Report was in a sense a feature of regulation that outlasted deregulation. The ICC required trucking firms to file annual reports starting in 1935, and continued to collect these reports until the ICC was abolished in 1995. However, after deregulation the form changed several times, becoming increasingly shorter.

The data I obtained cover the years 1977-1992. This captures the deregulatory and immediate post-deregulatory years.

Burks, from whom the dataset for this thesis was received, cautions (2012) that there are two important limitations to the Form M dataset:

- Firms below a certain size threshold were not required to report (three straight years of \$0.5 m. revenues until 1980, and \$1 m. thereafter). Because of this, there is no

information on small trucking companies, such as the majority of the new entrants after deregulation

- The ICC relied on voluntary compliance; many new entrants unintentionally or purposefully ignored the threshold as they grew in size; and some incumbents (mostly TL carriers) began to withdraw from reporting

More broadly, the major strengths and weaknesses of the dataset are:

Table 2-1: Strengths and Weaknesses of Form M Dataset

Strength	Weakness
Best dataset available for the period	Not a comprehensive dataset
Representative of large and medium-sized incumbents	Not representative of small carriers
Includes some larger new entrants	New entrants underreported
Good at identifying how individual companies changed	Reliability at capturing large and medium-sized companies declines over time
Large amount of financial and operating statistics	Prone to anomalies since quality control is weak
More granular than industry-level data	Aggregate at the company level

2.3. Dataset Impact on Methodology

In brief, the dataset is not a particularly clean or orderly one, but it does contain a lot of valuable information. The challenge, then, is how to construct the analytical and methodological framework in such a way as to maximally leverage the useful information while circumventing the weaknesses.

The way I do this is by focusing on year-to-year changes within individual companies and scaling up to the industry or segment level using medians. An unattractive feature of this method is that I cannot capture the effects of firms dropping out or entering. The method also does not give any greater weight to the largest companies, which is not as big a problem because of the relatively low concentration of the trucking industry.

However, the plausible alternative methods do not appear more attractive. Ideally, one would want to sum inputs and outputs over all the firms to represent the industry, thus taking into account

entrants, dropouts, and the relative growth of firms. But for this thesis, correctly accounting for new entrants or dropouts is complicated by the fact that the former did not necessarily start reporting and the latter cannot easily be differentiated from firms that simply stopped reporting. Further, industry-level totals, averages or weighted averages all suffer from likely bias arising from inclusion of questionable data.

Another alternative might be restricting the dataset to a small number of companies with clearly valid data. The problem is that there was a great deal of overturn in the industry, and such a method would severely restrict the dataset, especially on the truckload side (for example, a survivors analysis is impossible on the TL side, since only one company reports data for every year of the full study period). Also, judging the validity of data would most likely introduce quite a bit of selection bias.

What the chosen methodological framework sacrifices in precision, it makes up in robustness. There is reduced risk of anomalous data or sample selection substantially influencing the results. The median year-to-year changes reasonably capture how large and medium-sized trucking firms changed in the years succeeding deregulation. I update the basket of companies every year (as described later in this chapter), so that new entrants are accounted for, albeit only after their first year of reporting.

For the very high-level metrics in Chapter 3, I present a few results calculated as segment-wide medians. However, in the more detailed sections on productivity and price, I use the method described above – the *segment-wide median of firm-level year-to-year changes*. Since this tracks changes in metrics rather than the metrics themselves, I have to present yearly results as indexes off a base year. (For example, using the method I describe, I can determine for any year the relative price of labor compared to the base year, but not the actual price of labor in a particular year.)

The form changes once over the timespan of the study, between 1987 and 1988. Some of the categories changed in their definitions and seemingly also in how they were interpreted; and several of the observed productivity and price changes for 1987-88 are abnormally high (see Appendix A). For these reasons I replace the observed 1987-88 results with long-run averages of a group of surrounding years.

I segment companies into one of three categories: truckload, less-than-truckload, or mixed. This segmentation is done on the basis of percent of revenues from truckload operations (percent of ton-miles would be ideal, but it is not available). I classify companies with more than 80% of revenues from

TL operations as being truckload carriers. Those with more than 80% of revenues from LTL operations are less-than-truckload carriers. Those in between are mixed (or hybrid) carriers.

In Chapter 3, I examine the relative behavior of the three segments. However, in the remainder of the thesis I restrict the analysis to LTL and TL sectors. This is because the mixed segment rapidly shrinks because of the industry bifurcation (see Subsection 3.1.); by the end it is more a residual category of firms nearly qualifying as TL or LTL rather than its own well-defined sector.

For each of the TL and LTL sectors, I select for each year the top 50 companies by revenue. The reason for this is that the number of reporting carriers tends to decline over time; in the first few years (before the ICC threshold was raised) it is an order of magnitude larger than in later years. (The total number of company-year observations is 14,924. Per year it is around 2500-3000 from 1977-1980, around 400-500 from 1981-1986, and around 190-210 from 1987-1992.) I want to avoid distortions that might arise from smaller carriers being included some years but not others. At least 50 carriers are available for both sectors nearly every year, making that cut-off an attractive choice.

For each year-to-year “basket” of companies, I include a company if a) it is in the top 50 in either the first or second year; and b) it reports in the other year. The number of companies qualifying can be less than 50 or more than 50, depending on reporting discontinuities and overturn within the top 50.

The specific mathematical methodologies related to productivity and cost attribution are detailed in Chapter 3 and Chapter 4.

Chapter 3 – Industry Trends since Deregulation

This section details the major trends in the trucking industry since deregulation. The trends examined are:

- Industry bifurcation into truckload and less-than-truckload sectors
- Declining unit revenues, costs, and profits
- Increase in the number of trucking carriers
- Dominance of trucking relative to other modes

The more involved questions of productivity and price changes are left to later sections.

3.1. Industry Bifurcation into TL and LTL Sectors

Since deregulation, there has been a “bifurcation” in the motor carrier industry: firms have come to specialize in either truckload (TL) or less-than-truckload (LTL) operations. Prior to deregulation most large carriers were hybrids, performing both TL and LTL operations. Practically, this meant that they had physical LTL networks but also provided some truckload service, for example on backhauls.

TL and LTL operations were introduced in Chapter 1. Form M defines truckload shipments as those weighing 10,000 pounds or more, and LTL shipments as those weighing less than 10,000 pounds. The 10,000-pound threshold is a rule of thumb, but the distinction between operations is most logically thought of according to whether shipments are consolidated. In a TL operation, a driver will pick up a load from a shipper and deliver it straight to the consignee, without stopping to pick up additional freight. LTL operations are much more intensive. Because the shipments are smaller, a carrier will combine numerous geographically proximate shipments in its pick-up and delivery runs. In between, the

freight must be sorted and shipped between terminals in line hauls. LTL operations are thus conceptually similar to package parcel or postal operations, except that LTL shipment sizes are greater.

TL operations can involve general freight or specialized freight, where the latter requires the use of special trailers, such as flatbeds or refrigerated trailers (reefers). In turn, LTL operations can be subdivided into national and regional operations, depending on the geographic scope of a carrier's network. Shipping by truckload is almost always faster and cheaper (on a per unit basis) than LTL, but the quantity (or value) of freight to be shipped to any single destination must be large enough to justify purchasing an entire truckload haul.

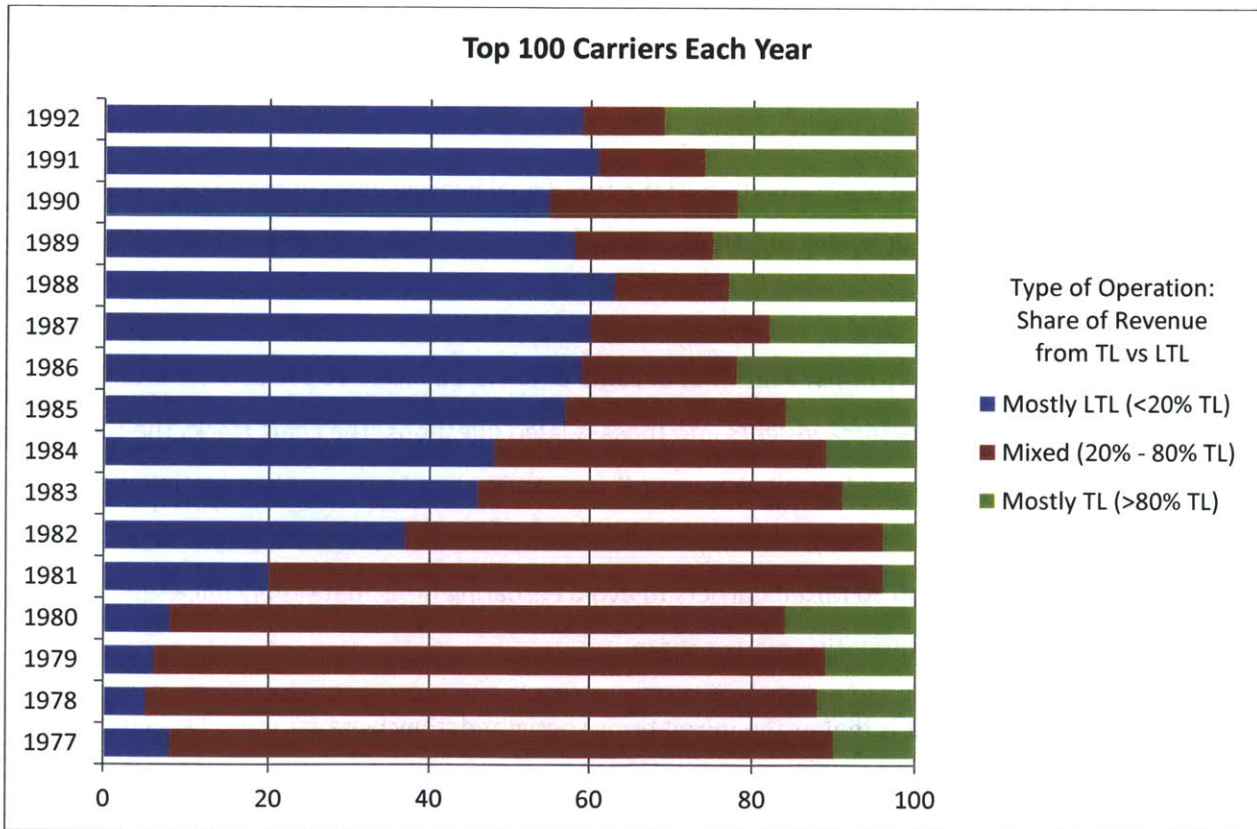


Figure 3-1 Bifurcation in the Trucking Industry, 1977-1992

Note: Basket of top 100 carriers by revenue, updated every year. Horizontal axis shows the share of companies in each segment (LTL-mixed-TL).

Source: Form M data, author's calculations

Figure 3-1 bears testament to the massive shift in carrier composition following deregulation. In relatively short order, the “mixed” carriers – those that offered a combination of TL and LTL services – were almost completely marginalized. Between 1977 and 1992, the share of the top 100 firms (by revenue) earning between 20%-80% of their revenues from TL operations plummeted from 82% to 10%. Increasingly, motor carriers were specializing in either TL or LTL.

The same trends are reflected on the following graphs (next page) of size and TL share, for selected years. 1979 is shown because it is the eve of the Motor Carrier Act, and 1992 because it is the last year of the dataset. 1985, an arbitrarily selected middle year, helps show the progression of the shifts. Note that in 1979 the mixed carriers were not only numerous, they also were the industry heavyweights. Over time the mixed category clearly “thinned out.” The charts hint at the fact that the top three mixed (later LTL) carriers (which were Roadway, Yellow, and Consolidated) increased their relative market dominance.

Both Figure 3-1 and Figure 3-2 also draw attention to another important trend: the growing emergence of the truckload carrier. Successful TL carriers like J.B. Hunt were gaining ground; in the years subsequent to this study period they came to rival the traditional heavyweights in their size. In fact, other data sources indicate that by the late 1990s, the top 100 carriers were roughly evenly split between TL and LTL firms.

Who were these new TL firms? And what became of the large mixed TL-LTL carriers after deregulation? Figure 3-3 offers some insights into these related questions. The chart tracks the top 50 mixed carriers in 1979, the eve of deregulation, over the next 10 years. Carriers either continued operations as TL, LTL or mixed carriers, or dropped out of the list of top 100 carriers (the analysis uses Top 100 Carriers instead of Top 50 Mixed Carriers to avoid ensnaring firms that simply fell a few positions in the rankings without losing market share).

Immediately apparent is that as the mixed firms specialized, they were far more likely to reorient themselves as LTL carriers than TL carriers. In fact, only a single Top 50 company went the latter direction. An even more likely outcome was dropping out – a fate that implies acquisition, bankruptcy, or significant loss of market share.

In short, change was quick in coming to the mixed carriers: the ones that survived the 1980s had embraced almost exclusively LTL operations. The new emerging truckload firms were not remnants of the pre-deregulatory large companies, but rather a new breed of competitor.

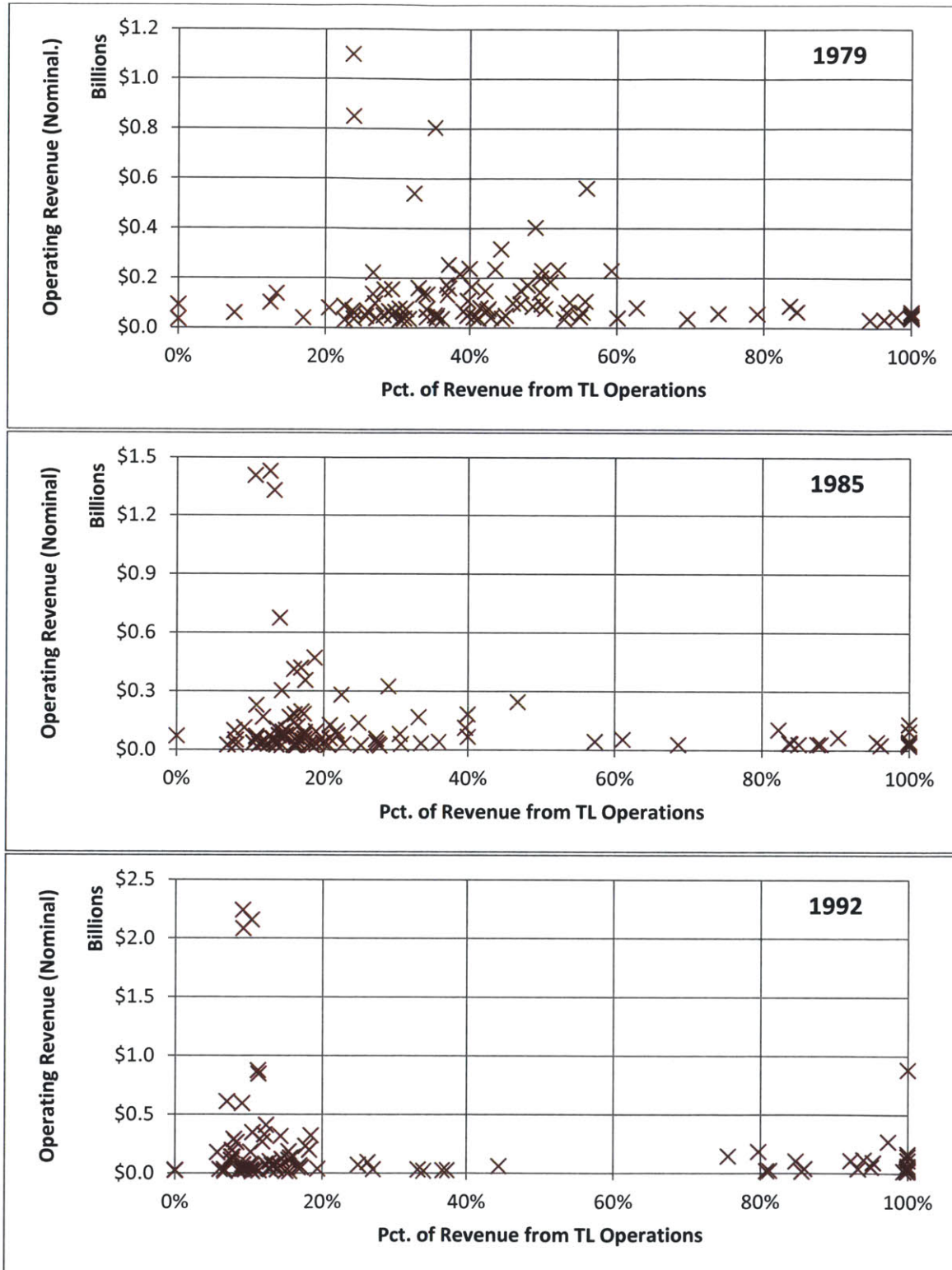


Figure 3-2 Top 100 Companies by Size and TL Share, Selected Years

Source: Form M data, author's calculations

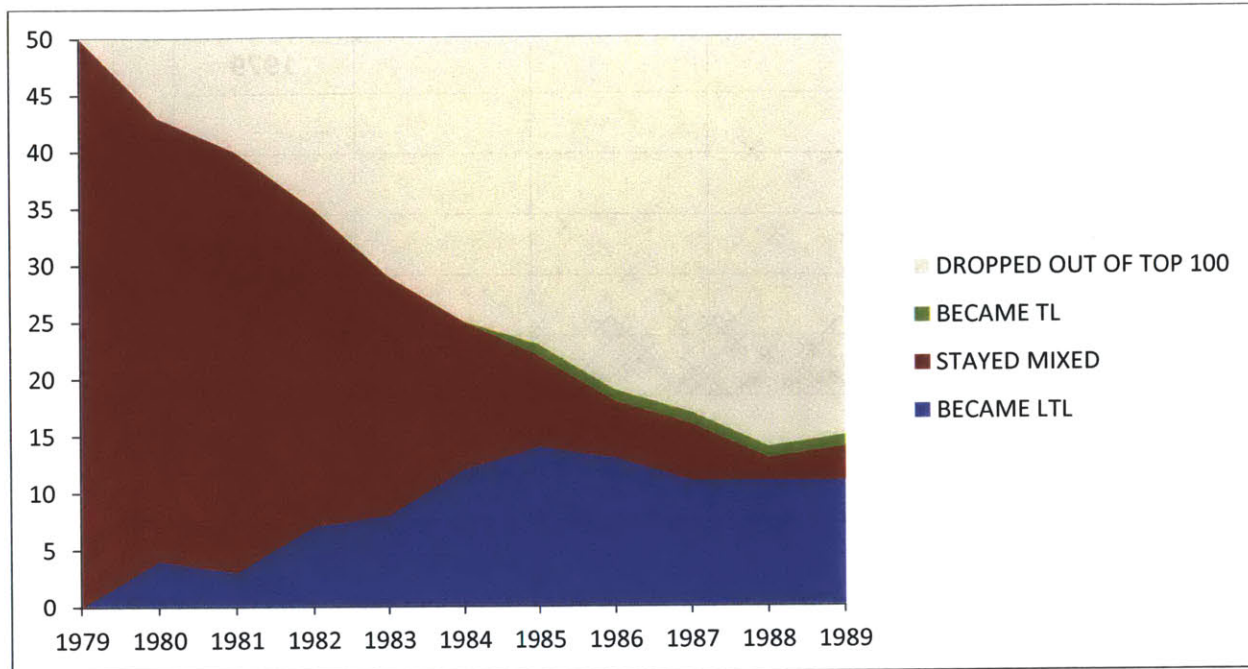
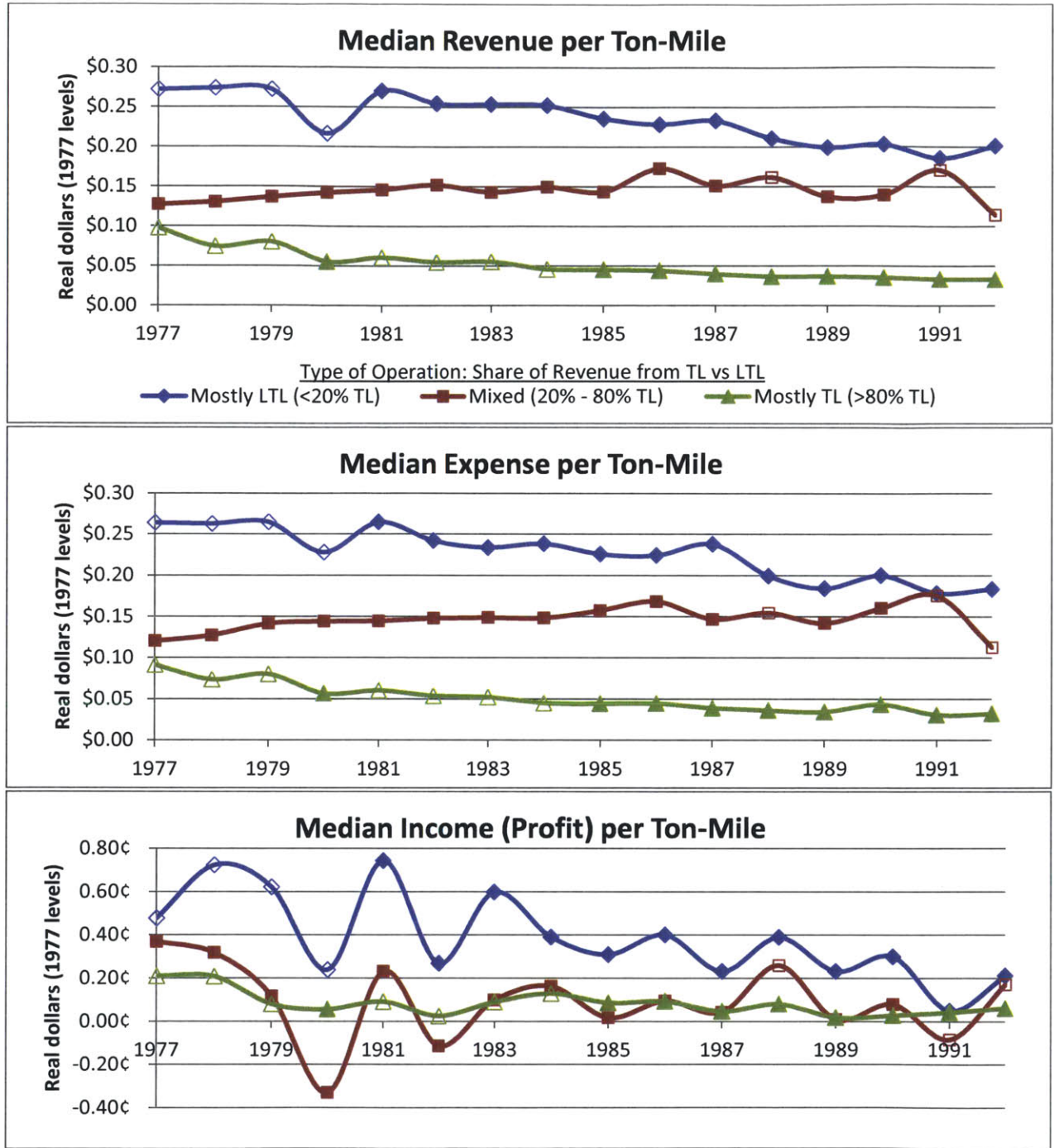


Figure 3-3: Fate of 50 Largest Mixed Carriers in Decade after Deregulation

Source: Form M data, author's calculations

3.2. Decline in Unit Revenues, Costs and Profits

Financial data for the TL, mixed and LTL carriers help illuminate why the market structure changed the way it did after deregulation. Figure 3-4 displays the unit revenue, expense and income (profit) for each year's top 100 companies, as ranked by total revenue. The income shown is net income, or the company's "bottom line." All the measures are expressed on a unit basis, in this case per ton-mile. Inflation adjustment is performed using the Bureau of Labor Statistics' Consumer Price Index. The median operator is used so as to avoid the effects of outliers, but note that the median is prone to low consistency where the number of observations is low; such cases should be interpreted with caution (sector-years with fewer than 15 observations are represented on the graphs as hollow data points).



#Obs.	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
Mostly LTL	8	5	6	8	20	37	46	48	57	59	60	63	58	55	61	59
Mixed	82	83	83	76	76	59	45	41	27	19	22	14	17	23	13	10
Mostly TL	10	12	11	16	4	4	9	11	16	22	18	23	25	22	26	31

Figure 3-4: Unit Revenue, Expense and Income for Top 100 Carriers, by Segment

Note: \$1 in 1977 = \$3.79 in 2012. Inflation adjusted with CPI

Source: Form M data, author's calculations

Several things stand out. First, both revenues and expenses are higher in the LTL sector than in the TL sector. Naturally, the sorting and aggregating required in less-than-truckload operations makes them more complex and so more input-intensive.

Real unit revenues and expenses decline over the time period, for both the TL and LTL sectors. In percentage terms, LTL prices decline by about 25%, while TL prices decline by roughly 40-50%. This makes approximately 2% p.a. and 3-4% p.a. respectively. Prices are a central way in which firms compete with each other, so the reduction in output prices is consistent with the hypothesis that competition increased after deregulation. Real unit revenues and expenses appear to stagnate for the group of mixed TL-LTL carriers. This could be a sign of struggling to compete and rein in costs, but the sector is too heterogeneous to confidently make such a conclusion. Recall that almost all mixed carriers moved toward focusing on LTL operations, so we would certainly expect to see convergence between the LTL and mixed sectors in terms of unit revenues and unit costs.

The income graph best illustrates the poor performance of mixed carriers immediately following deregulation. Notably, both the TL and LTL sectors were, on average, characterized by positive profits throughout this period (although some individual carriers were in the red). The LTL sector experienced more income volatility, but on a ton-mile basis its income tended to be higher than the truckload carriers. However, the mixed carriers appear to have gotten the “worst of both worlds:” the volatility of the LTL sector and the low incomes of the TL sector. In fact, in several years the majority of the mixed carriers were losing money. 1980, the year of deregulation, stands out: the average large mixed carrier lost nearly half a cent (in 1980 dollars) on every ton-mile it moved, and of the mixed carriers in the top 100, fully 62% were money-losers. This is striking because, as Figure 3-1 reminds us, the overwhelming majority of large carriers at this time fell into this “mixed” category. In contrast, the carriers that already specialized in either TL or LTL operations appear to have weathered the transition to increased competition with somewhat greater success.

3.3. Rapid Growth in New Entrants

In the late 1970s, accompanying an internal policy shift at the ICC in favor of easier entry, the number of ICC-regulated motor carriers began to increase (Figure 3-5). This arrested a long-term decline in the number of licensed carriers.

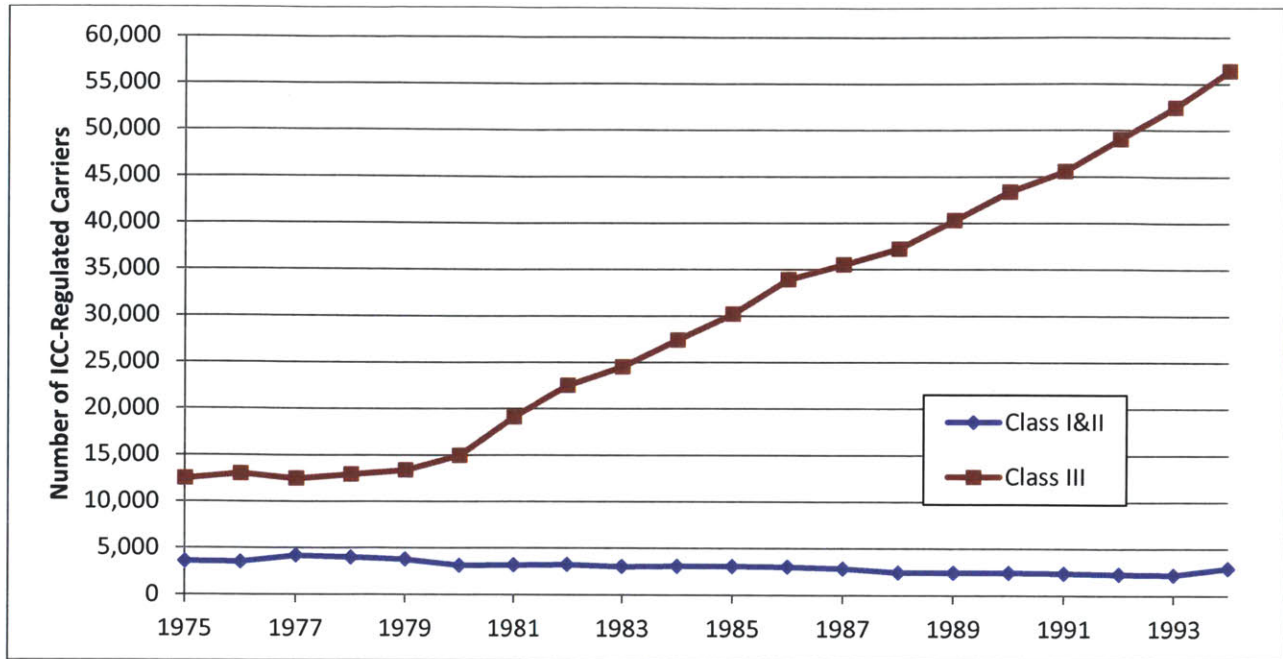


Figure 3-5: Rapid Growth in Number of Carriers after Deregulation

Note: Changes in classification thresholds: in 1981 from \$0.5 m. to \$1 m. in revenues, and in 1994 from \$1 m. to \$3 m. in revenues.

Source: American Trucking Associations' (ATA) annual Trends reports; some data points filled in using Caplice (1996), which references earlier ATA Trends reports.

The new entrants into the industry were overwhelmingly smaller carriers. The ATA data reflect segmentation by size rather than TL-LTL status, but the vast majority of small entrants were truckload firms; there was very little entry into the LTL market. Hence the figure above mirrors the trends for truckload carriers (rapid increase) and less-than-truckload carriers (decline).

In fact, there was substantial consolidation among large (Class I) mixed/LTL firms – by one source, the number fell from over 600 in 1976 to around 50 in 1995 (Corsi, 1996). Burks (2012) points out that the national 4-firm and 8-firm concentration ratios for the LTL sector for 1997, 39.3% and 57.9%, actually understate the effective concentration because some carriers only compete in certain geographical markets. In contrast, the 4-firm and 8-firm concentration ratios for the TL industry were only 11.4% and 15.9% (the 1997 Economic Census was the first to segment the industry into TL and LTL – see US Census Bureau 1997).

3.4. Increasing Dominance of Trucking

Since deregulation, trucking has gained dominance among modes of freight transportation. This subsection presents a selection of graphs based on data from the Bureau of Transportation Statistics (BTS) showing how trucking compares to other domestic modes of freight transportation. The BTS does not segment the industry into TL and LTL, but it does present the relative output, prices and commodity shares by mode.

As seen in Figure 3-6, rail, water and pipelines had roughly equivalent physical output in 1980, with trucking a clear fourth. In 25 years, the trucking industry more than doubled its ton-miles. Rail was also a success story, with pipelines stagnant and water diminishing.

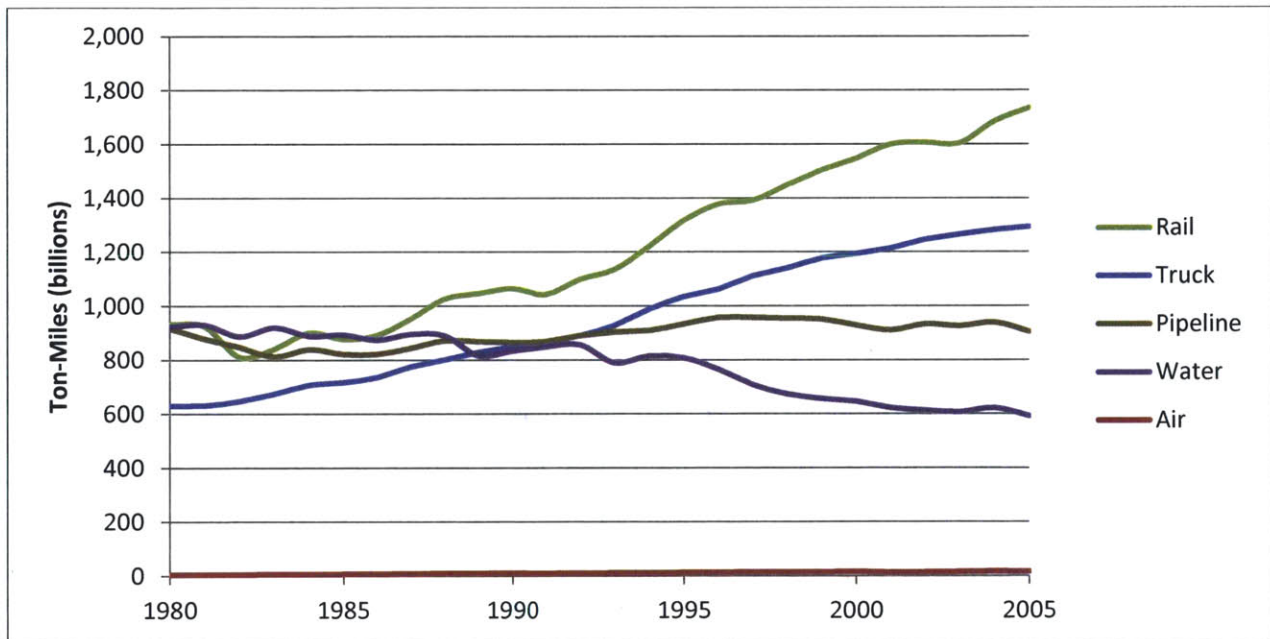


Figure 3-6: Ton-Miles by Mode of Transportation, since 1980

Source: Bureau of Transportation Statistics, Special Report (2007)

Figure 3-7 shows the relative prices of the major modes. Because of data comparability issues, pre-1990 prices are available only for rail and air. The key observation is that declining prices have not only been characteristic of the trucking industry – prices have also declined for railroads and airlines. The regulation of these industries was also reformed in the late 1970s; previous studies of the MIT U.S.

Transportation Productivity Initiative have addressed these industries (Kriem, 2011; Powell 2012; Donatelli, 2012).

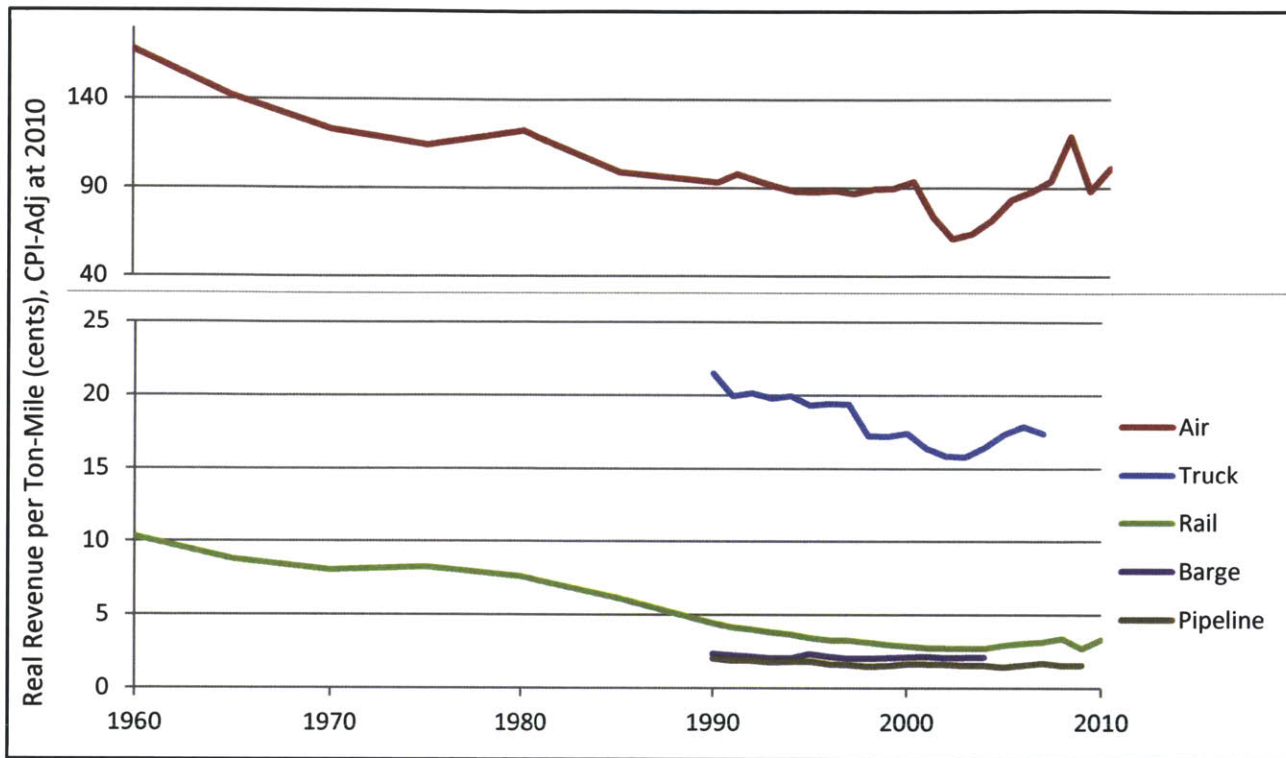


Figure 3-7: Unit Revenue by Mode of Transportation, since 1960

Note: BTS does not provide pre-1990 unit revenues for truck, barge, and pipeline modes
 Source: Bureau of Transportation Statistics; inflation adjustment by author

The Commodity Flow Survey (CFS), collected every five years by the U.S. Census Bureau in collaboration with the BTS, is another valuable source of information on the relative characteristics of the freight transportation industries. The first CFS was not until 1993, so the decade after deregulation is not reflected. However, the CFS is arguably the best source of comparative data on the various modes of transportation.

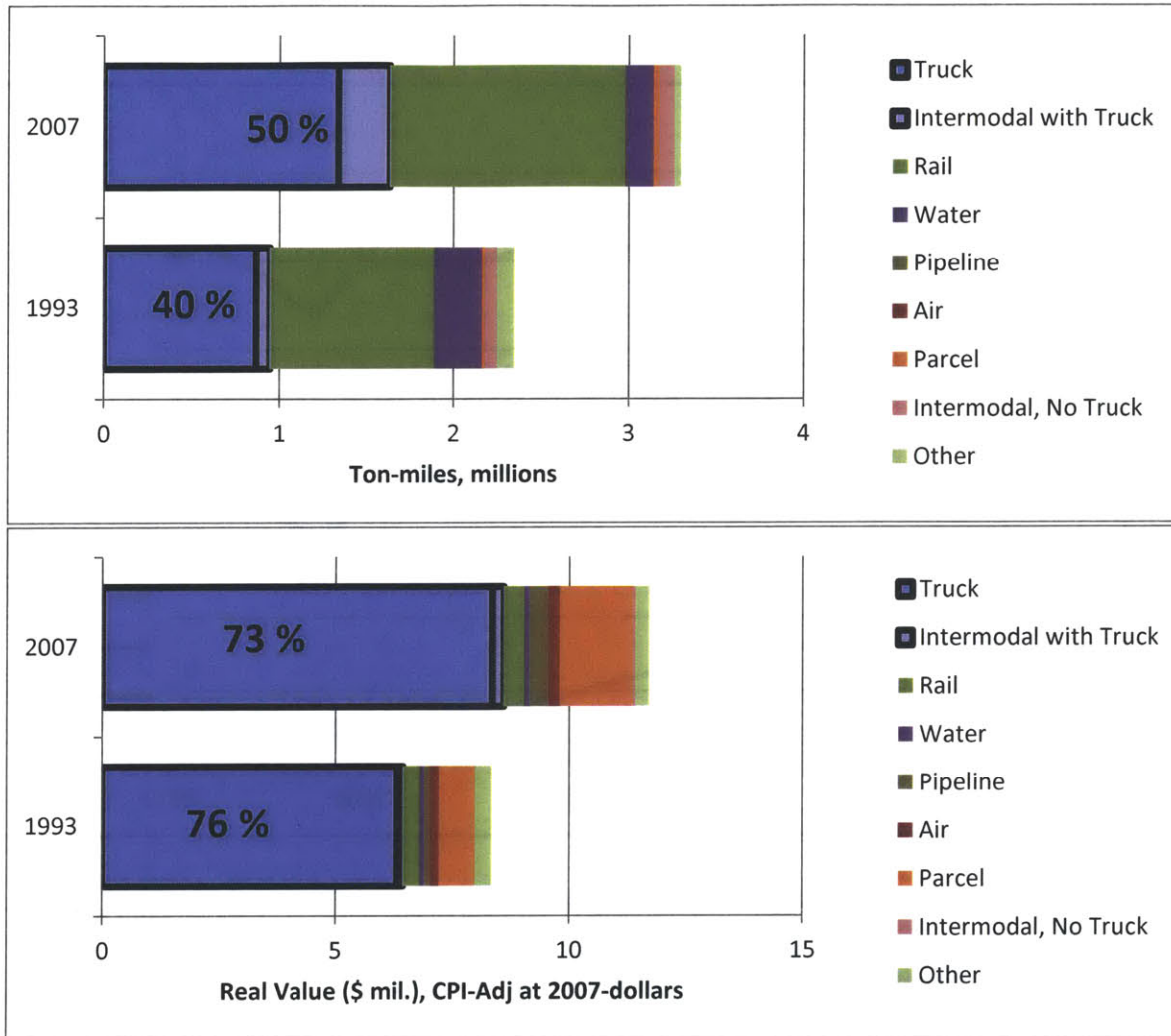


Figure 3-8: Trucking vs. Other Modes: Share of Ton-Miles and Value, 1993 vs. 2007

Note: Percentage listed is the share for the sum of Truck and Intermodal with Truck. Truck consists of For-hire, Private, and For-hire + Private. Intermodal with Truck consists of Rail + Truck and Water + Truck. Many air shipments and parcel shipments also involve truck movements, but these are not included in Intermodal with Truck. No ton-miles data for pipelines.

Source: Bureau of Transportation Statistics, Commodity Flow Surveys; mode categories aggregated by author; inflation adjustment by author

Note that the CFS distinguishes between single mode and intermodal movements. As Figure 3-8 shows, trucks alone moved 1.3 trillion ton-miles of freight in 2007, or 41% of all freight. Intermodal movements involving trucks (rail-truck or water-truck) accounted for another 9% of ton-miles (e.g. some of these ton-miles were by truck, some were by another mode). So trucking is involved in 50% of the nation's freight output, by ton-miles. Rail and water are the other major modes.

However, trucks tend to move higher value goods than do the rail and water modes. Trucks are responsible for nearly three-quarters of the nation's freight transportation by value. This does not even include air and parcel shipments, which also tend to rely partly on trucking. The value metric is distance-independent, so short hauls are not distinguishable from cross-country hauls. Although the data collected should allow value-miles to be computed, the BTS does not report it. One would surmise that trucking's share of value-miles is somewhere between the 50% and 73%. Another interesting basis for comparison is value density. The average ton moved by truck is worth just under \$1000 (Figure 3-9). In this regard, trucking trails only air and parcel.

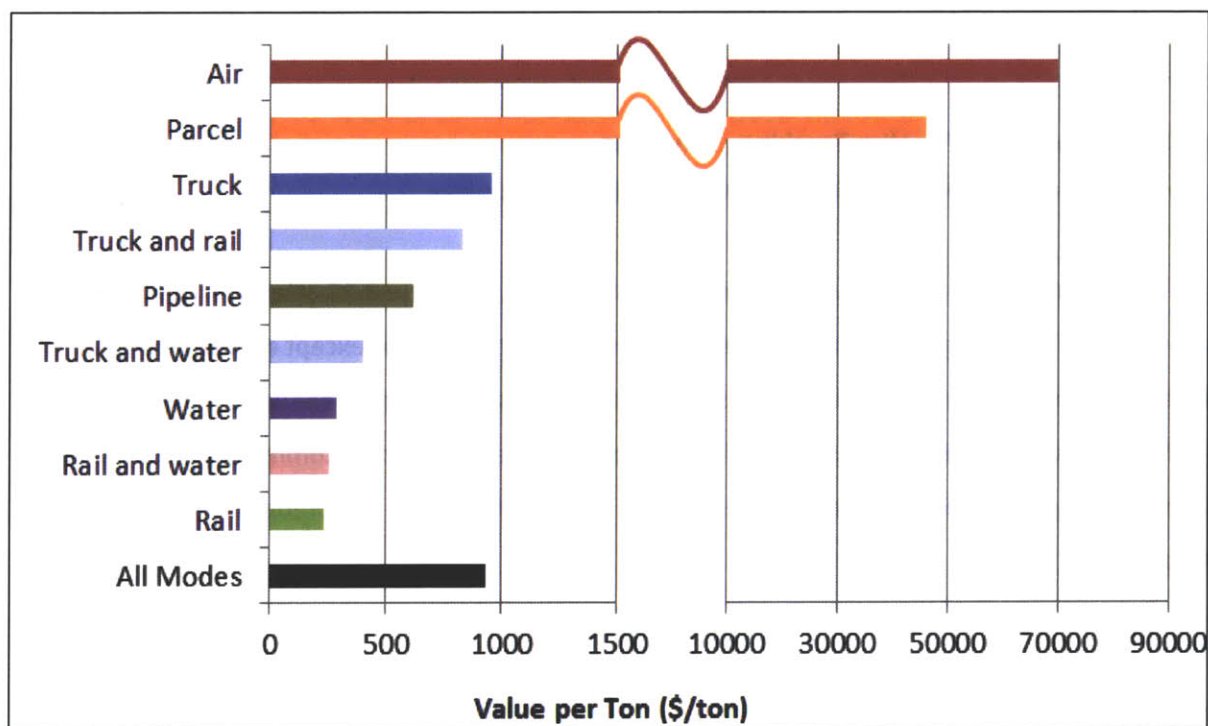


Figure 3-9: Value Density by Transportation Mode

Source: Bureau of Transportation Statistics, Commodity Flow Survey 2007

Figure 3-10 shows where the growth in trucking has come from: the for-hire segment, which was liberalized under deregulation. The growth in for-hire trucking has not abated as of 2007, whereas the output of private trucking has held steady. It should also be noted that the average length of haul for private trucking is only 57 mi., compared to 599 mi. for the for-hire segment (BTS CFS, 2007).

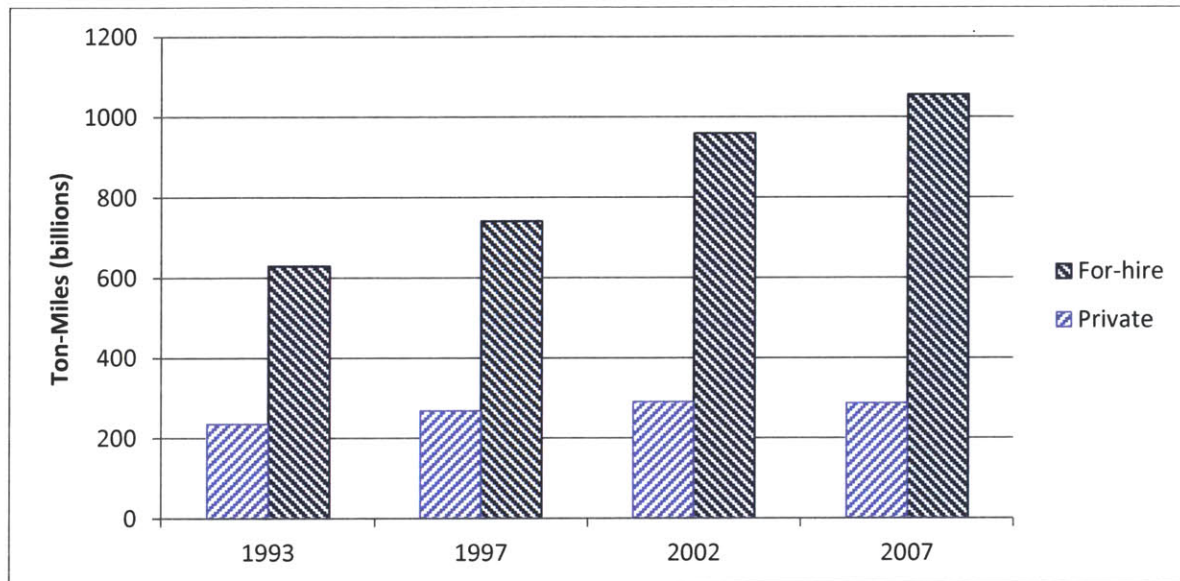


Figure 3-10: Private vs. For-Hire Trucking, Ton-Miles

Source: Bureau of Transportation Statistics, Commodity Flow Surveys

What commodities are moved by trucks? Most of them, as Figure 3-11 attests. When the major commodities are broadly grouped, trucking is heavily involved in all groups except coal and petroleum products, which move by rail. The dominant status of trucking is no less apparent when one breaks down these groups into 41 finer classes. Aside from coal/petroleum, the only commodity which relies lightly on trucking (< 1/3 of ton-miles) is cereal grains. Most commodities rely predominantly on trucking.

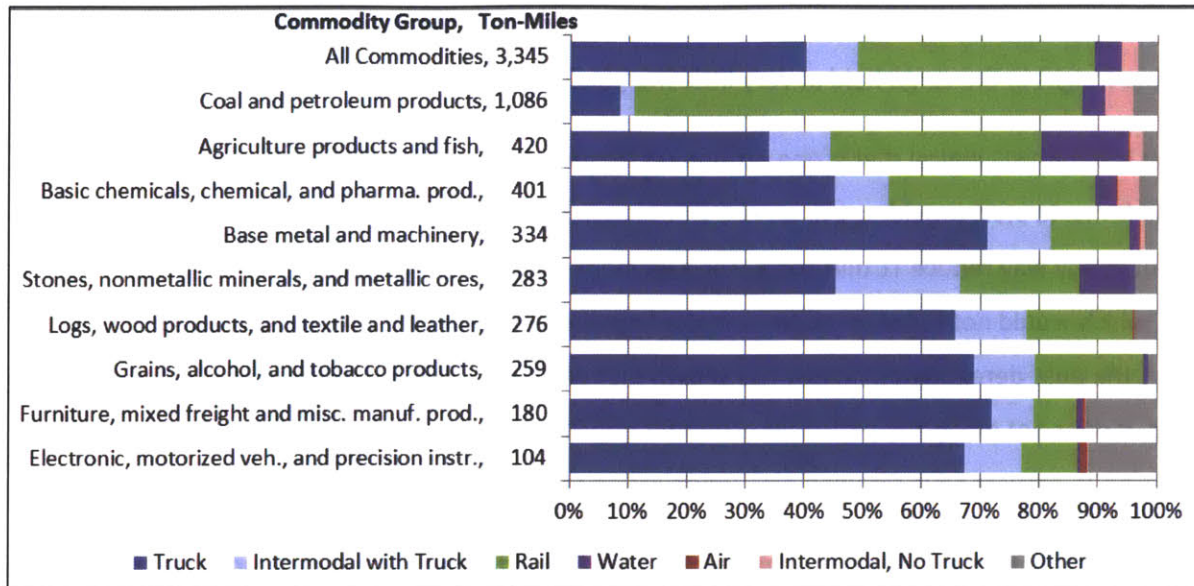


Figure 3-11: Commodity Groups by Transportation Mode

Note: No ton-mile data for pipelines.

Source: Bureau of Transportation Statistics, Commodity Flow Survey 2007

3.5. Conclusions on Industry Trends

The fundamental reason for the bifurcation in the trucking industry is most plausibly simple economics. Truckload and less-than-truckload operations are materially different from one another. Although both entail movement of freight by motor carrier and both compete for at least a certain weight range of freight, the physical structure of operations differs substantially. A truckload firm can be a fairly bare-bones business. With the elimination of major regulatory burdens in 1980 and the emergence of various brokers and third-party logistics providers (3PLs), little prevents even a single person with a leased truck from entering the market and successfully competing for freight. In contrast, LTL operations demand a physical network of terminals and a greater number of processes (e.g., picking up freight, aggregating, and sorting).

In economic terms, the bifurcation implies negligible or negative “economies of scope” or “cost complementarities.” This is to say that a carrier producing Service X cannot reduce its unit costs for X by starting to offer (more of) Service Y. Such economies do exist, for example, in the air passenger industry,

where an airline – already paying for aircraft, fuel, and crew for the passenger movement – can also carry some freight in the cargo hold at very little marginal expense.

It is intuitively logical that scope economies (in terms of service offering) do not exist for truckload firms: to start providing LTL service would require TL firms to construct costly terminals and would not in any way reduce TL unit costs. The argument is a little less intuitive in the case of LTL carriers, which would not seem to confront major impediments in adding some truckload service. However, the post-deregulation history has shown that while an LTL firm may more readily broaden its offerings, it does not enjoy any particular economic advantage from doing so. Another factor could be that hybrid/LTL carriers have retained high unionization rates, whereas TL carriers tend to be non-union.

Thus, it appears that the one-time dominance of hybrid carriers was an artifact of regulation: an unnatural outcome of a system that restricted entry, pricing and operations – a result that proved incongruous with the industry’s underlying economic impulse.

After deregulation, the number of for-hire carriers skyrocketed, more than doubling in less than a decade. The growth came overwhelmingly from owner-operators and other small truckload carriers. There was substantial consolidation among large LTL carriers, a development explained by the economies of scale associated with LTL operations. Output has continued to grow among for-hire carriers, whereas it has stagnated among private carriers: the cost of truckload service has become low enough, and service quality good enough, that relying on an in-house fleet no longer makes sense for many shippers. LTL carriers have faced increasing competition not just from low-cost TL firms, but also from package parcel carriers such as FedEx and UPS (Morrison, 1999).

Real output prices have declined not just for trucking, but also for air and rail freight. Between 1980 and 2005 trucking output more than doubled, a development no doubt supported by the reduced prices. Today, trucking is the preferred mode for most commodities, aside from low-value, high-volume (as well as long-distance, ultra-time-sensitive) commodities.

However, it is not exactly the case that the trucking industry’s success has been at the expense of other modes. In the last several decades, intermodal transportation has gained rapidly in popularity. For most of the commodity groups in Figure 3-11, intermodal’s share of ton-miles is around 10%. Intermodal transportation takes advantage of the low-cost long-haul capabilities of other modes and the geographic flexibility of trucking.

Chapter 4 – Productivity: Concept and Methodology

4.1. Productivity as a Concept

Productivity is, most fundamentally, how much output can be obtained from one or more inputs. Maximizing productivity is thus about minimizing the amount of inputs required to produce an output or, dually, maximizing the output from a given set of inputs. For a firm, productivity is one of the keys to maintaining profitable operations, while for a society productivity is a major long-term driving force of prosperity. Productivity analysis can be performed at just about any level: process, firm, or industry.

Confusion often arises over the exact meaning of “productivity.” Often, it may seem as though the term’s definition is governed by the famous Supreme Court Justice Potter Stewart maxim, “I know it when I see it” (*Jacobellis v. Ohio*, 1964). Indeed, classifying a specific initiative as either beneficial or injurious to productivity is frequently intuitive and subject to general consensus. Yet in quantifying productivity, there may be as many approaches as there are analysts.

This thesis uses the word “productivity” to mean physical productivity: the relationship between physical inputs and physical outputs. Examples of physical units in freight transportation are ton-miles and employees. This is not a universal approach. Sometimes revenue and/or expenditure are used instead of physical units, perhaps because physical metrics are unavailable or ambiguous, or because there are a large number of inputs or outputs. Further, an analyst may conceive of monetary measures as proxies for the value of service delivered, whereas typically physical metrics do not convey information about quality. The problem with this approach is that it conflates price effects (and so market dynamics) with true changes in the physical production process. A pure revenue-to-expenditure ratio, of course, represents profitability, and so any inclusion of revenues as outputs or costs as inputs

(even if adjusted for general inflation) will push the resulting ratio away from physical productivity and toward profitability.

Some analysts attempt to overcome this price effects problem by using quantity indexes as inputs and/or outputs. A quantity index can unite dissimilar units in a single metric – but while price is used to weight the constituent inputs (or outputs), any changes in price over time are factored out. Hence, for example, an increase in the price of a single input does not cause a reduction in productivity. Quantity indexes can be back-calculated from price indexes, by deflating revenues and/or costs by price indexes. The practitioner then makes the assumption that the price index is accurate and applicable. Price indexes can be used in either aggregate or granular manners. In the former case, an industry-level price index (e.g. labor price index) might be used to deflate industry expenses or revenues. This is beneficial if physical quantities are unavailable; but it is not superior to physical quantities, and aggregate price indexes are not appropriately applied to disaggregate data unless there is strong reason to expect homogeneity in pricing. More refined quantity indexes can be constructed using more complex price indexes or by combining many different price indexes. In principle it is possible to construct quantity indexes that combine many dissimilar inputs and outputs and that take into account quality changes. For instance, redirecting production from low-quality, low-price outputs to high-quality, high-price outputs can be reflected as an increase in productivity.

However, quantity indexes are not without limitations. Critically, their complexity can make them opaque: properly analyzing the results of such productivity computations requires a detailed understanding of how the indexes were constructed. Specifically, a quantity index may capture quality changes to differential extents depending on how the constituent units are defined. Without detailed knowledge of this, assessing the reasonableness of the magnitude of results is unintuitive, if not impossible. Further, in all cases where a price index is used to derive a quantity index, the resulting productivity findings are only as valid as the price index used.

This thesis focuses on physical productivity, and departs from physical measures very lightly (only in the estimation of physical fuel usage). One adjustment is used for the LTL industry – it is explained in Chapter 5. No attempt is made to control for the quality of inputs or outputs. Although it is easy to see why controlling for quality is theoretically attractive, the truth is that quality can never be fully controlled for, especially in something as heterogeneous as trucking. Second, the case can be made that quality can be seen as a factor explaining physical productivity, not as something external to be

factored out. Finally, where a control may be useful (such as concerning commodity mix), there is still a strong risk of creating ambiguity and confusion as to the meaning and appropriateness of the control.

4.2. Contextualization of Physical Productivity

If physical productivity is the ratio of physical outputs (e.g. ton-miles of freight) to physical inputs (e.g. hours of labor), then the role of productivity in the firm’s interest domain is simplistically depicted in Figure 4-1:

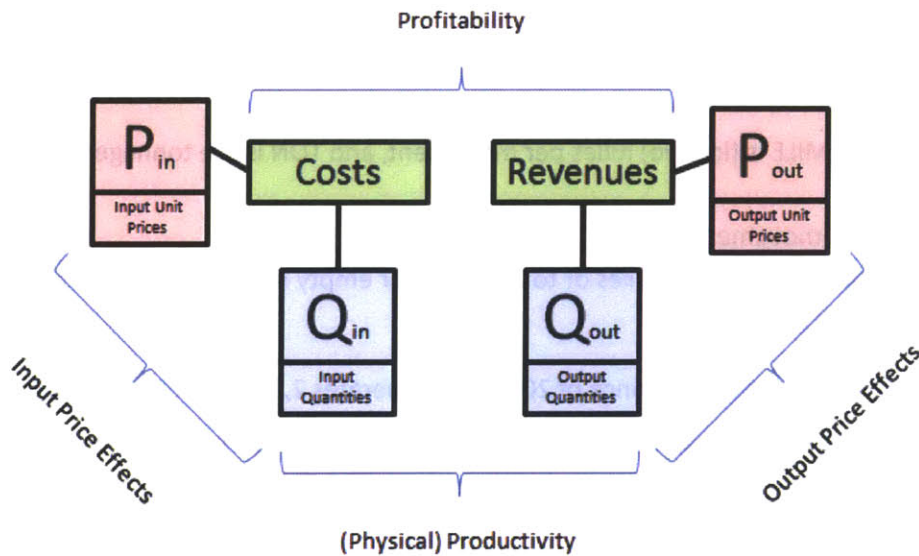


Figure 4-1: Role of Productivity in Firm’s Interest Domain

Assuming that a firm’s overarching objective is to maximize its profitability, the firm will seek to accomplish this in three ways: by obtaining low input prices (costs), by maximizing productivity, and by obtaining high output prices. It is thus clear that productivity is but one interest of the profitability-maximizing firm. It is also clear that, viewed in a supply chain context, there are conflicts between vertically adjacent companies: one firm’s input prices are simultaneously its suppliers’ output prices. In contrast, physical productivity gains (depending on their nature) may cause little enduring harm to suppliers or customers. This explains the attractiveness of productivity growth to both firms and policymakers.

In trucking, as in all freight transportation, the fundamental output is the movement of goods over distance. Defining productivity for the industry, in the simplest terms, involves determining what quantities of inputs are necessary to accomplish transportation of a given volume of freight between set origins and destinations. An improvement in productivity carries a dual connotation: increase the outputs for a certain set of inputs; or reduce the inputs needed to produce a certain output.

Probably the most widely used unit of physical output in freight productivity analysis is ton-miles (alternatively known as *loaded ton-miles* or *revenue ton-miles*), a metric computed by multiplying the net weight of a haul by its distance and summing over all hauls:

$$TM = \sum_m (MILE_m \times TON_m) \quad \text{Eq. 4.1}$$

where:

- TM is (loaded) ton-miles, MILE is (loaded) miles per movement, and TON is the tonnage per movement
- The summation is over all movements m
- Note that one could equally use loaded miles or total miles. For empty miles TON = 0, so there is no corresponding increase in ton-miles.

For example, shipping 10 tons over a distance of 200 miles generates 2,000 ton-miles. Of course, this implies that 10 tons over 200 miles is equivalent to 2 tons over 1000 miles. Ton-miles is not perfect and does not directly imply value: it does not account for commodities carried or differentiate between longer light hauls and shorter heavy hauls. It also takes no account of service quality. But other logical alternatives have even greater drawbacks. Bayliss (1988) claims tons to be superior, but his analysis is of the UK, and it is difficult to reconcile that with the case of the US, where a haul from Milwaukee to Chicago is clearly not the same as one from Long Beach to Chicago. In general, ton-miles tends to be the preferred physical unit of output in freight productivity studies.

The most fundamental inputs to a trucking operation are labor, capital, and fuel. In a physical sense, capital can be taken to mean equipment; in the trucking case, the vehicle is clearly the most fundamental form of equipment. Land and physical structures may or may not be a significant input, depending on the type of operation. Roads are in principle an input, but measuring the actual physical use of roads is hard: miles traveled is really an intermediate output and not an input; lane-miles of road may be available but does not appropriately scale to the firm level; and approximations of proportions

of asphalt or concrete required (based on the characteristics of a firm's trucks) are not readily available. Because carriers basically pay for roads on the basis of use, it is probably not unreasonable to exclude this aspect of productivity (whereas it would be in the case of rail, where a railroad must pay for its tracks whether it uses them or not).

Common metrics for these inputs are hours worked or number of employees, for labor; number of (various) revenue equipment units, for capital; and gallons of fuel.

4.3. Single Factor Productivity vs. Multifactor Productivity

Since virtually all production processes entail the conversion of multiple inputs into one or more outputs, a distinction must be made between single-factor (SFP) and multifactor (MFP) productivities. SFP is a "partial productivity:" the ratio of an output to a single input, for example ton-miles per hour of labor. MFP is the ratio of an output to multiple inputs. Since this requires combining inputs of dissimilar units, a common approach is to measure the *change* in MFP between two time periods, whereby the percent changes of all the relevant SFPs are combined using a weighting scheme that gives greater prominence to more important inputs. In this way, productivity represents the *change in the quantity of output in excess of that which is attributable to a change in the quantity of inputs*.

A related concept is total factor productivity (TFP). There is not always consistency in the use of these terms, but generally MFP is applied to a production process with a single output and multiple inputs; whereas TFP would apply to a process with multiple outputs and multiple inputs. This paper on the trucking industry assumes a single output and so uses MFP rather than TFP.

It can be instructive to conceptualize of TFP and MFP as matrices, with inputs listed along one dimension and outputs along another dimension. The single factor productivities would then be placed in the cells of such a matrix; in its entirety, the matrix would represent TFP (or, for a single output, MFP). Because interpreting such a matrix is unintuitive, MFP/TFP is often reduced to a "single number" using weighting schemes that reflect the relative importance of the various inputs and outputs. In spite of this, it is important to remember that this compression of the matrix into a single value is a simplification. In analysis it is often useful to look not only at MFP, but at the constituent partial productivities.

Single factor productivities can be thought of as point measures (e.g. 50,000 miles per employee per year). But what about multifactor productivity? Is it a value for a period, or is it a change between periods? Strictly speaking, it is the former – but as mentioned, combining dissimilar inputs is complex, so there is no obvious unit for MFP. The easiest way to represent MFP is as an index set to 100 (or some other number) in an arbitrary period. Thereby, one might speak of MFP increasing by 3% year-to-year, rather than of MFP being 3% in a certain year. In some places in this thesis, the latter style may be used since it is less cumbersome, but in these cases “MFP” should be understood as shorthand for the change in MFP.

It is easy to misunderstand single factor productivity as a concept. It should be stressed that SFP is only a partial view of the full productivity matrix. In general, it is not appropriate to say that SFP is the portion of total productivity attributable to or caused by a certain input. This is because a production process entails inputs being used in combination, not separately.

Most obviously, there tends to be at least some substitutability between inputs. For example, if machines (capital) replace humans in certain parts of a production process, labor productivity improves, but the total productivity change does not owe to increased work, effort or ability on the part of workers. Granted, the trucking industry would almost assuredly be on the low end of industries ranked in order of capital-labor substitutability; while there has been an increasing reliance on electronic devices in areas such as dispatching, it still takes one driver and one truck to move a load of freight. But substitutability is not the only issue. Consider increased speed limits (or reduced weight and length restrictions): labor and capital productivity both improve, but it would not be particularly informative to conclude that the changes in these SFPs was “thanks to” labor or capital. Hence, care should be taken in attributing responsibility among inputs on the basis of single factor productivities.

Another important issue is the weighting scheme. In TFP or MFP analyses, it is necessary to aggregate the various inputs (and outputs, in the case of TFP), into single input and output measures. In practice (in the example of inputs), the analyst observes the temporal percent change in each input and applies a weighting scheme to determine a single weighted percent change over all inputs. The choice of weighting scheme thus has an effect on conclusions about productivity.

The weighting scheme essentially reflects the relative extent to which each input, and by extension each partial productivity, is important to the firm. In principle, if inputs are directly substitutable (such as a person and machine that do the same tasks), one could conceive of weighting

schemes based on relative physical efficiency. However, in situations where there is no direct (short term) substitutability between inputs (as in trucking, where one cannot “substitute” an extra truck for a driver), the weighting scheme typically takes the form of relative cost shares. Hence, if a firm spends twice as much on labor as on capital, the change in labor is given twice the weight of the change in capital.

Difficulty arises when applying this methodology over the long term, where cost shares may change substantially. For year-to-year analyses, a logical approach is to allow the weighting scheme to update every year; however, this makes the productivities uninterpretable from a cumulative perspective. If cumulative analysis is desired, the weighting scheme should remain constant throughout the period of analysis.

There are several logical and valid choices for a weighting scheme, and its selection has a bearing on the conclusions that can be drawn from the productivity results. One alternative is to use the average weights across all years; this would be appropriate if there were no obvious patterns of change or if one did not have any special faith in any particular year. A second option – the one used in this thesis – is to choose the final year’s weighting scheme – so as to reflect the most recent perspective on relative value. A third option is presented by Scheppach and Woehlcke (1975). It is often the case that during recessions, firms do not decrease inputs in lockstep with the decline in output. This may be because of the unattractiveness of selling equipment at low prices, the difficulty of reducing workforce, and a general belief in “riding out the storm.” Clearly, such a firm will be unproductive during such periods of slack capacity. These periods will be undesirable for use in weighting because the share of inputs is plainly suboptimal (i.e. the firm will be better able or more willing to cut certain inputs than others). Scheppach and Woehlcke’s recommendation is to select for weighting one single period that clearly represents a time of peak production.

The difference between using a weighting scheme that changes by year and one that is constant roughly boils down to the following: do we want to know judge the productivity changes *from a past perspective*, or *looking back from a later perspective*? This is illustrated by a simple example: suppose there are two relevant productivities – labor and fuel – and in some past year labor productivity improved while fuel productivity declined. If at that time labor was much more important than fuel, then the labor gain should indeed outweigh the fuel drain. But suppose today fuel costs are almost as high as labor costs – then the contribution of those past changes to today’s position is not as beneficial as it appeared then. This example also illuminates why variable weights are inappropriate for cumulative

analysis, especially if the relative weights change substantially over time (in an extreme case, MFP could increase every year but decrease cumulatively)!

But to repeat: the weighting scheme is simply needed to condense the MFP matrix to a single number. Any weighting scheme does not really reveal the value of productivity: a better way of judging value is by calculating the change in unit cost attributable to productivity factors (see Chapter 6).

The weighting schemes used in this thesis are:

TL: 58.3% labor, 26.2% capital, 15.5% fuel

LTL: 83.1% labor, 11.5% capital, 5.4% fuel

These are determined from 1992 averages cost shares among the top 50 TL and LTL carriers. Note that labor comprises a substantially larger share of costs on the LTL side.

4.4. Multiphase Productivity and the Trucking Industry

The notion of a production process with an output and a set of inputs is something of a stylization in the first place. In many processes, it is possible to conceive of intermediate inputs and intermediate outputs. Figure 4-2 shows how such a “multiphase” productivity concept can be applied to the trucking industry. In brief, it can be argued that in trucking there exist multiple types of inputs and outputs that lend themselves to a convenient linear arrangement, where each “phase” is a natural extension of the preceding one. By implication, productivities are associated with each of these phases.

Applied to the trucking industry, these phases are as follows:

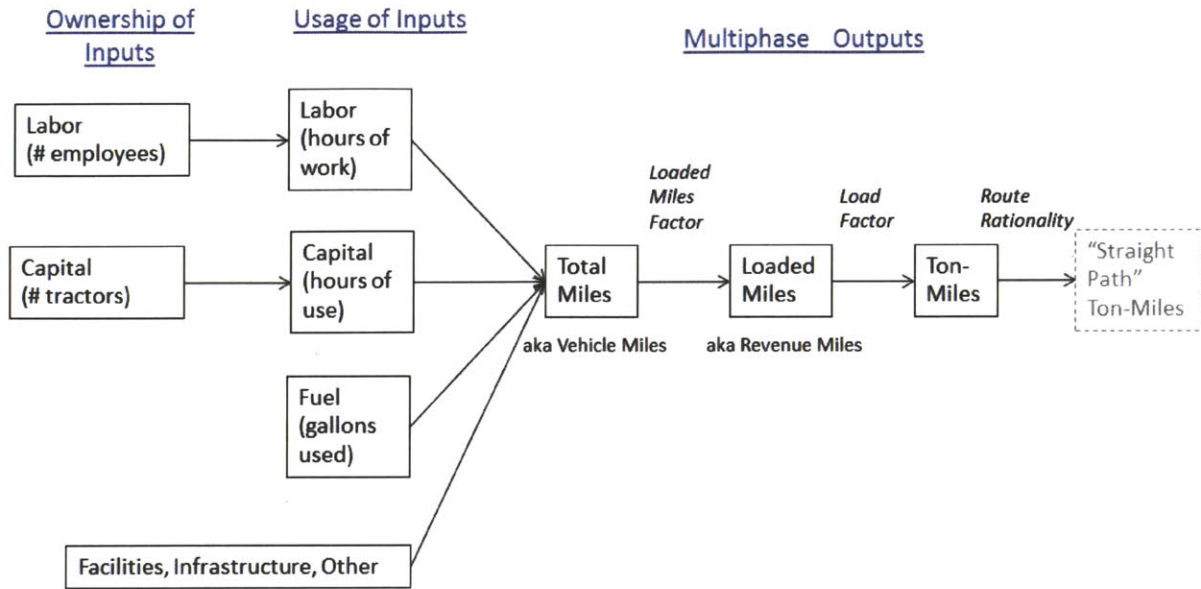
- *Input Utilization*: how many hours do employees work; how many hours per day are trucks in operation?
- *Per Mile Productivity*: how many miles can one achieve per employee, per tractor, or per gallon of fuel?
- *Loaded Miles Factor*: for what portion of the total miles is a vehicle loaded?
- *Load Factor*: how much freight is in the truck?
- *Route Rationality*: how direct is the route taken?

In principle, one could carry the analysis still further. The key point is that any computed multifactor productivity will depend on these various intermediate productivities. In fact, one's definition of inputs and outputs should depend on the intermediate productivities of interest, because different parties will be interested in different aspects of the multiphase process. Consider the load factor: a truckload carrier that is paid by the mile may not care for maximizing the amount of freight moved per load; but an environmental policy analyst interested in emissions might find it relevant if trucks move half-full.

Aside from these considerations, the selection of inputs and outputs is obviously also governed by the availability of good data. In the case of the Form M data, there are several notable gaps that preclude a full understanding of multiphase productivities. For one thing, hours of work is only provided for drivers paid on an hourly basis, which means that for this study it is not possible to construct the labor input as hours worked or equivalent full-time employees. The second important omission is the absence of loaded miles, which means that a company's ratio of loaded ton-miles to total miles conveys information about both empty miles and load factor. Figure 4-2 also shows the multiphase concept with the "best available" data available from the Form M dataset.

It should be clarified that multiphase outputs are not the same thing as multiple distinct outputs (for the latter, see e.g. the work of Jara-Diaz (2002)). Arguably trucking does "produce" multiple services, but things like cargo handling are clearly ancillary to the main output of freight movement. Also, the trucking industry has output heterogeneity in the commodities moved, but this is not modeled in this thesis. Multiphase productivity applies to linear production processes where successive outputs cannot be produced absent the preceding intermediate outputs. For instance, when ton-miles of freight are produced, miles are necessarily produced as well. There may be correlations between productivities (e.g. greater load factor implies lower miles per gallon), but fundamentally the same production path applies to each unit of production.

IDEAL SCENARIO



BEST WITH AVAILABLE DATA (Form M)

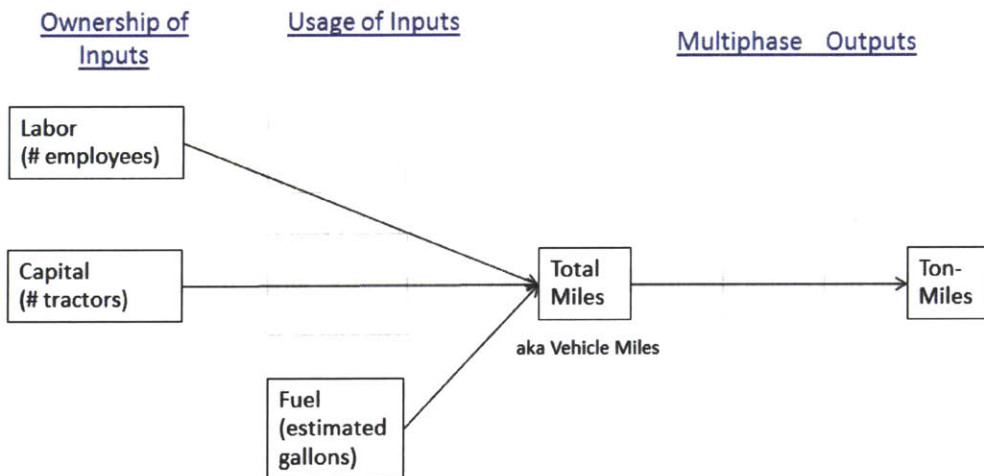


Figure 4-2: Concept of Multiphase Productivity for Trucking Industry

4.5. Definition of Inputs and Outputs for This Thesis

The multifactor productivity analysis in this thesis uses five key measures:

- *Ton-Miles*: total intercity (loaded) ton-miles
- *(Total) Miles*: total intercity miles (empty + loaded)
- *Employees*: total company employees, plus the reported “drivers rented with trucks” (to account for the fact that some companies reported owner-operators as rented drivers rather than owner-operator employees)
- *Tractors*: total company tractors, plus leased tractors and “drivers rented with trucks”
- *Fuel*: millions of BTU of fuel. Actual gallons of fuel is not reported in Form M, so this is an estimate formed by dividing each firm’s fuel expenditure by the average annual No. 2 diesel price in the transportation sector (DFACD) for a given year, as reported by the Energy Information Administration (EIA)

The fuel price estimate is not ideal, because to the extent that any firm has price advantages (e.g. because of geographic advantage), these will be misrepresented as physical fuel productivity; and it is also assumed that the fuel price from the EIA is accurate and applicable. Despite these limitations, fuel prices would seem least firm-variable of any input prices, and fuel productivity constitutes a relatively small part of MFP, so the approximation seems superior to excluding fuel altogether.

Some other factors that could conceivably be included as inputs are not, for example facilities and roads. This is because there is no good physical data on these factors. Some analyses have used “other expenses” as a catch-all category to cover things like administrative and facility expenses. The danger with this is the virtually guaranteed conflation of physical productivity with price effects. Although there is an intuitive attractiveness to ensuring “all bases are covered” by including some kind of proxy for all conceivable inputs, it should be remembered that MFP as a single-number measure is simply a weighted average of partial productivities; hence, if one partial productivity is missing the others just gain a greater weight. Adding an extra input that is biased by price effects is not inherently an improvement and may well be detrimental.

This study treats miles as the intermediate output and ton-miles as the final output. It can be argued, with merit, that the trucking industry’s output is very diverse: geospatially, temporally, in the commodities transported, and in the quality of service. Certainly, the output characteristics are more heterogeneous than physical products made on an assembly line. The trouble is that this leads very quickly to massive complexity. With detailed lane-level data, such diversity can be controlled for, but it is

not reflected in the firm-level Form M dataset. To be fair, this issue does not just affect the trucking industry, it really affects any industry with output diversity (which, with the growth of services and personalization, is most industries). The fact is that all trucking involves the transportation of freight from one point to another. The issue, then, is not so much whether physical productivity is valid but rather whether physical productivity changes are associated with, or accompanied by, changes in quality or other output characteristics. Such changes, if they can be identified, can be analyzed alongside productivity results.

As introduced in Chapter 2, there are several limitations to the Form M dataset. The first is data quality: the quality of the Form M dataset declined as the ICC's interest in and capacity for quality control waned. Although the dataset is the best available for the time period, it is largely difficult to ascertain the accuracy of any individual company's reported data. Outlier elimination is tricky and prone to a tradeoff between including bad data and eliminating good data.

The second major issue is that the trucking industry is heterogeneous and unconcentrated. The companies reporting data to the ICC were the large and medium-sized ones, not the tens- or hundreds of thousands of small firms. Also, there are missing data from some companies. Because of this, one cannot simply aggregate ton-miles or employees across all firms and gain a reasonable estimate of industry totals.

Another important aspect of the Form M dataset is that the number of firms reporting continuously throughout the entire time period is small, because of both large industry turnover and spotty reporting. This is especially a problem on the TL side.

The mathematical approaches must take account of these practical restrictions; methods that are appropriate for good, clean datasets are not necessarily appropriate here.

In the next subsections, the mathematical formulations for productivity are introduced. The scheme used to weight inputs in this MFP analysis is the relative expenditure on the three inputs (labor, capital and fuel) for a given sector (TL, LTL) for the final year (1992). Relative weights are computed for each company and sectoral averages are determined using a weighted average that gives greater power to larger companies (using revenue as a proxy for size). The theoretical merits of using different kinds of weighting schemes are discussed previously in this chapter. Note, however, that the methodology of taking medians is not very precise to begin with, and for this study the variability introduced from using

a different weighting scheme (such as an average of all the years, or even variable weights) would have a relatively small effect on the MFP findings.

4.6. Mathematical Formulation of Multifactor Productivity

The issue of mathematical functional form is largely distinct from the question of how to construct inputs and outputs as such. The choice of functional form is essentially a question of how to condense the matrix of partial productivities into a single MFP value. Probably the most common approach is the growth accounting method, which is based on the work of Robert Solow. This assumes a linear combination of inputs and outputs; it treats productivity as explaining the change in output above and beyond any changes in inputs. This is the approach used in a recent study of the trucking industry by Apostolides (2009), as well as the other MIT Transportation Productivity Initiative studies. An alternative formulation is the Tornqvist index, which assumes a multiplicative combination and so makes use of natural logarithms. In his study, Apostolides found these two methods to yield similar results. This paper does not go further into the Tornqvist formulation.

The traditional input-output formulation of multifactor productivity is:

$$\frac{\Delta T}{T} = \frac{\Delta Q_o}{Q_o} - \sum_i \left[\delta_i \frac{\Delta Q_i}{Q_i} \right] \quad \text{Eq. 4.2}$$

where:

- $\Delta T/T$ is the change in MFP
- Δ signifies the change in a metric between successive years
- Q_o is the output
- Q_i are the inputs
- δ_i are weighting factors reflecting the relative importance of the various inputs, where $\sum_i [\delta_i] = 1$

This study uses three inputs: labor (L), capital (K) and fuel (F). Substituting these three inputs for Q_i in the above formulation, and re-denominating the output Q_o as Q for simplicity, produces the following equation for multifactor productivity:

$$\frac{\Delta T}{T} = \frac{\Delta Q}{Q} - \left(\alpha \frac{\Delta L}{L} + \beta \frac{\Delta K}{K} + \gamma \frac{\Delta F}{F} \right) \quad \text{Eq. 4.3}$$

This equation reflects the traditional presentation of the growth-accounting formula, but note that it is mathematically equivalent to:

$$\frac{\Delta T}{T} = \alpha \left(\frac{\Delta Q}{Q} - \frac{\Delta L}{L} \right) + \beta \left(\frac{\Delta Q}{Q} - \frac{\Delta K}{K} \right) + \gamma \left(\frac{\Delta Q}{Q} - \frac{\Delta F}{F} \right) \quad \text{Eq. 4.4}$$

as well as:

$$\frac{\Delta T}{T} = \left(\frac{\Delta Q}{Q} - \frac{\Delta N}{N} \right) + \alpha \left(\frac{\Delta N}{N} - \frac{\Delta L}{L} \right) + \beta \left(\frac{\Delta N}{N} - \frac{\Delta K}{K} \right) + \gamma \left(\frac{\Delta N}{N} - \frac{\Delta F}{F} \right) \quad \text{Eq. 4.5}$$

where, in all three equations (Eq. 4.3, Eq. 4.4, Eq. 4.5):

- $\Delta T/T$ is the change in MFP
- Δ signifies the change in a metric between successive years
- Q is the final output
- N is the intermediate output
- L is the labor input, K is the capital input, and F is the fuel input
- α, β, γ are weighting factors reflecting the relative importance of the three inputs, measured on the basis of their relative costs; and $\alpha + \beta + \gamma = 100\%$

4.7. Mathematical MFP Formulation Used in this Thesis

The MFP approach used in this thesis is built around individual firm-level changes. These firm-level trends are observed across a large quantity of firms and extrapolated to the TL and LTL sector level. The basket of firms representing the sectors changes every year.

The transformations reflected in Eq. 4.3-Eq. 4.5 are central to the MFP approach used in this study of the trucking industry. Productivity is effectively computed at the firm level, in the form of partial productivities. The firm-level productivities of qualifying companies are extended to the sector-

level using medians, and the partial productivities are combined into MFP at the sector level. This subsection goes on to motivate this approach and explain in greater detail how it is implemented.

Because of the dataset limitations previously introduced, the traditional and otherwise most logical approach of constructing inputs and outputs is problematic for this study. Many productivity analyses use industry totals or averages to construct representative inputs and outputs, and then apply the MFP formula per Eq. 4.3.

There are two major reasons why this study eschews that approach: data availability and data quality. First, aggregating across companies would require excluding companies that do not report all fields (ton-miles, labor, capital, fuel), which would limit the dataset. (For instance, suppose we have company data on ton-miles, labor, and fuel but not capital. By excluding this company, we are needlessly “throwing out” data on the partial productivities of labor and fuel.) Ton-miles, in particular, go underreported in some years.

Second, and more important, there is a reasonable amount of data of questionable quality: using totals or averages leads to large bias and distortion, while subjectively excluding borderline data makes the conclusions vulnerable to analyst error.

The mathematical transformations in Eq. 4.3-Eq. 4.5 are the foundation for working around these problems. The transformed equation Eq. 4.5 is built not around inputs and outputs as such, but around partial productivities computed for each qualifying firm. Recall that for a single company (or any single entity) there is no mathematical difference. But the transformation allows the sector-level productivities to more reasonably represent the constituent companies, by reflecting the *median changes* in productivities across the companies.

The three basic steps are:

- 1) Calculate firm-level year-to-year partial productivity changes (e.g. the change in miles minus the change in employees)
- 2) Take the median, across the sector, for each partial productivity
- 3) Weight the partial productivity changes using sector-level weights, to produce MFP

The equation then becomes:

$$\frac{\Delta T}{T} = \text{Mdn}_i \left(\frac{\Delta Q}{Q} - \frac{\Delta N}{N} \right)_i + \alpha \times \text{Mdn}_j \left(\frac{\Delta N}{N} - \frac{\Delta L}{L} \right)_j + \beta \times \text{Mdn}_k \left(\frac{\Delta N}{N} - \frac{\Delta K}{K} \right)_k + \gamma \times \text{Mdn}_l \left(\frac{\Delta N}{N} - \frac{\Delta F}{F} \right)_l \quad \text{Eq. 4.6}$$

where:

- $\Delta T/T$ is the change in MFP
- Q is the final output, N is the intermediate output, L is the labor input, K is the capital input, and F is the fuel input
- Δ signifies the change in a metric between successive years
- Mdn is the median operator
- $z = \{i,j,k,l\}$ refers to qualifying companies that report a pair of variables (i.e. both of them) for successive years. These variable pairs are i- ton-miles and miles, j- miles and labor, k- miles and capital, l- miles and fuel; Mdn_z indicates the median over all values z
- The partial productivities are computed for each company z
- α, β, γ are weighting factors reflecting the relative importance of the three inputs, measured on the basis of their relative costs; and $\alpha + \beta + \gamma = 100\%$

This equation can be rewritten to specifically include the variables used in this study (neglecting subscripts for simplicity):

$$\frac{\Delta T}{T} = \text{Mdn} \left(\frac{\Delta TM}{TM} - \frac{\Delta MILE}{MILE} \right) + \alpha \times \text{Mdn} \left(\frac{\Delta MILE}{MILE} - \frac{\Delta LAB}{LAB} \right) + \beta \times \text{Mdn} \left(\frac{\Delta MILE}{MILE} - \frac{\Delta CAP}{CAP} \right) + \gamma \times \text{Mdn} \left(\frac{\Delta MILE}{MILE} - \frac{\Delta FUEL}{FUEL} \right) \quad \text{Eq. 4.7}$$

where:

- $\Delta T/T$ is the change in MFP
- TM is the final output, in (loaded) ton-miles
- MILE is the intermediate output, in total miles
- LAB is the labor input, in employees
- CAP is the capital input, in truck tractors
- FUEL is the fuel input, in gallon equivalent (estimated from price and expenditure data)
- Δ signifies the change in a metric between successive years
- The partial productivities are computed for each company
- Mdn is the median operator, where the median is taken across all companies
- α, β, γ are weighting factors reflecting the relative importance of the three inputs, measured on the basis of their relative costs; and $\alpha + \beta + \gamma = 100\%$

The transformed growth accounting equation allows us to leverage the maximum amount of useful information from the dataset, while mitigating the risk of anomalies by not giving undue weight to any one particular data point. Note that the transformed formula is mathematically consistent with the traditional growth-accounting formula, since it reduces to Eq. 4.3 for the case of a single entity.

As a reminder, this approach only accounts for companies that have data for any two successive years. This means that the MFP findings apply to internal firm changes, but not for the sector-wide effects of low-performing firms dropping out and being replaced by more competitive firms. To include such events is not possible using the selected approach. The basket of companies changes every year, so new entrants are accounted for only after their first year of reporting.

Chapter 5 – Multifactor Productivity Performance in Trucking

This chapter shows multifactor productivity (MFP) performance in the US trucking industry in the years succeeding deregulation. The formula used harnesses the concept of multiphase productivity introduced in Subsection 4.4. , and the formulas are as introduced in Subsection 4.7. The final output is (loaded) ton-miles, and the three inputs are labor, capital and fuel.

The MFP findings reflect changes in physical productivity, rather than value or price changes. The findings reflect changes at the firm-level among the largest motor carriers, and the basket of companies under consideration changes every year. This means data is included for firms that report in successive years and are in the Top 50 in their sector (TL-LTL) in either year. For a full explanation of why this approach was chosen, see Chapter 2.

Recall that this methodology implies a few qualifications. The effect of a dropout being replaced by a new entrant is not reflected. The findings apply to the largest trucking firms, but may not apply to small ones. All qualifying firms have equal weight. Finally, there may be exogenous variables that impact productivity, such as length of haul or composition of goods carried.

The trucking industry is divided into truckload (TL) and less-than-truckload (LTL) sectors, which provide fundamentally distinct forms of service. For a reminder of the operational differences between the two sectors, see Subsection 3.1.

One adjustment is performed to the LTL sector. As part of the industry bifurcation, mixed carriers largely came to specialize in LTL service, and in fact LTL firms also increased their share of LTL operations. The issue is that TL operations are inherently more productive than LTL operations, so a sector-wide increase in LTL operations would tend to bring down productivity. In fact, this is exactly what is witnessed, as Figure 5-1 attests. Allowing for these changes to affect productivity would to some extent challenge the whole point of subdividing the industry into TL and LTL sectors.

For this reason, the LTL sector is further divided into two subcategories – an unrestricted set, LTL-U, and a restricted set, LTL-R. LTL-U consists of all qualifying LTL firms, as introduced previously. LTL-R is a reduced subset of LTL-U, where carriers with changes in their share of TL vs. LTL operations have been removed for that year. The threshold is set at 2.5 percentage points (e.g. a carrier moving from 18% TL in Year 0 to 15% TL in Year 1 would be excluded for that year). The selection of a threshold was based on careful analysis of MFP convergence (for more information, see Appendix A). Note that subdividing the TL industry in the same way did not produce noticeable trends, and there were no clear shifts in TL vs. LTL operations over this period, so a TL-R category was rejected.

Figure 5-1 shows cumulative MFP performance for TL, LTL-R, and LTL-U. The interpretation is that without adjusting for operational shifts, LTL productivity performance was flat. But part of the poor performance is explained by simple operational shifts – that LTL carriers were becoming more heavily LTL. If we only consider carriers whose LTL share held steady, the LTL sector makes up some, but not all, of the TL sector’s productivity performance.

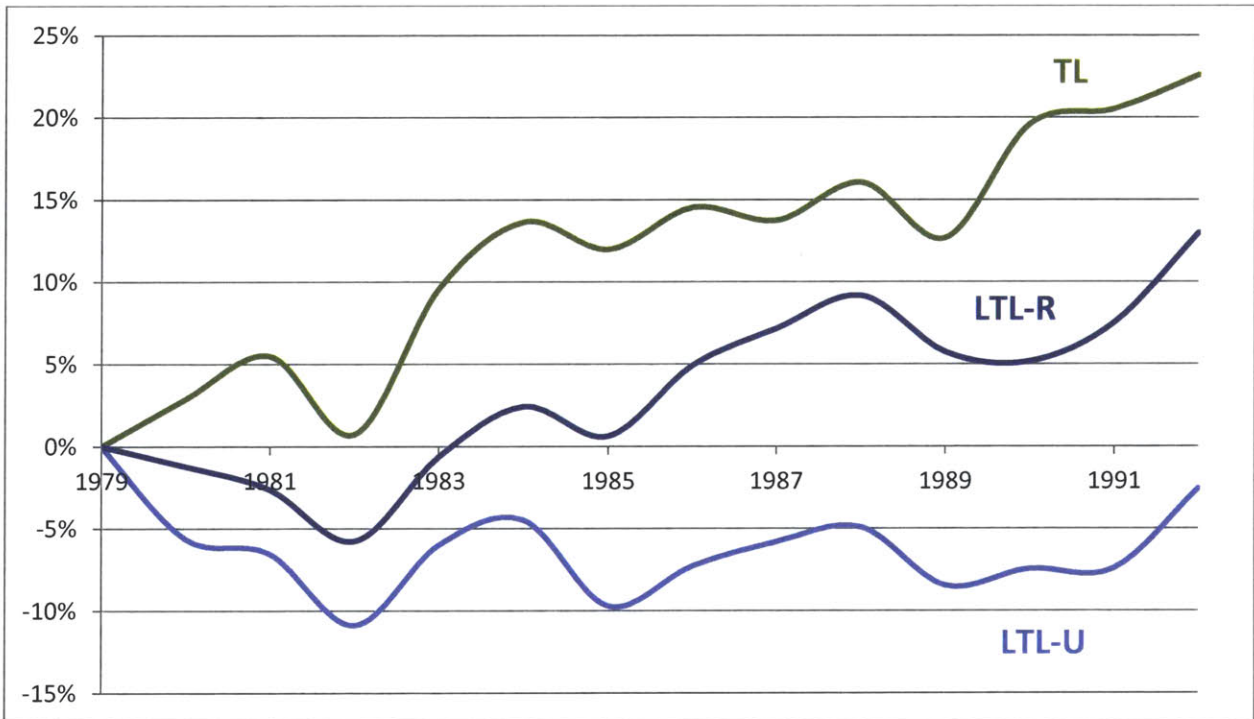


Figure 5-1: Cumulative MFP Growth – Restricted and Unrestricted LTL Set

Source for all figures in this chapter: Form M data, author’s calculations

Both LTL-R and LTL-U tell a story, but for the remainder of this report, the LTL sector will be represented by LTL-R, the restricted set. LTL-U is heavily influenced by the problem of operational shifts, and would seem to be less informative. Results for both sets are presented in Appendix A .

5.1. Cumulative MFP Growth

For cumulative analysis, the base year is set to 1979, the eve of “deregulation.” Although deregulation was a gradual process, 1979 would appear to be a more appropriate base year than any other year.

Figure 5-2 shows the cumulative multifactor productivity performance of the TL and LTL sectors. The cumulative change is simply the compounded yearly changes.

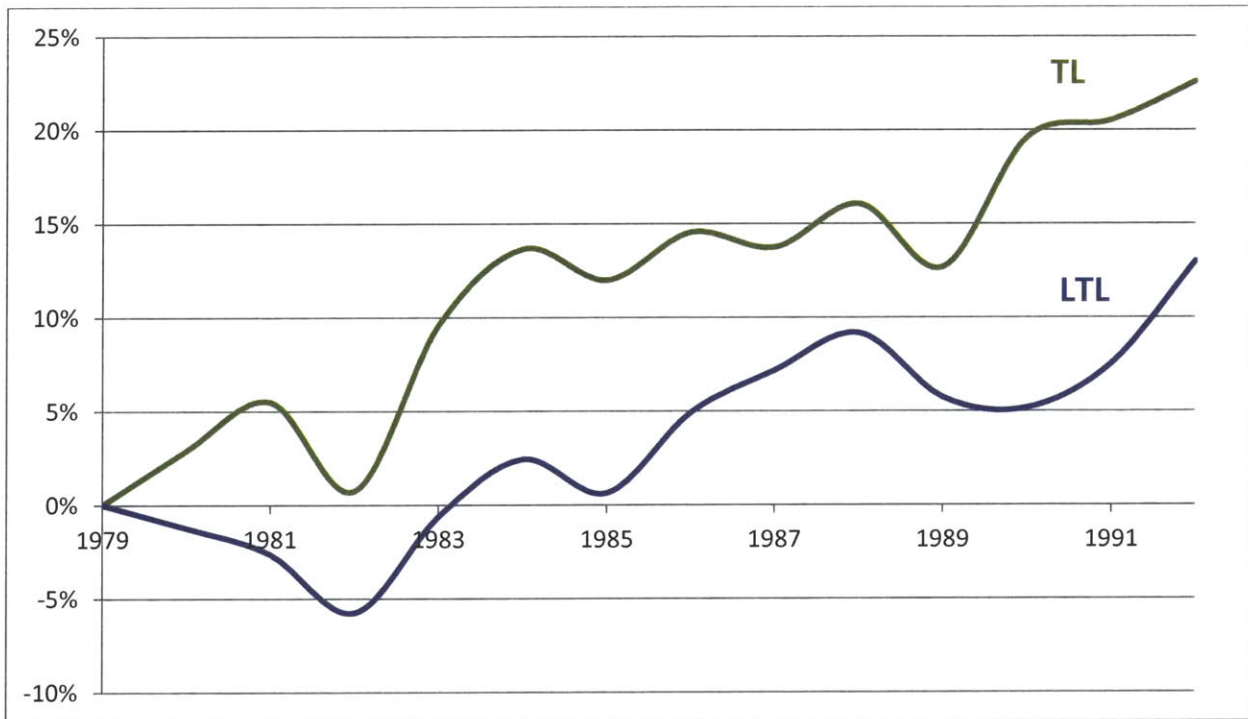


Figure 5-2: TL vs. LTL Multifactor Productivity Growth (Cumulative)

The truckload sector exhibits superior productivity performance than LTL, even after controlling for operational shifts. TL productivity improves by 23% between 1979 and 1992, or about 1.6% per annum, averaged over the entire period.

On the LTL side, productivity growth is 13% cumulatively, or about 1% per annum. (Without adjusting for operational mix, productivity actually declines by 3% cumulatively.)

Overall, productivity growth is positive, but not spectacular. It would be more than a stretch to claim some kind of productivity revolution in the trucking industry after deregulation. The more likely explanation is that carriers were able to better pursue operational efficiencies after burdensome restrictions were removed, and as competition heightened the incentive for exploiting technological advances.

That productivity performance would be superior in the truckload sector is not entirely surprising. LTL carriers tended to be unionized, and may have been more resistant to change. As well, insofar as there was an oversupply of LTL companies, productivity performance may have been hurt by excess capacity.

5.2. Yearly MFP Growth

Figure 5-3 displays the year-to-year productivity performance of the two sectors. Note that the years 1978 and 1979 are also shown, although they do not factor into Cumulative MFP. Note also that for a given year, the graph shows the percent change on the previous year.

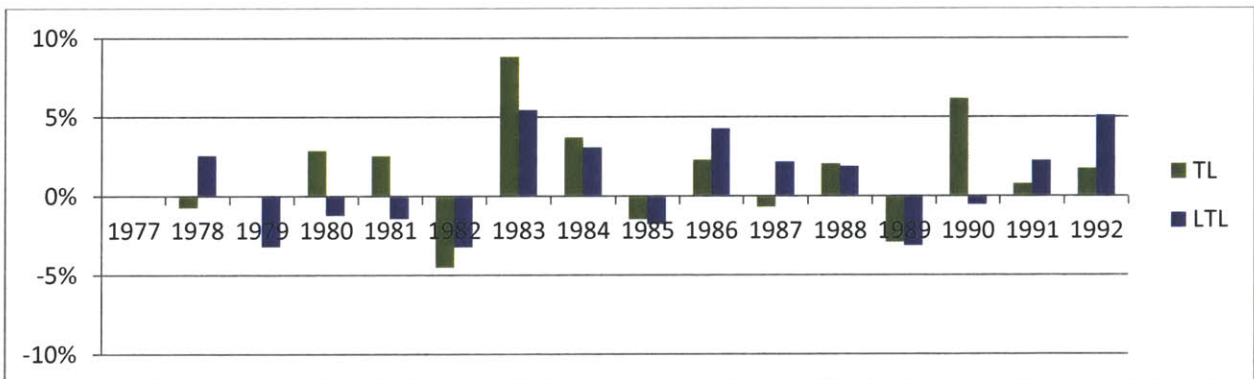


Figure 5-3: TL vs. LTL Multifactor Productivity Growth (Yearly)

The early years appear to be the source of much of the divergence between the two sectors. Whereas truckload productivity improved in 1980 and 1981, LTL productivity stalled. Over the last ten years, both sectors exhibited comparable positive MFP growth: 2% p.a. for TL and 1.7% p.a. for LTL.

Both sectors had negative productivity performance in 1982, 1985 and 1989. Since the quality of the data is not perfect, interpreting year-to-year changes is not as safe as assessing the cumulative, long-term trends. Because of these concerns, this paper does not delve deeply into the underlying causes of productivity performance. However, it seems very likely that recession had something to do with the reduction in productivity in 1982. This is because there is a “stickiness” with which firms can and do reduce workforce and physical capital in response to declining production. The flip side is that companies may be expected to emerge leaner and more competitive after recession. Indeed, the data tend to show that years of poor productivity performance are followed by years of exceptional performance.

5.3. Cumulative Single Factor Productivities

Figure 5-4 and Figure 5-5 display cumulative single factor productivities (SFP) for the two sectors. In these charts, load productivity (ton-miles to miles) has been incorporated in all three SFPs. It is worth noting that load productivity decreased on the LTL side, which had a negative effect on all three SFPs; this is discussed further in the next chapter. (For detailed tables of single factor productivities, see Appendix B Appendix A .)

For the LTL sector, MFP performance closely tracks labor productivity performance. Labor productivity is by far the largest component of MFP on the LTL side, reflecting the fact that labor is easily the costliest input for LTL carriers.

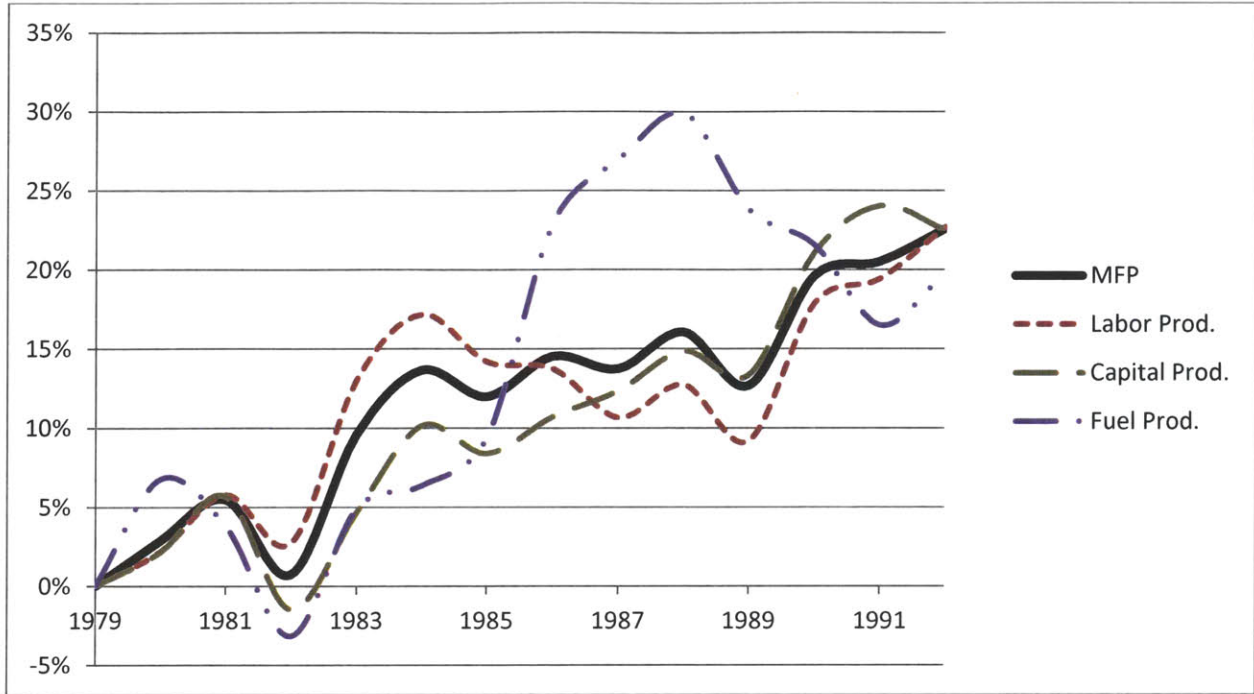


Figure 5-4: Cumulative Single Factor Productivity Performance of the TL Sector

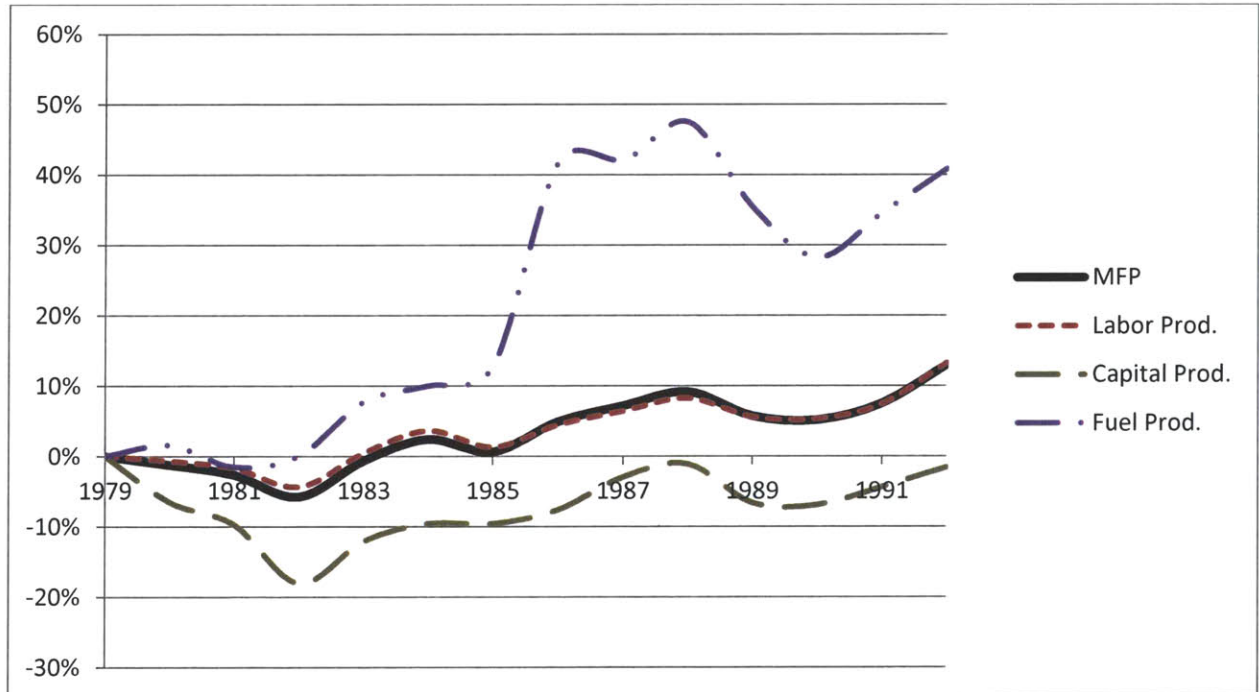


Figure 5-5: Cumulative Single Factor Productivity Performance of the LTL Sector

Labor productivity and especially capital productivity are a drain on the LTL side. For both of these, there appears to be slow and steady progress after an initial post-deregulation drop. TL single factor productivities are more volatile, which is not unexpected given both the large overturn and the low operating burdens in this sector.

Fuel productivity appears to be the most volatile component of MFP, even though it might be expected to be the most stable. It is important to remember that unlike the other variables the fuel input is an estimate and therefore is not as reliable as the other inputs. The implicit assumption is that the EIA fuel prices are representative of the prices paid by the firms in this study, and that all companies pay the same price. If these assumptions are violated, then changes in fuel price could be misidentified as fuel productivity changes. It is possible that this is behind the anomalously high performance in both sectors between 1986-1988. In any case, fuel productivity is percentage-wise a small component of multifactor productivity, and the long-term trend is positive as expected; hence, it makes more sense to include fuel as an input than to exclude it, in spite of the limitations.

As stated, individual year-to-year insights should be treated as less certain than broad, long-term trends.

5.4. Conclusions on Trucking Productivity

Firm-level multifactor productivity increased by about 1.6% p.a. in the truckload sector and 1% p.a. in the LTL sector in the post-deregulatory period. LTL productivity was negative between 1979 and 1982, but after 1982 productivity growth was almost as high in LTL as in TL.

Physical productivity improvements allowed firms to decrease unit costs, but input prices were also a factor. The next chapter separates the two kinds of factors and illuminates their relative roles in reducing unit costs.

Chapter 6 – Unit Costs Decomposed into Productivity and Prices

Perhaps the most striking indicator of increased competition in the trucking industry after deregulation was the rapid decline in trucking prices. This, in turn, was largely explained by a corresponding decrease in unit costs. But how were these cost reductions obtained? What role did productivity play, and how does this compare to the role played by other factors?

The purpose of this chapter is to mathematically decompose unit cost into its constituent factors, for the purpose of illuminating the relative role of productivity.

6.1. Basic Mathematical Approach

The method is essentially one of partial derivatives. Ignoring the particulars of the trucking industry for now, suppose there is a known relationship $A = B \times C$. Then, by manipulating either B or C, we are by definition also changing A. If B increases by 5%, then A also increases by 5%. This means that if we know how B and C have changed over time, we also know how B and C have affected A over time.

This will be first illustrated by way of example, and then the general equation is provided.

Example (Multiplicative):

$$\text{In time period 0,} \quad A = B \times C$$

$$\text{In time period 1,} \quad A' = B' \times C' = 1.05B \times 1.10C$$

i.e. B has increased by 5% and C has increased by 10%;

then B has increased A by 5%, and C has increased A by 10%

(though note that the cumulative increase is not 5%+10%, but $1.05 \times 1.10 \rightarrow 15.5\%$)

The above applies for any multiplicative relationship. Note that the initial values of A, B and C are not important, only the changes in the variables. However, for an additive relationship, the initial values do matter, at least on a relative basis.

Example (Additive):

$$\text{In time period 0,} \quad A = B + C$$

$$\text{and } \frac{B}{A} = \beta = 0.6, \frac{C}{A} = \gamma = 0.4, \text{ and } \alpha = \beta + \gamma = 1.0$$

$$\text{In time period 1,} \quad A' = B' + C' = 1.05B + 1.10C$$

$$\text{Then the effect of B on A is: } [(1.05 - 1)0.6 + 1] / 1 = 1.03 \text{ or } +3\%$$

$$\text{Similarly, the effect of C on A is: } [(1.10 - 1)0.4 + 1] / 1 = 1.04 \text{ or } +4\%$$

In summary, B increases by 5%, and causes a 3% increase in A, while C increases by 10% and causes a 4% increase in A.

The effect of both combined is $[(1.05)(0.6) + (1.10)(0.4)] / 1 = 1.07$ or 7%, which is indeed 3% + 4%.

The general mathematical equations for three-variable relationships are as follows:

Multiplicative relationship

$$A = B \times C \quad (\text{A,B,C are for initial period})$$

$$aA = bB \times cC \quad (\text{a is change in A; b is change in B; c is change in C})$$

$$\text{Partial change in A due to B: } a_B = b$$

Eq. 6.1

Partial change in A due to C: $a_C = c$

Eq. 6.2

Additive relationship

$$A = B + C \quad (A, B, C \text{ known for initial period})$$

$$aA = bB + cC \quad (a \text{ is change in A; } b \text{ is change in B; } c \text{ is change in C})$$

$$\beta = \frac{B}{A}; \gamma = \frac{C}{A}; \alpha = \beta + \gamma \quad (\alpha, \beta, \gamma \text{ are relative weights, or seeds})$$

$$\text{Partial change in A due to B: } a_B = [(b - 1)\beta + \alpha] / \alpha \quad \text{Eq. 6.3}$$

$$\text{Partial change in A due to C: } a_C = [(c - 1)\gamma + \alpha] / \alpha \quad \text{Eq. 6.4}$$

Notes:

- The purpose of the seeds α, β, γ is to emphasize that only the relative values are important. If the seeds are selected to be shares, then necessarily $\alpha = 1$. Alternatively, one could set the seeds to the initial values rather than proportions, but this would not be necessary
- $a, b,$ and c are the changes in A, B and C, defined as ratios (i.e. new year's value over old year's value)

This can easily be extended to relationships with additional variables.

6.2. Methodology Applied to the Trucking Industry

For the trucking industry, we can decompose unit expense using simple structural relationships that are true by definition:

$$\left(\frac{EXP}{TM}\right) = \left(\frac{EXP}{MILE}\right) \left(\frac{MILE}{TM}\right) \quad \text{Eq. 6.5}$$

$$\left(\frac{EXP}{TM}\right) = \left[\left(\frac{LABEXP}{MILE}\right) + \left(\frac{CAPEXP}{MILE}\right) + \left(\frac{FUELEXP}{MILE}\right) + \left(\frac{OTHEXP}{MILE}\right)\right] \left(\frac{MILE}{TM}\right) \quad \text{Eq. 6.6}$$

$$\left(\frac{EXP}{TM}\right) = \left[\left(\frac{LABEXP}{LAB}\right) \left(\frac{LAB}{MILE}\right) + \left(\frac{CAPEXP}{MILE}\right) \left(\frac{CAP}{MILE}\right) + \left(\frac{FUELEXP}{MILE}\right) \left(\frac{FUEL}{MILE}\right) + \left(\frac{OTHEXP}{MILE}\right)\right] \left(\frac{MILE}{TM}\right) \quad \text{Eq. 6.7}$$

where:

- EXP/TM is unit cost, or total expense per loaded ton-mile
- EXP/MILE is per mile cost, or total expense per total mile
- MILE/TM is the inverse load productivity, or total miles per loaded ton-mile
- LABEXP/MILE is labor expense per total mile
- CAPEXP/MILE is capital expense per total mile
- FUELEXP/MILE is fuel expense per total mile
- OTHEXP/MILE is other expense per total mile, where the other category includes all costs other than labor, capital and fuel
- LABEXP/LAB is the unit price of labor, or total labor expense per employee
- LAB/MILE is the per-mile inverse labor productivity, or employees per mile
- CAPEXP/CAP is the unit price of capital, or total capital expense per tractor
- CAP/MILE is the per-mile inverse capital productivity, or tractors per mile
- FUELEXP/FUEL is the unit price of fuel, or total fuel expense per gallon
- FUEL/MILE is the per-mile inverse fuel productivity, or gallons per mile

The key point is that using such decomposition it is possible to isolate productivity effects from price effects. Note that four factors, MILE/TM, LAB/MILE, CAP/MILE, and FUEL/MILE, are the inverses of physical productivity ratios. Three other factors, LABEXP/LAB, CAPEXP/CAP and FUELEXP/FUEL are simply the unit input prices of labor, capital and fuel and have nothing (directly) to do with productivity. OTHEXP/MILE is a catch-all category that includes miscellaneous other costs (such as taxes and administrative expenses); it cannot be decomposed into productivity and price because it has no appropriate physical unit.

A multistep process is used to attribute partial responsibilities among the variables. First, the change in EXP/TM is distributed among EXP/MILE and MILE/TM. Then, the effect assigned to EXP/MILE is further distributed among LABEXP/MILE, CAPEXP/MILE, FUELEXP/MILE and OTHEXP/MILE. Finally, the change in EXP/TM attributable to LABEXP/MILE is distributed among LABEXP/LAB and LAB/MILE; the same is done for capital and fuel.

The result is that it is possible to isolate the change in EXP/TM caused individually by each variable on the right-hand side in Eq. 6.7. Note that because of the presence of some multiplicative relationships, one cannot necessarily sum all of these percent changes to 100%.

Complexity is introduced into this particular study by the fact that industry averages are not reliable, and so medians have to be used for all of the variables. Of course, if $a_i = b_i \times c_i$, in general it is the case that $[Mdn(a)] \neq [Mdn(b)] \times [Mdn(c)]$. This means that there will be residuals that need to be allocated among the variables to ensure internal consistency of the formulas. Conceptually, there are many ways this could be done. This thesis allocates the residuals as follows:

For multiplicative relationships:

Where $A = B \times C$ and $aA = bB \times cC$ as defined before, but with a, b, and c representing medians:

Define residual as $\varepsilon = a/bc$; allocate ε_b and ε_c such that $(\varepsilon_b)(b) \times (\varepsilon_c)(c) = a$

There are two cases:

$$\text{If } \frac{(a-1)}{\text{absmax}(b-1, c-1)} > 0 : \quad \varepsilon_b = (\varepsilon)^{\left[\frac{\text{abs}(b-1)}{(\text{abs}(b-1) + \text{abs}(c-1))} \right]} \quad \text{Eq. 6.8}$$

$$\text{and} \quad \varepsilon_c = (\varepsilon)^{\left[\frac{\text{abs}(c-1)}{(\text{abs}(b-1) + \text{abs}(c-1))} \right]} \quad \text{Eq. 6.9}$$

$$\text{If } \frac{(a-1)}{\text{absmax}(b-1, c-1)} < 0 : \quad \varepsilon_b = \varepsilon_c = (\varepsilon)^{[1/2]} \quad \text{Eq. 6.10}$$

where:

- abs is a function that takes the absolute value
- absmax is a function that takes the value whose absolute value is highest (not to be confused with the maximum of absolute values)

The two cases are rooted in the assumption of different causes of residuals. In the first case, A moves in the same direction (+ or -) as B and C, or, if B and C move differently, the dominant of the two. The residual is distributed preferentially to whichever of B or C changed more. In the second case, A moves in the opposite direction as B and C, or in the opposite direction of whichever changes more. In this case, the residual is assumed to be not just a numerical discrepancy but an unexplained incongruity; so the residual is allocated equally to B and C.

Then:

$$\text{Adjusted partial change in A due to B:} \quad a_B^* = a_B \times \varepsilon_b = b \times \varepsilon_b \quad \text{Eq. 6.11}$$

$$\text{Adjusted partial change in A due to C:} \quad a_C^* = a_C \times \varepsilon_c = c \times \varepsilon_c \quad \text{Eq. 6.12}$$

For additive relationships:

Where $A = B + C$ and $aA = bB + cC$ as defined before; and where this can be rewritten as $a\alpha = b\beta + c\gamma$ using the seeds α, β, γ as defined before.

Define residual as $\varepsilon = a\alpha - b\beta - c\gamma$; allocate ε_b and ε_c such that $\varepsilon_b + \varepsilon_c = \varepsilon$

Here, the residual is simply allocated proportionally to each of the variables B and C.

$$\varepsilon_b = (\varepsilon) \left(\frac{b\beta}{b\beta + c\gamma} \right) \quad \text{and} \quad \varepsilon_c = (\varepsilon) \left(\frac{c\gamma}{b\beta + c\gamma} \right) \quad \text{Eq. 6.13 - 6.14}$$

$$\text{Adjusted partial change in A due to B:} \quad a_B^* = a_B + \varepsilon_b \quad \text{Eq. 6.15}$$

$$\text{Adjusted partial change in A due to C:} \quad a_C^* = a_C + \varepsilon_c \quad \text{Eq. 6.16}$$

6.3. Price and Productivity Findings for the Trucking Industry

Both the TL and LTL sectors saw large decreases in unit costs after deregulation: 39% for TL and 18% for LTL. (Note that these results are similar to, but not the same as, the unit cost findings in Subsection 3.2. The methodology and number of firms differ; also, in this chapter as in the last, the LTL sector is represented by the reduced (LTL-R) set so as to factor out operational shifts – see the introduction to Chapter 5).

In both sectors, productivity was a factor reducing unit costs, but input prices were a more important factor.

The cumulative results are shown in Figure 6-1 and Figure 6-2. An example of the interpretation of these graphs is as follows: between 1979 and 1992, productivity factors collectively caused a 17% reduction in the unit costs of TL companies.

More detailed cumulative results are displayed in Table 6-1, and in Appendix B .

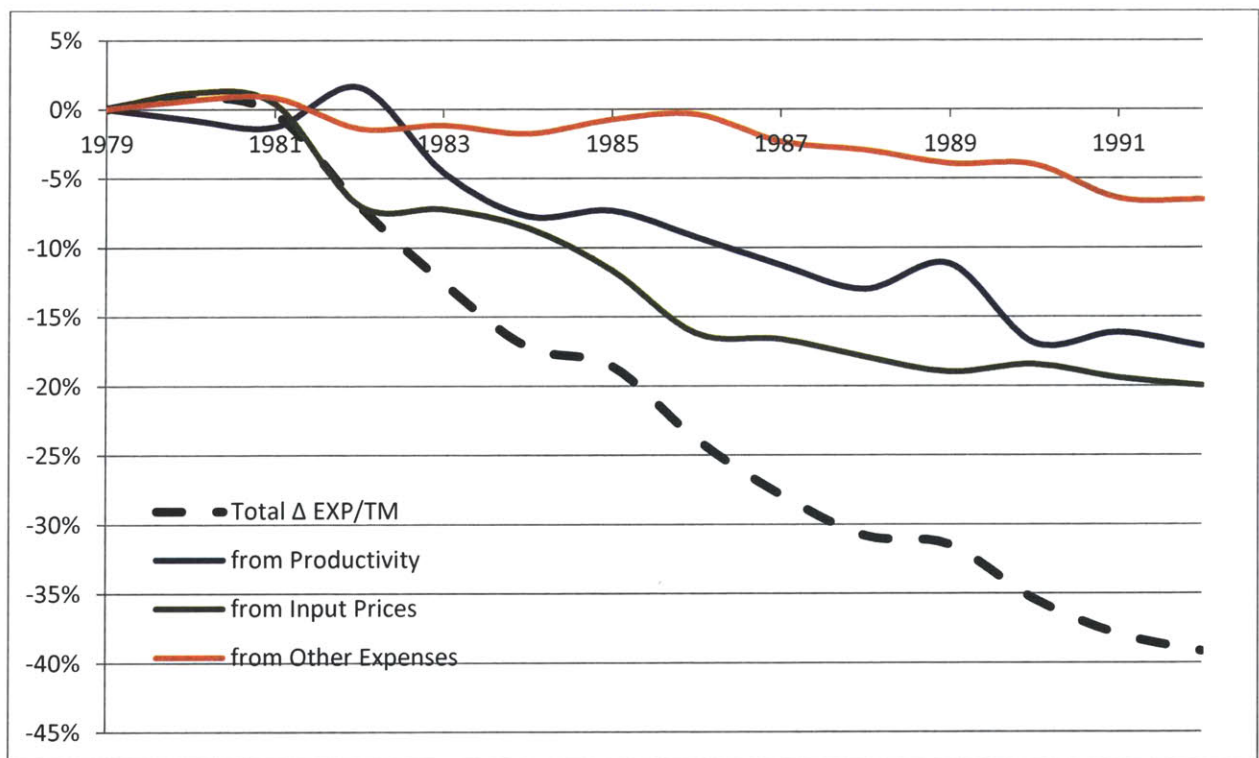


Figure 6-1: Cumulative Impacts of Productivity and Price Factors on Unit Costs – TL Sector

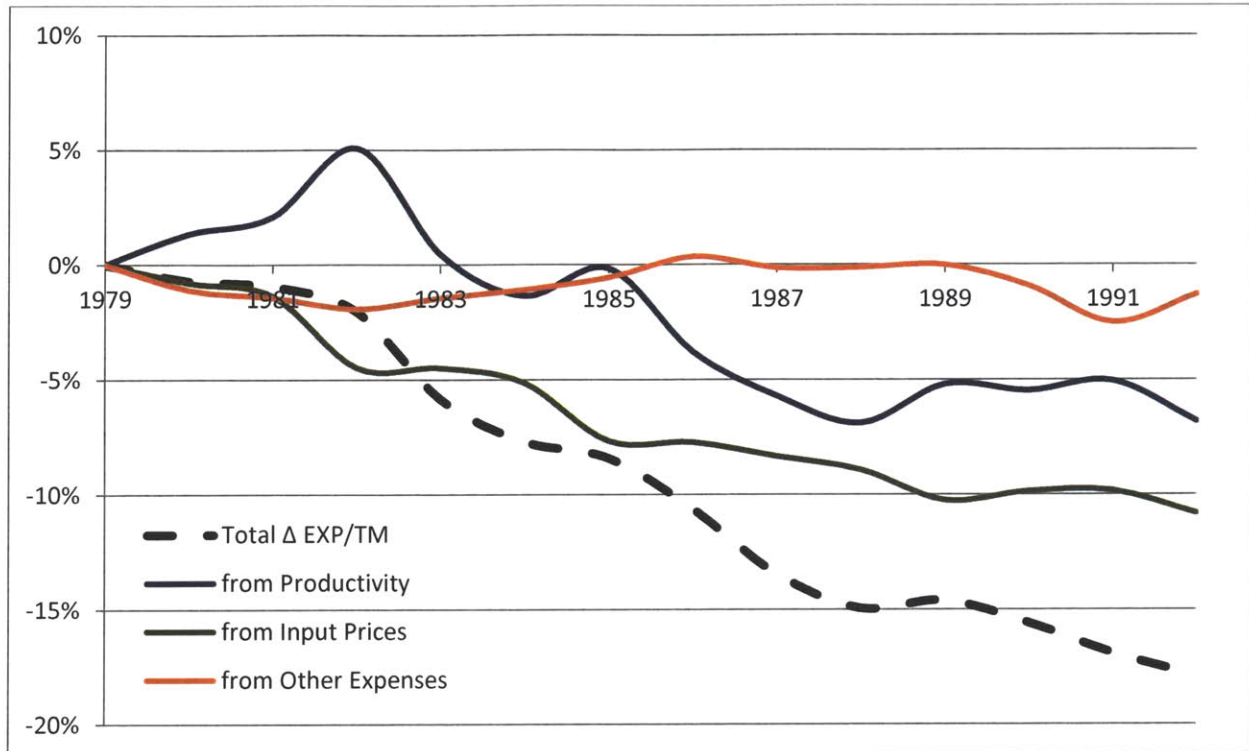


Figure 6-2: Cumulative Impacts of Productivity and Price Factors on Unit Costs – LTL Sector

Source for both figures: Form M data, author's calculations

Table 6-1: Cumulative Effect of Productivity and Price Factors on Unit Costs

Variable	Variable Name	TL Sector	LTL Sector
TOTAL Change in Unit Cost	EXP/TM	-39%	-18%
from Load Productivity	MILE/TM	+1%	+12%
from Labor Costs	LABEXP/MILE	-19%	-19%
from Per Mile Labor Productivity	LAB/MILE	-10%	-13%
from Labor Input Prices	LABEXP/LAB	-12%	-8%
from Capital Costs	CAPEXP/MILE	-9%	-3%
from Per Mile Capital Productivity	CAP/MILE	-4%	-1%
from Capital Input Prices	CAPEXP/CAP	-6%	-2%
from Fuel Costs	FUELEXP/MILE	-5%	-3%
from Per Mile Fuel Productivity	FUEL/MILE	-3%	-3%
from Fuel Input Prices	FUELEXP/FUEL	-3%	-1%
from Other Costs	OTHEXP/MILE	-7%	-1%
SUBTOTAL, from Productivity Factors		-17%	-7%
SUBTOTAL, from Input Price Factors		-20%	-11%
SUBTOTAL, from Other Factors		-7%	-1%

Table 6-2: Cumulative Change in Productivity and Price Factors

Variable	Variable Name	TL Sector	LTL Sector
Change in Unit Cost	EXP/TM	-39%	-18%
Change in Load Productivity	TM/MILE	-1%	-14%
Change in Labor Costs	LABEXP/MILE	-47%	-35%
Change in Per Mile Labor Productivity	MILE/LAB	+23%	+22%
Change in Labor Input Prices	LABEXP/LAB	-24%	-14%
Change in Capital Costs	CAPEXP/MILE	-40%	-32%
Change in Per Mile Capital Productivity	MILE/CAP	+19%	+10%
Change in Capital Input Prices	CAPEXP/CAP	-32%	-16%
Change in Fuel Costs	FUELEXP/MILE	-45%	-50%
Change in Per Mile Fuel Productivity	MILE/FUEL	+23%	+42%
Change in Fuel Input Prices	FUELEXP/FUEL	-15%	-15%
Change in Other Costs	OTHEXP/MILE	-29%	-12%

Source for both tables: Form M data, author's calculations

Note the difference between the two tables.

Table 6-2 shows the changes in the variables themselves, whereas Table 6-1 shows the effect those changes have on unit costs. The order is consistent between the two tables, but note that positive productivities in

Table 6-2 have a downward effect on unit costs in Table 6-1.

Largely because labor was the most costly input for both sectors, labor cost reductions exert the biggest impact on total unit costs. Although unit fuel costs decline by a similar magnitude, they exert less impact because of the relatively low importance of fuel costs.

Notice that labor productivity gains were higher for the TL sector, but in spite of this, labor productivity causes a 10% reduction in unit costs for TL carriers, and a 13% reduction for LTL carriers. The reason is that labor comprises a larger share of input costs for LTL carriers, which need extra workers for peddle runs and terminal operations.

A major negative component of LTL productivity is the load productivity, which actually leads to a 12% increase in unit costs. Load productivity is the ability to convert total miles into loaded ton-miles; it reflects both load factors and avoidance of empty miles. To the extent that the observed poor performance reflects vehicles carrying lighter commodities and "cubing out" before "weighing out", it may not be a big concern for carriers. The data do not allow this hypothesis to be evaluated. However, it

is interesting that about half the cumulative effect was from the first three years after deregulation alone (see Appendix B), which might suggest that LTL carriers, having lost their geographical monopolies and oligopolies, struggled to compete and could no longer fill their trucks with freight.

Input prices had a clear and substantial downward impact on unit costs. As with productivity factors, it is important to keep in mind that the relative importance of the three inputs is not equal. Fuel prices rose sharply in the early 1980s and then contracted just as sharply; however, they had a relatively small impact on total unit costs. Labor prices were the major component of price impacts. Decreasing labor prices caused a 12% decline in TL unit costs and an 8% drop in LTL costs. The labor unions, much more dominant in the LTL sector, likely played a role in stanching the declines. However, the decrease in labor prices was appreciable and the magnitude of the effect on unit costs was comparable to that of the labor productivity effect.

It should be noted that this is not an exact method. The goal is to judge the relative impacts of various factors. Note that the productivity changes in this chapter are close to, but not exactly the same as, the productivity changes in Chapter 5. The reason is that this chapter viewed partial productivities as ratios, not differences; also, the use of medians introduces some imprecision.

The capital price, in particular, is approximate: there is no good data on expenditures specific to truck tractors, which are the physical unit of the capital input. Instead, the capital expense includes amortization of all revenue equipment, costs of renting tractors, and certain other equipment and maintenance costs. But to the extent that the capital price is biased, it only affects the relative impacts of capital productivity and capital input prices: any bias in the capital price does not impact non-capital factors.

Chapter 7 – Perspectives on Regulation, Competition and Productivity

Since the late 1970s, there have been noticeable changes in regulation, competition and productivity in the trucking industry. But how are these related?

The quest for a smoking gun – a conclusive, irrefutable link between deregulation and changes in performance – is an obsession of obvious allure. After all, in the absence of such proof it is easy to question whether changes in performance are not caused, or at least heavily influenced, by external forces. Such skepticism, of course, is fair. Trade has soared: since 1980, the real value of imported goods has more than tripled, and the real value of exported goods has more than doubled (U.S. Census Bureau, 2013). The value of the commodities that are shipped has increased, as America's economic base has shifted away from industrial production (industry's value added as a share of GDP has diminished from roughly one-third to one-fifth between 1980-2010 (World Bank, 2013)).

A typical method of establishing such conclusive evidence is through the use of econometric techniques, most basically multiple regression. The power of these techniques comes from the ability to quantitatively isolate a potentially large number of relationships, and so allow counterfactual scenarios to be modeled. But as the complexity of the modeled system increases, the accuracy of the models can become deceptively poor. A serious problem is endogeneity, especially due to omitted variables. If some explanatory variables are not included (or for that matter included inappropriately), and are in real life correlated with included variables, then the relevant parameter estimates are biased, and potentially profoundly biased. With respect to trucking, the regulatory and deregulatory period did not overlap, which means a proper analysis would have to account for all manner of factors – from shipper demand patterns to the characteristics of competing modes – that would have influenced trucking supply and demand. Just as importantly, deregulation was not a single event. Deregulation started gradually in the late 1970s and continued into the 1980s and 90s. A binary regulation-no regulation variable, interacted or not, would seem to be problematic. All of this is not to suggest that an econometric approach is

necessarily useless, only that its usefulness is far from guaranteed. The accuracy of the findings is likely to be disappointing, compared to the results arising from the same approaches applied to more tractable problems, such as the changing of a single law or the concurrent pursuit of different regulations in different jurisdictions. In other words, it is unlikely to actually produce a true “smoking gun,” because it is easy to think of myriad ways in which even the best models could be challenged.

This paper eschews the smoking-gun approach. Instead, I demonstrate the key mechanisms through which the regulatory changes impacted the trucking industry. I provide quantitative support, based on both my own and others’ analyses, demonstrating the changes that took place. The final step is necessarily the reader’s own judgment.

7.1. A Conceptual Framework Linking Regulation, Competition and Productivity

In this first part of Chapter 7, I examine concepts; and in Subsection 7.2. I go on to apply the concepts to the trucking industry.

I first return to the concept of productivity, which was simplistically depicted in Figure 4-1. That figure did not incorporate the quality of inputs or outputs. But if we define quality as a multidimensional vector of physical (non-price) characteristics, then it is clear that quality plays an important role in the production process. Subsection 7.1.1. argues that it makes more sense to view quality as a factor affecting productivity than as something external to be controlled for.

Subsection 7.1.2. goes on to argue that if quality is a factor that affects productivity, maximum physical productivity is not something always to be desired. In fact, there is a *productivity tradeoff*, which means productivity is traded off against output quality and input price in determining how much net value a producer can create. This is something to bear in mind when assessing physical productivity results.

Subsection 7.1.3. examines the relative roles of regulation, competition and innovation on the net value that a firm produces. I show that there are both direct and indirect effects, and that the various forces should be seen as an interaction of incentives and capacities.

7.1.1. Productivity and Quality: How they fit together

Most strictly defined, productivity is the relationship between physical inputs with defined physical attributes and physical outputs with defined physical attributes. This can be thought of as the amount of inputs of a particular quality required to produce a unit of output of a particular quality. If productivity improves, fewer inputs of the same quality are needed to produce the same quality output. Under this strict definition, physical productivity improvements are always advantageous because they by definition allow the producer to get more for less. This can be thought of as “true” physical productivity.

In reality, productivity so strictly defined is impossible to measure, let alone make sense of. For any production process, true physical productivity is represented by a massive number of matrices of inputs versus outputs. Each matrix contains partial productivities (single input to single output), and there is a separate matrix for each unique combination of physical attributes (qualities). Of course, quality is multidimensional, and one can conceive of an almost endless number of ways in which the physical attributes of inputs or outputs can vary. Also, since production processes are often interrelated and interdependent, there would be correlation structures between the matrixes.

The point is that true physical productivity is so complex that measuring even small slices of it is extraordinarily challenging. Even if such a structure can be crudely approximated, a collection of partial productivity matrixes is not easily understood. Condensing these matrixes requires some kind of quality weighting scheme similar to the one needed to combine inputs. This in turn means that physical quality has to be valued, implying another departure from the purely physical realm.

This thesis takes a more relaxed view; physical productivity is defined as the relationship between physical outputs of any quality and physical inputs of any quality. Quality then becomes one of the factors that affect physical productivity. Controlling for quality, while conceptually entirely valid, can be a trap of sorts. Results from different studies are hard to compare; the complexity makes it harder to spot mistakes; and findings are easy to misunderstand. The central issue is that quality can never be fully factored out, so studies will differ in hard-to-interpret ways simply because of how and to what extent quality is introduced.

As mentioned, under a strict definition of physical productivity, productivity improvements are always advantageous (although a firm may pursue a negative partial productivity with respect to one

input if it means they can reap a positive partial productivity with respect to another, more important, input).

Traditionally, a distinction is made between two sources of true physical productivity: efficiency and technological change. Efficiency relates a production process to the state of the art; this is also the foundation of the economic concept of x-inefficiency. Technological change entails an improvement (or arguably also reduction) in the state of the art.

7.1.2. Maximum Physical Productivity: Is it always desired?

If the definition of physical productivity is relaxed to let quality vary, then it is clear that high physical productivity is not always most advantageous. In other words, using the barest minimum of inputs to produce something is not always smart. This is because achieving a high productivity may well imply either a) sacrificing output quality; or b) having to use higher quality (hence costlier) inputs.

This means that there exists a tradeoff, which we may call the *productivity tradeoff*. This can be thought of along three dimensions: physical productivity can be traded off against high quality outputs and/or low input prices. A firm will wish to pursue all three of these, all else being equal, but in general it cannot maximize all of these simultaneously.

One way to visualize this is by analogy to the classic project management triangle, in which the three corners represent cost, time and quality. The traditional interpretation of the triangle is that no one facet can be changed without affecting the others, and that optimizing all three is not possible. In this variation on the classic triangle, time, quality and cost are neatly replaced by productivity, output quality and input prices. A company could use the cheapest inputs and churn out the maximum output, but its products would not be of high quality. Or it could use cheap inputs to produce good quality outputs, but not very productively. Finally, it could produce high quality outputs at high productivity, but doing so would require good, expensive inputs. Of course, the firm could also find that the optimum production process involves some balanced combination of the three.

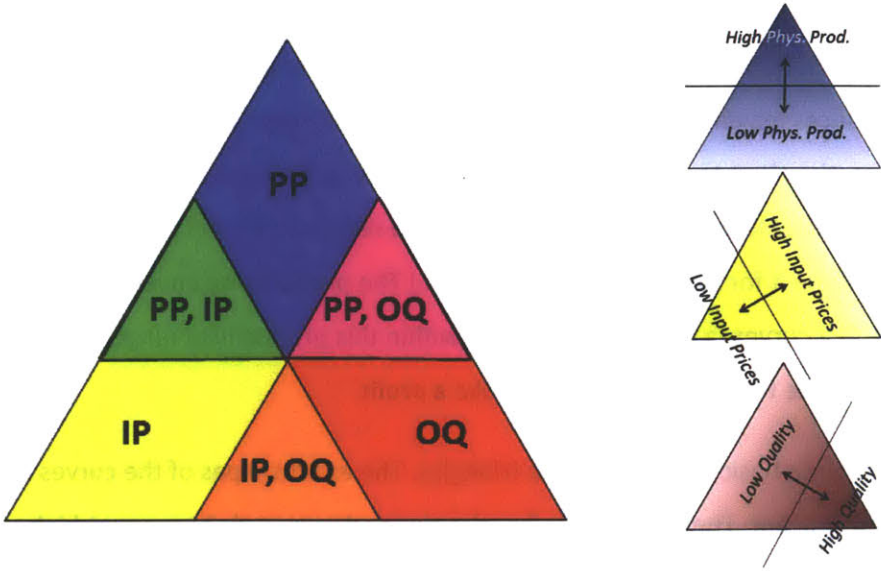


Figure 7-1: The Productivity Tradeoff as an Application of a Project Management Triangle
Tradeoff between Physical Productivity (PP), Input Price (IP) and Output Quality (OQ)

This tradeoff could also be viewed in a conceptually more rigorous way by invoking the concept of benefits and costs. The benefit is the value derived from the customer, or the customer's willingness to pay for the product. The cost is the cost to the producer to make the product. These are not to be confused with revenue, which is what the producer is paid by the customer. All three can be expressed on the basis of an average unit of output.

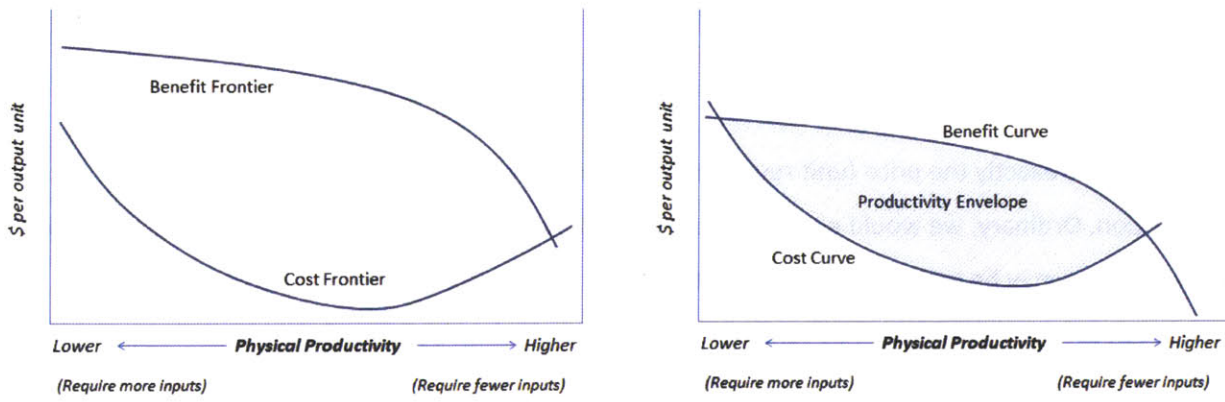


Figure 7-2: Productivity Frontiers and Productivity Envelope

The productivity frontiers in Figure 7-2 represent the maximum benefit and minimum cost that can be obtained at any physical productivity level. However, at any productivity level, the particular combination of inputs that produces maximum benefit is not necessarily the same as the one that produces minimum cost. Hence, the chart to the right shows, for any level of physical productivity, the maximum *difference* between attainable benefit and cost. (There is no reason to expect smooth functions for the curves, but assume it for simplicity of visualization.) The productivity envelope is the area between the benefit and cost curves: a producer operating within this productivity range can (ignoring competition) produce value for its customers and make a profit.

These graphs show the same basic tradeoffs as the triangles. The exact shapes of the curves are not as important as the general concept. The unit benefit frontier slopes downwards because at high productivity it may be harder to produce high quality outputs. The unit cost frontier slopes downwards because at low productivity more inputs are needed; this is somewhat attenuated by the fact that low productivity could be achieved using low-quality, low-price inputs. The curve slopes up again because very high productivity operations may demand high-quality, high-price inputs.

The point is that operating at maximum physical productivity is not necessarily rational.

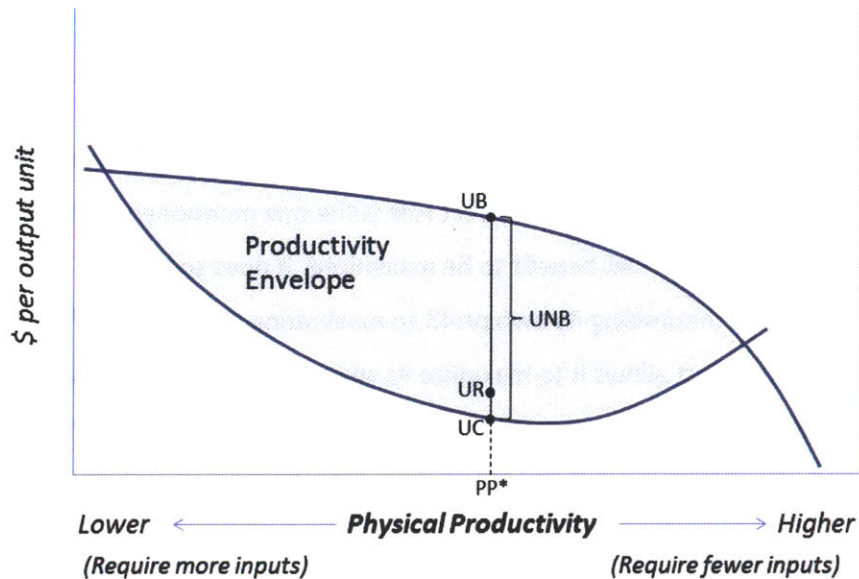
The benefit and cost are functions of several broad variables, some within the control of the firm:

$$\text{Unit Benefit} = f(\text{Output Quality, Customer Valuation of Quality})$$

$$\text{Unit Cost} = f(\text{Input Prices, Physical Productivity})$$

$$\text{Input Prices} = f(\text{Input Quality, Market Forces, Controllable Factors})$$

Where exactly the price (unit revenue) falls depends on a variety of factors, including competition. Ordinarily, we would expect the price to fall somewhere within the productivity envelope, although there may be cases where it falls outside (this is not sustainable, but may be pursued for a while, such as when a producer has sunk costs and its marginal revenue exceeds marginal cost even while average revenue is below average cost).



UB = Unit Benefit (value to customer)
 UC = Unit Cost (to producer)
 UR = Unit Revenue (the price paid to producer by customer)
 UNB = Unit Net Benefit = UB-UC

PP* = Optimal Partial Productivity – where the producer should operate so as to maximize UNB.

“Unit” means the average per unit of output. The graphs could be conceived for either short-run or long-run (output-variable) perspectives.

Figure 7-3: Submaximal Productivity as a Rational Strategy

The next several paragraphs will refer to Figure 7-3. If a profit motive exists, the producer will seek to maximize [UR-UC] and the consumer will seek to maximize [UB-UR] (again, in a broad sense, since companies could also have alternate priorities such as chasing market share). The concurrence of these incentives implies that there is an incentive for the unit net benefit UNB to be maximized.

The existence of such an incentive is what supporters of heavy regulation often implicitly point to in support of their stance. So long as both producer and customer wish to maximize their own profit, surely there would be incentives in favor of unit cost control (including productivity), and high quality.

The issue is that the incentive must be matched by a capacity, and the capacity comes from competition. In a competitive market, the customer has a high capacity for constantly pursuing the most advantageous product. The customer has not only the incentive to maximize [UB-UR], but an ability to do so. Perceptions (valuation) of quality can vary by customer and change quickly, so the unit benefit curve is neither simple nor stationary. In fact, estimating a unit benefit curve is so complex as to probably be fruitless. (As an aside, the complexity of the benefit curve is why it is practically troublesome to view productivity in *value* terms – i.e. as the ratio of benefit created to cost incurred – a view that otherwise has clear attractiveness.) Without the mechanism of competition pushing the market toward maximal UNB, such maximum net benefit is unlikely to be attained.

7.1.3. Competition and Regulation: Their Direct and Indirect Impacts

Competition has both direct and indirect effects. The direct role is of two kinds. One, competition exerts downward pressure on (excess) producer profits, by allocating more of the net benefit to the customer and less to the producer. (It is thus easy to see the appeal to some producers of barriers to competition, regulatory or otherwise.) The second direct role is the one mentioned in the last paragraph – competition provides the capacity for net benefit to be maximized. It does so by transforming the producer’s incentive from maximizing its own profit to maximizing net benefit. After all, the customer will choose whichever product allows it to maximize its share of net benefit. Those producers that can oblige will get the business, and the larger their advantage over other producers, the larger the profit they will make.

There are three fundamental channels that the producer can pursue to increase net benefit, and they are the three mentioned earlier in this chapter: increasing quality of outputs, improving productivity, and reducing input prices. The direct effect of competition is to motivate the producer to trade off these factors in a more optimal manner.

The indirect effect of competition is potentially even more powerful. The producer is incentivized to use whatever tools it can – technological, organizational – to not only reach the industry state of the art, but also to surpass it. This is an ongoing force, and harnesses tools like innovation in products and production techniques, discovery of new niches and scope economies, and smarter purchasing strategies. The manifestation is a shift in the benefit and/or cost frontiers (Figure 7-4) and a widening of the productivity envelope.

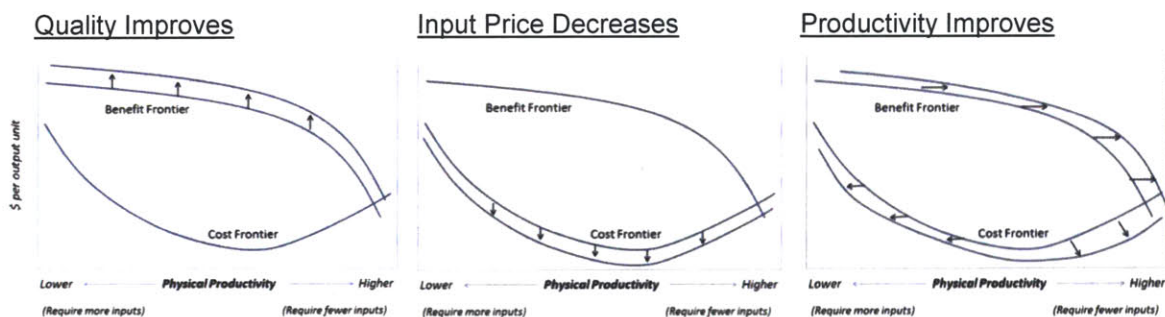


Figure 7-4: Quality, Price and Productivity Transformations: Impacts on Productivity Frontiers

The graphs in this chapter are obviously a simplification in many ways, but they illustrate how productivity and competition can be related. The benefit curve applies to a homogenous customer with particular tastes; differences in tastes would cause variation (e.g. if the customer had no preference for high quality, the benefit curve would be flat). Niches are hard to visualize and display. Also, there's no incorporation of marginal benefits and costs that would indicate *how much* any customer would buy. This is a problem because economic theory usually assumes the market is set at such a quantity as where marginal revenue equals marginal cost. To incorporate the extra dimension of quantity (and thus MB, MR or MC) into these graphs would be complicated. But the central conclusions remain: physical productivity is but one component of optimal operation, and competition makes it the producer's incentive to maximize net benefit.

Regulation also has direct and indirect effects. The direct effect of regulation is on the physical production process and on prices. Laws can restrict or mandate productivity, quality, or input/output prices. Typically, such laws exist to protect some other societal interest that would be unduly compromised if companies were given free rein to pursue their own self-interest. Such direct effects of regulation pose a burden for companies, but do not impact the level of competition.

The indirect effect of regulation, harder to measure but no less real, is that it can influence the level of competition itself. In fact, regulation can help or hinder competition (or be neutral to it, as just mentioned). Antitrust (competition) laws are examples of regulation that promotes competition, by forbidding price-fixing and controlling concentration in industries. Regulations inhibiting competition can be very apparent (e.g. blocking new entrants from challenging an incumbent) or subtle (e.g. burdening some companies – such as small ones – disproportionately).

The direct and indirect effects of regulation and competition, introduced in the preceding paragraphs, are tied together schematically in Figure 7-5 and Figure 7-6. Figure 7-5 shows how regulation and competition directly and indirectly affect value (value is used as shorthand for value added, or net benefit). Figure 7-6 elaborates on the direct effects.

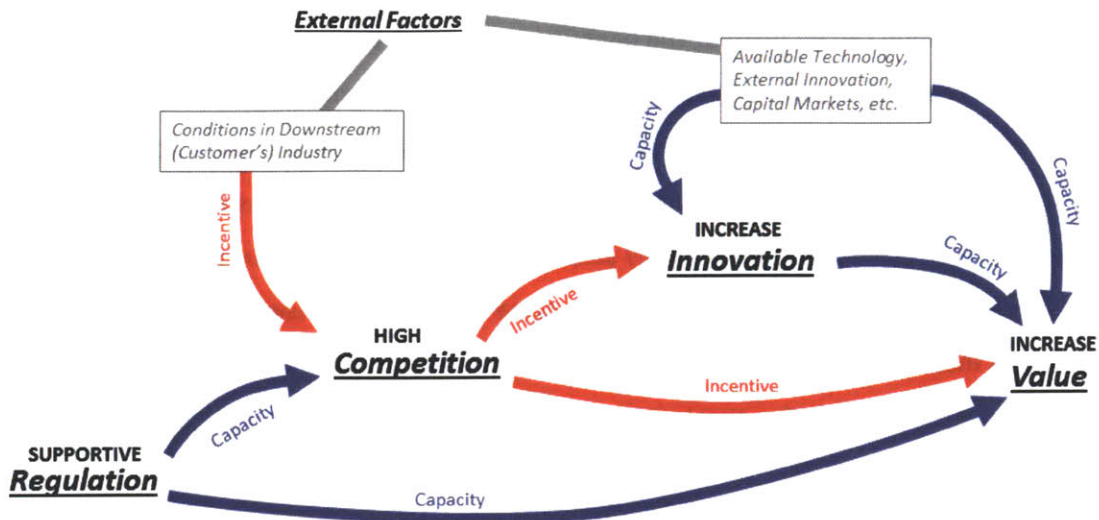


Figure 7-5: Conceptual Relationship between Regulation, Competition, Innovation and Value

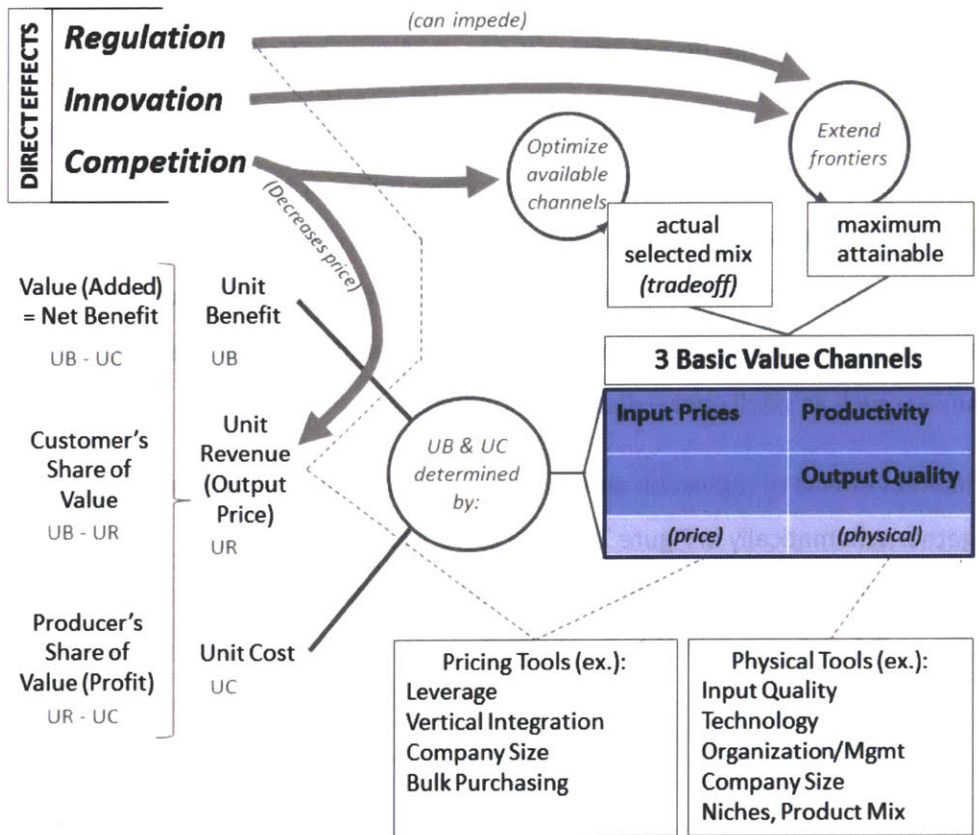


Figure 7-6: Direct Impacts on Productivity, Quality and Price

Figure 7-5 illustrates why one cannot necessarily neatly divide responsibility for firm performance among factors such as regulation or competition. Forces such as high competition are driven by both incentives and capacities, and both need to exist.

As alluded to earlier, competition has to do with the extent to which customers are maximizing their share of the value, given the existing capabilities of producers (e.g. if the customer identifies a more advantageous product than what they are using, are they switching to it?) The basic incentive for competition comes from the customer: the customer has to seek value. The capacity is affected by regulation: competition can be squashed or allowed to thrive. The schematic omits it for simplicity's sake, but industry structure also has a role: high concentration can also squash competition, and in such an environment regulation or the threat of regulation can be an additional incentive in favor of competition.

The purpose of high competition is to create incentives: a motivation to optimize the production process using what is available and known and a motivation to innovate to advance the state of what is possible. But the motivation must be matched by a capacity, which means external forces also play an important role.

The direct effects are illustrated in Figure 7-6. The direct effects of competition are to bring down unit revenues (thus allocating more of the value to the customer) and to maximize the value created by motivating the producer to optimize its operations. A gain in innovation or a loosening of regulations both increase what the producer has "to work with." (Note a corollary is that if the innovation or regulatory change involves a channel that the producer and customer do not prioritize, not much value is created). A new innovation or regulatory change can transform physical productivity, output quality, or input price without affecting the other channels, in the manner that was shown in Figure 7-4 (although a specific innovation could simultaneously transform multiple channels).

Nothing in the forgoing is to suggest that high competition need have uniformly positive effects. First, high competition can become destructive (*or ruinous / cutthroat*) competition: this happens when companies chronically price at less than unit cost, inhibiting them from making needed investments. This is a major concern in industries with high fixed costs, because physical capital can deteriorate severely as long-term investments are deferred. A second, related, problem of high competition is that even while the incentive for innovation improves, the capacity may decline. This is related to the classic Schumpeter hypothesis that large, concentrated firms are best positioned to innovate. A third concern is

that while productivity and quality improvements are arguably positive for all parties, decreases in input prices (notably wages) can be more contentious socially. Fourth, if some producers come to dominate the market, they may start to pursue anticompetitive strategies such as predatory pricing. Fifth, there may be distributional effects of productivity gains: even if most parties gain, there may be some losers. In trucking, one such issue that troubled regulators was geographically remote shippers. And sixth, there may be externalities that could negatively affect the social net benefit, for example safety concerns.

The next subsection applies the regulation-competition-productivity framework to the post-deregulation trucking industry, and summarizes the positive and negative impacts of deregulation based on the findings from this thesis and past studies.

7.2. Regulation, Competition and Productivity in the Trucking Industry

The productivity tradeoff is something that this thesis does not explicitly apply to the trucking industry. The Form M dataset does not include any data on service quality. Nonetheless, the existence of tradeoffs is important to bear in mind when drawing conclusions about the rate of observed productivity growth. Since quality can never be fully controlled for, the tradeoff affects all physical productivity analyses to some degree or other. The rudimentary analysis that I did do on this issue suggested that there were large firms operating at relatively low productivity and making a healthy unit profit, implying that their operating position was rational. Of course, this thesis focused on changes in productivity rather than productivity itself, and the question of whether low-productivity carriers were more or less inclined to pursue productivity advances remains an open one.

The following subsections demonstrate how the mechanisms introduced in Subsection 7.1.3. unfolded in the trucking industry.

7.2.1. Deregulation: Impacts on Competition and Productivity

1) Direct Effect of Regulation on Value and Productivity: Before deregulation, onerous route and commodity restrictions lead to unnecessary circuitry and inefficiency, harming productivity. Carriers found it difficult to take advantage of geographical or other economies by expanding into new markets or filling back hauls, because operating certificates were scarcely forthcoming from the ICC. The Rule of Eight – which forbade contract carriers from having more than eight customers – and other similar regulations also limited firms' operations.

It is important to note that the trucking industry today is not free from regulation (virtually no industry is). Gross weight limits, speed limits, driver hours of service (HOS) regulations, fuel efficiency standards, insurance requirements, and vehicle safety standards are some notable examples of trucking regulation. All of these exist to protect some compelling social interest. As trucking interests regularly point out, regulations such as HOS rules do have a tangible negative impact on productivity. Still, it is an open question whether or to what extent these have anything more than a direct effect on the value carriers produce. When the impact on productivity is direct, the calculus is simply whether the social benefit outweighs the harm to truckers and shippers. The more insidious and troublesome regulations are those that harm competition.

2) **Indirect Effect of Regulation – via Competition:** There were several ways in which trucking regulation hurt competition, most notably pricing and entry. These were described in greater detail in Chapter 1, but the point is that motor carriers set rates collectively, precluding price competition, and incumbent carriers were protected against competitors on a geographic basis.

Figure 7-7 illustrates the regulated era from the perspective of Porter’s Five Forces framework.

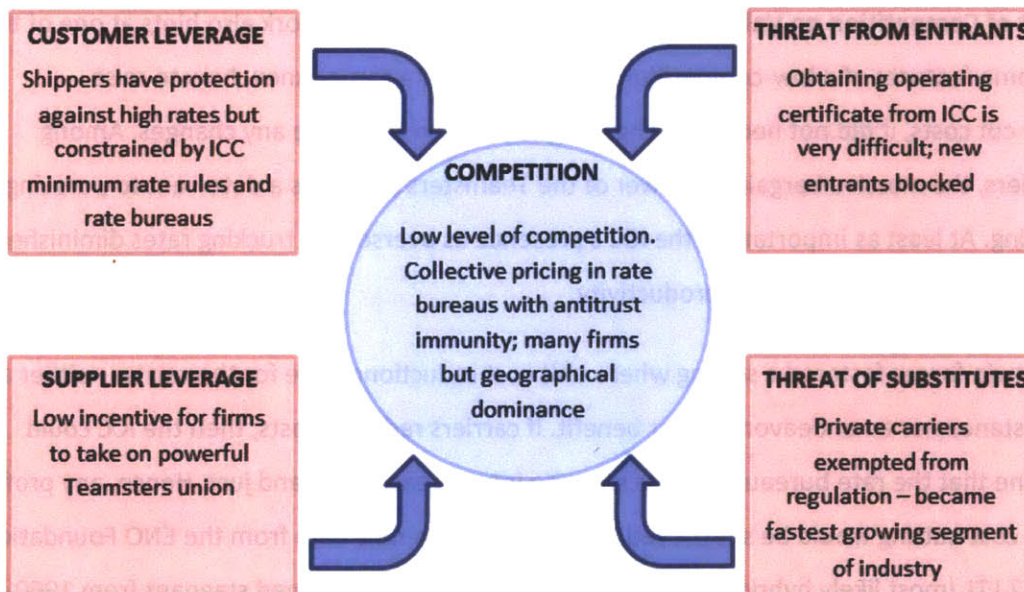


Figure 7-7: Porter’s Five Forces Applied to Regulated Trucking Industry

Porter's framework serves as a reminder that it is difficult to completely squelch competition, because of the threat of substitute products. While the other major modes were also heavily regulated, private motor carriage was not, and it rose to become the fastest growing part of the trucking industry before deregulation (Teske, 1995). Companies that needed to ship freight were electing to purchase their own vehicles and hire their own drivers. Since deregulation, private trucking remains widely used for short distance shipments, but the post-deregulation re-emergence of for-hire carriers is an indication that competition in the for-hire industry was lagging, and this had a lot to do with regulation.

Furthermore, the rapid changes in industry structure, the mass of new entrants and bankruptcies, and the declining unit costs and profits are all highly suggestive of regulation's impedance of competition.

Finally, an interesting study was performed by Rose (1985). She examined the share prices of major publically traded trucking firms, and found that regulatory reforms significantly reduced the expected future profits of firms. For general freight carriers (largely the mixed carriers), Rose's model suggests an average loss of 31% of pre-reform equity. These findings are consistent with the hypothesis of abnormal rents during the regulatory period. Effectively, investors were anticipating regulatory liberalization to induce a more competitive market.

3) Direct Effect of Competition on Value and Productivity: Porter's framework also hints at one of the most troublesome features of a low-competition industry. Even if a carrier knew how to raise productivity or cut costs, it did not necessarily have a good reason to pursue any changes. Among unionized carriers, the massive bargaining power of the Teamsters served as a deterrent to pursuing labor cost cutting. At least as importantly, the ICC's presence as overseer of trucking rates diminished carriers' incentive to cut costs and raise productivity.

These twin forces fostered a setting where unit cost reductions were for the carrier neither a path of no resistance nor an endeavor of clear benefit. If carriers reduced costs, then the ICC could surely determine that the rate bureau-set rates were no longer reasonable and just. Hence, any profits obtained from cost-cutting would be short-lived. Revenue per ton-mile data from the ENO Foundation representing 27 LTL (most likely hybrid) carriers show that real prices remained stagnant from 1960-1980, dropping thereafter (Figure 7-8). One can surmise that unit revenues would have tracked unit costs fairly closely. A stagnation in both is entirely consistent with the hypothesis that the low-competition environment was not supportive of value creation.

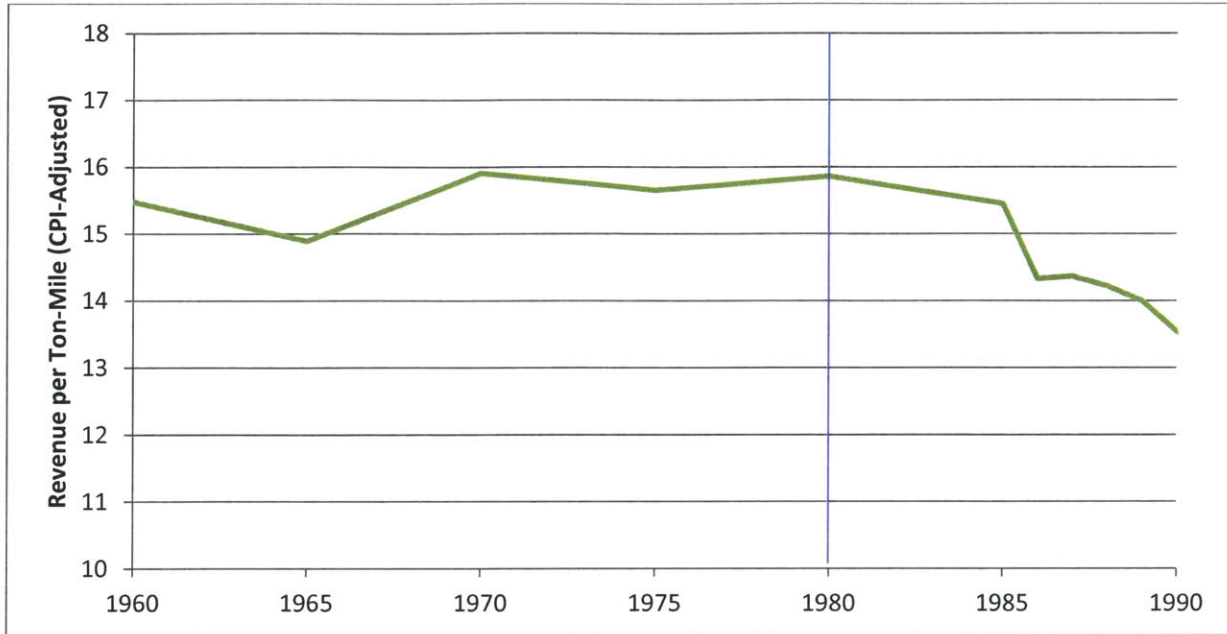


Figure 7-8: Stagnant LTL Rates Prior to Deregulation

Note: Sample of 27 general freight common carriers providing LTL service. Inflation-adjusted to 1979 dollars; \$1 in 1979 equals approximately \$3.16 in 2012.

Source: ENO Foundation, cited in Lieb (1994); inflation adjustment by author

Morrison and Winston (1999) note that most of the net benefits of trucking deregulation have accrued to shippers (and by extension consumers). Citing Winston (1990), they estimate a conservative annual net benefit to shippers of more than \$18 b., and that benefit has surely only increased over time. Part of the benefit is from increased service quality, in the form of improved service time and service time reliability. The authors note that the large improvements in service quality even surprised the economics profession, which had championed deregulation.

Net benefit gains have more than just direct impacts on shippers: they also allow shippers to better trade off transportation costs against other (e.g. inventory) costs. The reliability of the trucking industry has helped enable a widespread shift to just-in-time inventory policies.

Insofar as competition constantly incentivizes carriers to offer the most value to shippers, this effect can be thought of as “the gift that keeps on giving.” To the extent that the downstream markets are themselves competitive, much of the net benefit carries on to the end consumer.

4) Indirect Effect of Competition – via Innovation: In a study on trucking productivity, Apostolides (2009) identified six key technological advances since the 1980s:

- On-board computers (OBCs) collect data on truck performance and operation. OBCs have reduced the labor time needed for processing transactions, and have allowed analysts to track fuel utilization and perform remote diagnostics of truck performance
- Electronic Data Interchange (EDI) systems have enabled carriers and shippers to transmit transaction and other information in an easier, more accurate and timelier manner than before
- Automatic Vehicle Location (AVL) technologies enabled vehicle tracking, and satellite communications (SATCOM) technologies additionally allowed dispatchers and truck drivers to communicate in real time
- Computer-Aided Routing (CAR) and Dispatching (CAD) are computer hardware and software used to optimize route selection and fleet routing. This has improved productivity through better utilization of trucks and a reduction in the number and extent of empty hauls, especially back hauls
- Maintenance-tracking software (MTS) have led to more time- and cost-effective maintenance of vehicle fleets
- Various computerized systems have enabled the electronic marketing, buying and selling of transportation services

It may be impossible to know to what extent these changes were hastened by increased competition, but there is every reason to believe competition encourages the adoption of new technologies, and there is certainly much evidence of the adoption of such technologies in the trucking industry.

Other production transformations that may or may not be considered “innovation” have also influenced firms’ capacities. In the 1980s-90s trailer sizes continued to increase, with 53-foot trailers replacing 45-foot semitrailers as the industry standard (FHWA, 1993).

7.2.2. Real and Feared Negative Consequences of Deregulation

This subsection returns to the issue of possible negative ramifications of deregulation and competition that were raised at the end of Subsection 7.1.3. Each concern is addressed in turn.

1) **Ruinous Competition:** As was shown in Figure 3-4, profits declined after deregulation, and for many carriers (especially hybrid TL-LTL carriers) profit was negative in certain years after deregulation. This indicates that the transition to a deregulated environment was not smooth. Carriers sought to compete on the basis of price, and for some that meant driving prices below unit costs. Carriers that were unable to cut unit costs went bankrupt. However, this problem appears to be confined to the chaotic years immediately after deregulation. Trucking is not a very capital-intensive industry and there is no indication that carriers are earning subnormal profits and chronically underinvesting in capital. (Also, as illustrated by the history of railroad regulation, economic regulation by no means guarantees adequate investment.) Overall, while profit per ton-mile has declined, total ton-miles have risen.

2) **Capacity for Innovation:** The crux of the Schumpeterian view is that big companies can afford to take on large research and development projects, the benefits of which are not immediate, because they are not constantly concerned about being undercut by competitors. In fact, this argument is much more about the merits of concentration than the faults of competition, because a concentrated industry where the big players are all investing in R&D (or anything else) can still manage to be quite competitive. (In fact, in such a situation, a lack of competition is likely harmful for innovation.) At any rate, the point does not seem entirely germane to the trucking industry, as trucking has never been particularly concentrated, and the core of the production process (one truck, one driver) holds steady. Trucking seems much better suited to reap the rewards of external innovations than to be a source of innovation for the economy.

3) **Declining Wages:** One channel in a firm's toolkit for increasing net benefit is to effect downward pressure on unit input prices, including wages. In the case of wages, it is debatable whether this is societally positive. What does seem clear is that trucking wages have declined in real (inflation-adjusted) terms since deregulation. This thesis finds labor price declines (accounting for wages & fringes) to 1992 of 24% for the TL sector and 14% for the LTL sector. Other studies of the trucking industry have given this question far more attention. Monaco (2006) finds a similar decrease for the same period, and estimates the direct effect of deregulation on wages to be 12.4%. See also Rose (1987), Hirsch (1988) and Belzer (1994), which hold deregulation responsible for around 15%-20% wage declines.

In truth, it is more appropriate to think of deregulation as the catalyst than the cause of wage declines. Deregulation let non-unionized carriers freely compete against unionized ones, and in doing so ravaged the leverage of the powerful Teamsters union. Wages are now freely negotiated (in a general sense) between motor carriers and workers. Nothing about such a free-market arrangement inherently suggests that wages should rise or fall. The decline in trucking industry wages parallels similar declines in many other blue-collar industries and has to do with broad economy-wide trends such as mechanization and offshoring.

It is not obvious that trucking labor as an interest has been a net loser from deregulation. As output has increased, so has the need for drivers (see Figure 7-9). In addition, the loss of Teamster dominance appears to have been beneficial for certain drivers, such as minorities. Peoples (2001) finds that black-white wage gaps fell from 12.7% to 0.8% for unionized companies after deregulation (after controlling for factors like education and experience; the gaps also fell for non-unionized companies).

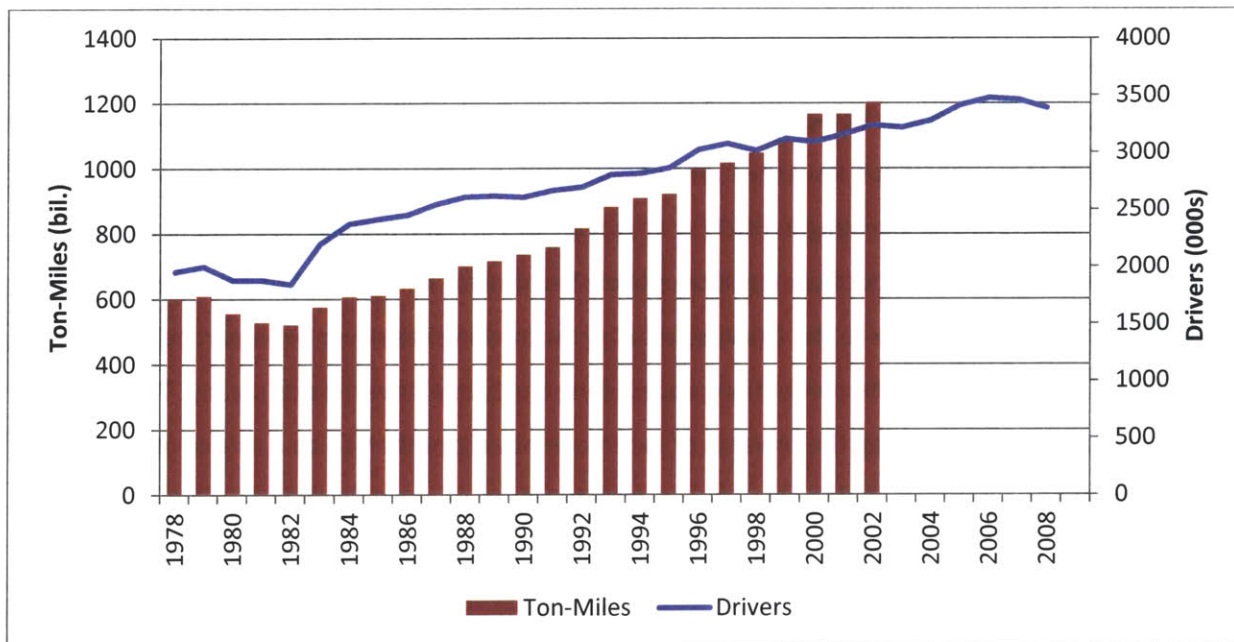


Figure 7-9: Increase in Output and Drivers since Deregulation

Source: American Trucking Associations' (ATA) annual Trends reports (various years)

4) **Market Dominance and Anticompetitive Behavior:** This has always been more of a concern with railroads than truckers. The trucking industry is not highly concentrated and roads are ubiquitous, so the

presence of captive shippers as such is not a concern. In many ways, shippers are less captive now than before, because all carriers are free to compete in virtually any market.

5) **Distributional Effects:** During the deregulatory debate of the 1970s, the spectre of diminished service to small communities was raised as an argument against deregulation. Teske (1995) refers to a number of studies – both internal to the ICC and external – showing that these fears did not materialize. He quotes Due's (1990) conclusion that "the majority of the studies of the impacts of trucking deregulation on the quantity, quality, and cost of regulated trucking service to rural communities have found the impacts to be neutral or positive."

This result should not be surprising. Although one of the objectives of regulation was to protect geographically disadvantaged shippers, the impacts of low competition were negative for small and large communities alike. In fact, to the extent that incumbent carriers could dominate small markets, the competitive harm may have been especially acute to certain small communities. Morrison and Winston (1999) conclude that "large shippers in high-density markets have undoubtedly gained more than small shippers in low-density markets, but small shippers have been able to share in some of the benefits from lower rates through third-party logistics firms." Hence although large communities may have gained more, the "rising tide" does appear to have lifted all boats.

Carriers that could not adapt to the post-deregulatory competitive environment also suffered as a result of deregulation. Figure 7-10 shows the bankruptcy rate rising substantially in the early 1980s. The bankruptcy gap between the trucking industry and the economy as a whole rose in the early 1980s, only to retreat in the early 1990s. The reality is that the threat of bankruptcy is a natural and necessary component of a competitive market. But the transition to a competitive marketplace was not painless.

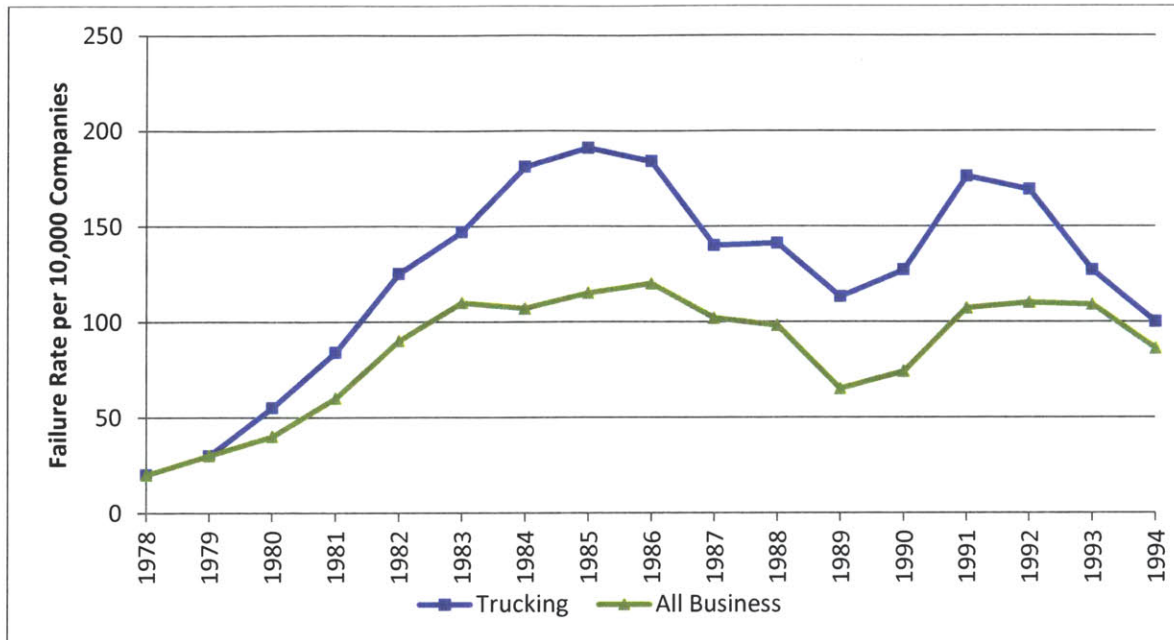


Figure 7-10: Increase in Bankruptcy Rate after Deregulation

Note: Basis of measurement was revised in 1984

Source: American Trucking Associations' (ATA) annual Trends reports (various years)

Original Source: Dun & Bradstreet Failure Data

6) **Negative Externalities:** One objective of regulation was to protect the safety of the nation's roads. In fact, safety was one facet of the regulatory structure that was not eliminated; today the trucking industry is regulated by various federal agencies, including the US Department of Transportation's (DOT) Federal Motor Carrier Safety Administration (FMCSA). However, the argument has been made, with some merit, that high competition can harm safety. It can do so by discouraging proper maintenance of vehicles, motivating drivers to speed to meet deadlines, disincentivizing proper training and monitoring, or leading drivers to work long hours to make up for low wages.

Teske (1995), reviewing a number of safety studies, concludes that "no careful analysis has discovered a positive relationship between deregulation and trucking accidents." Belzer (2000) does link competition to driver fatigue, and cites findings that 2/3 of drivers admit regularly violating DOT hours-of-service regulations and 1/3 admit dozing off or falling asleep at the wheel at least once over the past 30 days. Data from the DOT demonstrate (Figure 7-11) that the fatal crash rate has plummeted since around 1980, with large trucks outperforming passenger vehicles. Data on non-fatal crashes are only available from 1989 but show a decline of an even greater magnitude.

In conclusion, there is some cause for concern, but no safety crisis in the US trucking industry. Regulations tailored specifically to safety will continue to have to strike a balance between not overburdening carriers and protecting the safety of drivers and the traveling public.

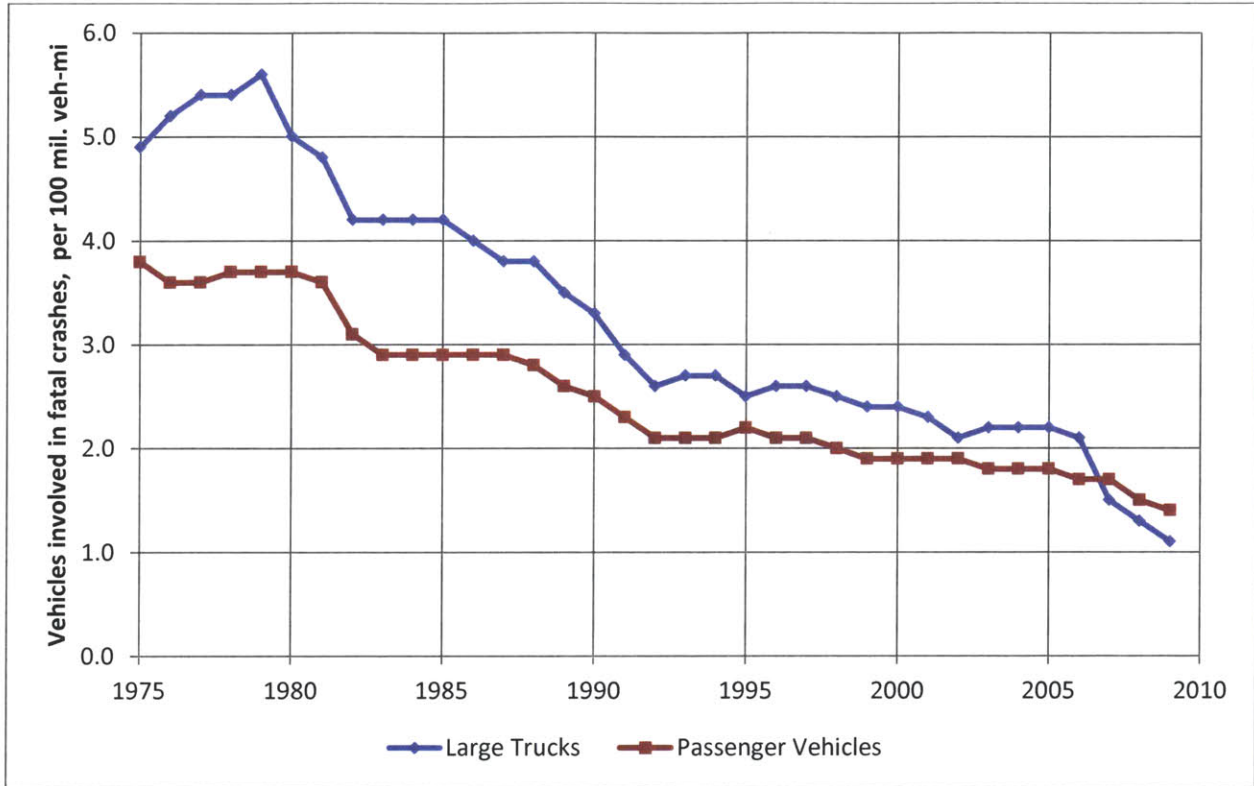


Figure 7-11: Declining Fatal Crash Rate since Deregulation

Note: Number of trucks and passenger vehicles involved in fatal crashes per 100 million vehicle miles traveled

Source: US Department of Transportation, Large Bus and Truck Crash Facts 2009

Chapter 8 – Conclusion

8.1. Regulation in Retrospect

A dynamic, competitive trucking industry today seems so natural that it is easy to forget how different things were 30-odd years ago. For nearly half a century, basic economic aspects of trucking were subject to heavy-handed control. There are several important lessons from the trucking deregulation experience.

First, enormous changes can take place in very short order when competition is allowed to flourish. The sudden bifurcation of the industry into truckload and less-than-truckload sectors, and the massive upswing in the number of carriers, are perhaps the most impressive examples.

Second, the benefits of such fundamental regulatory changes were not of a one-off nature. Competition incentivizes producers to use all available tools to produce greater value, including harnessing new technologies and other innovations. These indirect benefits of regulatory liberalization are complex, powerful, and enduring.

Third, even incremental regulatory changes can produce a large market response, if the changes are the right ones. It is easy to fall into the trap of thinking the trucking industry was fully deregulated in 1980. Yet rate bureaus were not disbanded nor stripped of their antitrust immunity, nor was the ICC's control over entry taken away. But the competitive forces unleashed made these distinctions seem minor.

Fourth, the impetus for regulatory reform does not always come from the parties that stand to gain the most. In the case of trucking, the main beneficiaries of deregulation – shippers – were broadly satisfied with trucking service during the regulated period. It would have been difficult to predict the transformations in costs and service quality that took place. One is only left to wonder for how long

trucking regulation may have survived had such dire deterioration in the railroads not compelled Congress to devote attention to the issue of transportation regulation.

Finally, a regulatory structure is not just a set of laws and rules: it quickly becomes an institution in its own right. In theory, heavy regulation can provide a potential for system optimization, or at least a capacity for managing the system in a careful, rational way. But these promises can be illusory. Even the cleverest regulators would have found it hard to foresee the true potential of the trucking industry, much less effectuate it.

Meyer et al, writing in 1959, recognized several additional kinds of problems with the regulatory structures of the transportation industries that, once in place, were hard to arrest. The regulatory structure created vested interests, such as large and established companies; it encouraged transportation providers to seek protection from competitors rather than improve their products; and it cultivated a kind of passiveness among regulators who could, for example, be uninterested in dealing with a large number of firms.

Of course, there exist valid rationales for regulation. Meyer, a foremost critic of transportation regulation as it was practiced in the middle of the 20st century, himself identified (Meyer, 1959) certain market failures that could justify regulation. But adverse side effects are not akin to market failure. Every market will have certain unattractive aspects; if regulation is used to correct them, it is critical to consider the potential effect on competition. The experience of the trucking industry is instructive. Because of its low concentration and low physical entry barriers, economists had long labeled it an ideal candidate for a high competition setting. Yet for over 40 years, competition was restrained. Once the regulatory structure was entrenched it seemed so familiar to most parties involved that even the participants who would have benefitted most from deregulation did not appreciate the industry's full potential. The rail industry makes for another interesting case study. Even though rail has high fixed costs, it was only after deregulation that traffic volumes and productivity reversed decades of mediocrity and decline (Gallamore, 1955).

Figure 8-1 is simply an extension of Figure 3-5, but it concisely illustrates the pattern break that took place in trucking. For decades, the number of carriers declined as entry was controlled. In the mid-1970s, the ICC relaxed its entry policy, but the growth in that period was minuscule compared to the proliferation of carriers after deregulation.

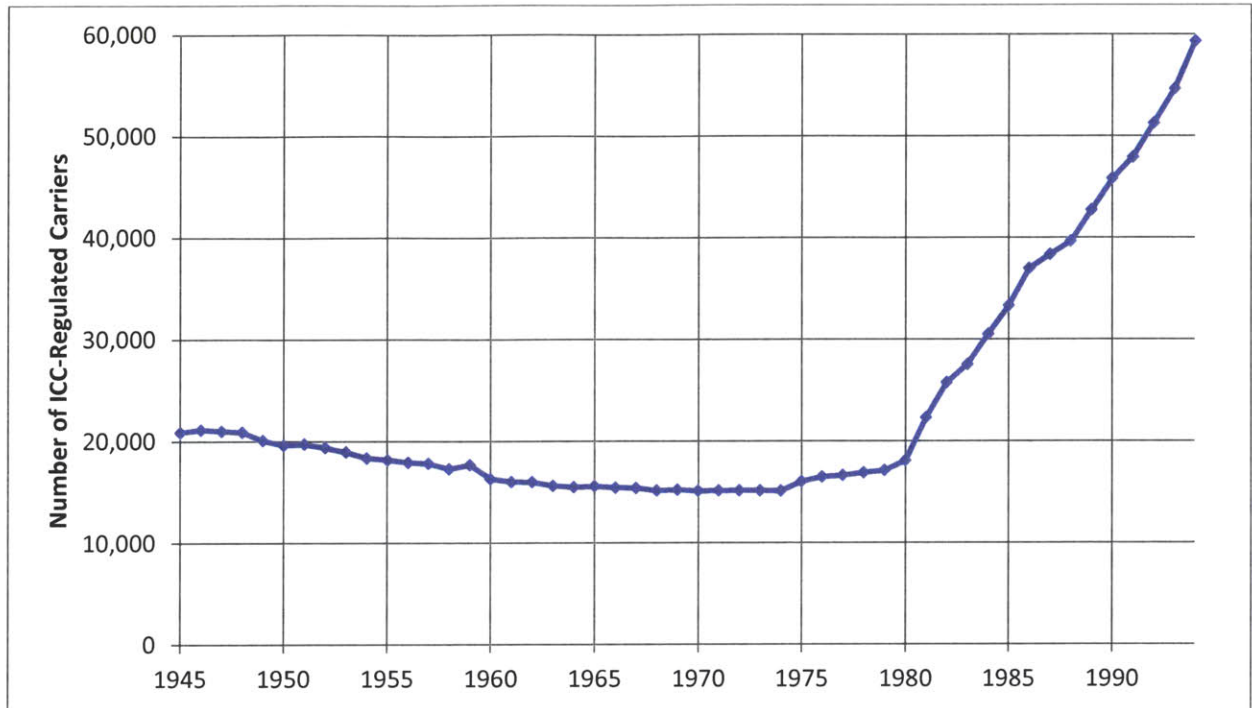


Figure 8-1: Deregulation: A True “Pattern Break”

Data: American Trucking Associations’ (ATA) annual Trends reports

Thirty-odd years ago, a paradigm shift toward deregulation transformed the American economic landscape, not just in transportation but in sectors like energy and finance. Enough time has passed to allow us retrospectively to assess the wisdom of these endeavors. Although some of the perspectives presented in this thesis can be extended to other fields, I must stress that this thesis is fundamentally about the experience of the trucking industry. Since 2008, the financial sector has been thrust into the public spotlight, and its regulatory past has become a contentious issue. Like finance, trucking is critical to the nation’s economic success, and is relied upon at many stages of supply chains. But the trucking industry is lowly concentrated, has substitute products in the form of other modes, and does not affect anything as fundamental as the money supply. All of that is to say that bankruptcies, even of the largest carriers, do not threaten the vitality of the trucking industry. It survived a mass of bankruptcies in the 1980s and emerged stronger.

8.2. Directions for Future Research

This thesis has explored physical productivity at the firm level. It did not causally tie productivity changes to specific changes in the production process. It also did not take account of the composition of trucking output, in terms of length of haul or commodities carried; nor did it delve into measuring aspects of quality, such as travel time and reliability. If the Boyer-Burks study (2009) can be used as a rough gauge, around 30% of physical productivity may have to do with composition effects. But the dataset used for the core analysis in this thesis did not allow for all of these effects to be explored in greater depth. Such analysis would probably be better served with a more disaggregate dataset, perhaps at the lane level. Although it may be difficult to represent the whole industry, lane-level studies can provide valuable insights into the more detailed aspects of the production process. Unfortunately, I had difficulty tracking down this kind of historical data, and it is not clear that it is out there.

There is much additional analysis that could be performed using the Form M data. One option would be to pay more attention to the performance of individual companies. It could be valuable to examine whether productivity gains came disproportionately from the already-productive companies (suggesting a shift of the productivity frontier) or from the less-productive companies gaining ground. It would be interesting to simultaneously examine the unit profitability of firms operating at different productivity levels, so as to make judgments about the rationality of their operating position (i.e. did some low-productivity companies rationally trade off lower productivity against other advantages).

8.3. Ten Observations about Post-Deregulation Trucking

- 1) The Motor Carrier Act (MCA) of 1980 substantially liberalized the trucking industry and was part of a larger deregulatory movement across the domestic transportation industries.
- 2) “Deregulation” did not happen overnight: the ICC had started to liberalize its policies several years in advance, and the MCA weakened rather than eliminated the regulatory structure.
- 3) The key aspects of the regulatory structure were: entry restrictions via operating certificates; price controls and (in practice) collective pricing; and bureaucratic restrictions relating to firm classification. The collective effect of these was to curtail competition.
- 4) After deregulation the industry rapidly bifurcated, as carriers came to specialize in truckload (TL) or less-than-truckload (LTL) operations.
- 5) In the 1980s there was rapid overturn in the industry as the bankruptcy rate peaked and the number of new entrants skyrocketed. The vast majority of new firms were small truckload carriers.
- 6) Real output prices, stagnant for decades, dropped by an annual 2% p.a. for LTL and 3-4% for TL in the decade or so after deregulation (the period for which I have detailed data). Indications are that real prices continued to decline into the 1990s and 2000s.
- 7) Output price declines were enabled by reduced unit profits and reduced unit costs. Responsibility for unit cost declines seems to be shared between physical productivity factors and input price factors, with the latter somewhat more impactful.
- 8) Physical multifactor productivity increased by 1.6% p.a. for TL and 1% p.a. for LTL from 1979-1992. There was no productivity revolution in trucking, but the increased productivity did significantly contribute to unit cost savings.
- 9) Real labor input prices declined by around 24% for TL and 14% for LTL from 1979-1992. In addition to those workers whose wages were cut, other net losers from deregulation included the labor union and uncompetitive carriers that went bankrupt. The big winners were shippers and (by extension) consumers, who reaped the benefits of lower prices and higher service quality.
- 10) Trucking output has more than doubled in the 30 years after deregulation, and today trucking is perhaps the most dominant mode of freight transportation. These developments owe to the increased competitiveness of trucking, the ascendancy of intermodal transportation, and shifts in transported commodities toward smaller, high-value items.

References and Data Sources

- American Trucking Associations, American Trucking Trends, various years
- Annual Reports (Form M) data for motor carriers of property. The author would like to thank Dr. Stephen Burks, University of Minnesota and Dr. Thomas Corsi, University of Maryland.
- Apostolides, A. (2009). Estimation and Analysis of Multifactor Productivity in Truck Transportation: 1987-2003. Bureau of Transportation Statistics, Office of Advanced Studies
- Bayliss, B. (1988). The Measurement of Supply and Demand in Freight Transportation. Avebury.
- Belzer, M. (1994). Paying the Toll: Economic Deregulation of the Trucking Industry. Economic Policy Institute.
- Belzer, M. (2000). Sweatshops on Wheels: Winners and Losers in Trucking Deregulation. Oxford University Press.
- Boyer, K. and Burks, S. (2009). Stuck in the Slow Lane: Traffic Composition and the Measurement of Trucking Productivity. *Southern Economic Journal*. Vol. 75, No. 4, pp. 1220-1237
- Burks, S. and Guy, F. (2012). What Are Over-the-Road Truckers Paid For? Evidence from an Exogenous Regulatory Change on the Role of Social Comparisons and Work Organization in Wage Determination." Institute for the Study of Labor (IZA) Discussion Paper #6375
- Bureau of Labor Statistics, CPI-U, U.S. All-City Average, available 1913-present
- Bureau of Transportation Statistics, Commodity Flow Surveys, various years
- Bureau of Transportation Statistics (2007). A Decade of Growth in Domestic Freight. Special Report.
- Caplice, C. (1996). An Optimization Based Bidding Process: A New Framework for Shipper-Carrier Relationships. MIT Doctoral Dissertation.
- Corsi, T. (1996). Current and Alternative Federal Size and Weight Policies: Less-Than-Truckload Motor Carriers. University of Maryland, College of Business and Management.
- Coyle, J., Bardi, E., and Novack, R. (2006). Transportation. Thomson South-western.
- Donatelli, D. (2012). Evolution of US Air Cargo Productivity. MIT Master's Thesis.
- Federal Highway Administration (1993). Trucking Industry Overview. Chapter 3: Truck Fleet and Operations.

- Fernald, John. (1997). Roads to Prosperity? Assessing the Link between Public Capital and Productivity. *Board of Governors of the Federal Reserve System: International Finance Discussion Papers*.
- Gallamore, R. (1995). Regulation and Innovation: Lessons from the American Railroad Industry. Chapter 15 of Gomez-Ibanez, J., Tye, W. and Winston, C. (1999). *Essays in Transportation Economics and Policy*. Brookings Institution Press.
- Hirsch, B. (1988). Trucking regulation, unionization and labor earnings: 1973-1985. *Journal of Human Resources*. Vol. 23, pp. 296-319.
- Jacobellis v. Ohio (1964). U.S. Supreme Court ruling: Concurrence by Stewart.
- Jara-Diaz, S. et al. (2002). A multioutput cost function for the services of Spanish ports' infrastructure. *Transportation*. Vol. 29, pp. 419-437.
- Kriem, Y. (2011). Productivity of the US Freight Rail Industry: a Review of the Past and Prospects for the Future. MIT Master's Thesis.
- Lieb, R. C. (1994). *Transportation*. Dame Publications.
- Meyer, J.R., Peck, M.J., Stenason, J. and Zwick, C. (1959). *The Economics of Competition in the Transportation Industries*. Harvard University Press.
- Monaco, K., Brooks, T. and Bitzan, J. (2006). A Time Series Analysis of Wages in Deregulated Industries: A Study of Motor Carriage and Rail. *Journal of Applied Economics*. Vol. IX, No. 1, pp. 105-118
- Morrison, S. and Winston, C. (1999). Regulatory Reform of U.S. Intercity Transportation. Chapter 14 of Gomez-Ibanez, J., Tye, W. and Winston, C. (1999). *Essays in Transportation Economics and Policy*. Brookings Institution Press.
- Oum, T., Tretheway, M. and Waters, W. (1992). Concepts, Methods and Purposes of Productivity Measurement in Transportation. *Transportation Research A*. Vol. 26A, No. 6, pp. 493-505.
- Peoples, J. and Saunders, L. (1993). Trucking Deregulation and the Black/White Wage Gap. *Industrial and Labor Relations Review*, Vol. 47, No. 1, pp. 23-35.
- Porter, M. (1979). How Competitive Forces Shape Strategy. Part I of Porter (1998). *On Competition*. Harvard Business School Press.
- Powell, R. (2012). Productivity Performance of US Passenger Airlines since Deregulation. MIT Master's Thesis.
- Rose, N. (1985). The Incidence of Regulatory Rents in the Motor Carrier Industry. *The RAND Journal of Economics*. Vol. 16, No. 3, pp. 299-318.
- Rose, N. (1987). Labor rent sharing and regulation: evidence from the trucking industry. *Journal of Political Economy*. Vol. 95, pp. 1146-1178.

- Rothenberg, L. (1994). *Regulation, Organizations, and Politics: Motor Freight Policy at the Interstate Commerce Commission*. University of Michigan Press.
- Scheppach, R. and Woehlcke, L. (1975). *Transportation Productivity*. Lexington Books.
- U.S. Energy Information Administration. *Distillate Fuel Oil Price in the Transportation Sector (DFACD), 1970-2010*.
- Teske, P., Best, S. and Mintrom, M. (1995). *Deregulating Freight Transportation: Delivering the Goods*. The American Enterprise Institute. The AEI Press.
- US Census Bureau (1997), NAICS 484121 and NAICS 484122
- US Census Bureau (2013), U.S. Trade in Goods – Balance of Payments Basis vs. Census Basis
- Winston, C. et al. (1990). *The Economic Effects of Surface Freight Deregulation*. The Brookings Institution.
- World Bank (2013). *Industry, value added (% of GDP)*.
- Ying, J. (1990). The Inefficiency of Regulating a Competitive Industry: Productivity Gains in Trucking Following Reform. *The Review of Economics and Statistics*. Vol. 72, No. 2, pp. 191-201.

Appendices

Appendix A – Supplementary Results: Productivity

A.1. Results from 2-Step vs. 1-Step Methods

This section compares the results presented in Chapter 5 with those obtained with another similar method. The primary method is the two-step method, which decomposes productivity into multiple phases, where the intermediate output is miles. The alternative is the one-step method, which compares ton-miles to inputs directly; miles are not incorporated. For the equations used, see subsection A.2. of this appendix.

One advantage of the two-step method is that it reveals additional information (e.g. about load factors). The major reason why the two-step method is selected for this thesis is that it leverages additional data, since ton-miles is sometimes underreported. With more observations, the median proves a more consistent statistic.

The sectors are truckload (TL) and less-than-truckload (LTL). LTL is represented by LTL-U, where the U stands for unrestricted. The restricted set LTL-R is a subset of LTL-U where LTL carriers with big year-to-year operational shifts are removed. This reduces a certain type of bias arising from changes in carrier shares of TL vs. LTL operations (see Chapter 5).

Table A-1: Multifactor Productivity (Cumulative) – By Different Methods

sector method	TL		LTL-U		LTL-R	
	2-Step	1-Step	2-Step	1-Step	2-Step	1-Step
1977						
1978						
1979						
1980	3%	-3%	-6%	-6%	-1%	-5%
1981	5%	-1%	-7%	-7%	-3%	-4%
1982	1%	-11%	-11%	-12%	-6%	-5%
1983	10%	-3%	-6%	-7%	-1%	1%
1984	14%	2%	-4%	-7%	2%	3%
1985	12%	-1%	-10%	-10%	1%	2%
1986	15%	1%	-7%	-7%	5%	6%
1987	14%	3%	-6%	-4%	7%	9%
1988	16%	5%	-5%	-3%	9%	11%
1989	13%	2%	-8%	-6%	6%	8%
1990	20%	7%	-7%	-7%	5%	7%
1991	21%	9%	-7%	-5%	8%	9%
1992	23%	11%	-3%	-2%	13%	12%

Table A-2: Multifactor Productivity (Annual) – Different Methods

sector method	TL		LTL-U		LTL-R	
	2-Step	1-Step	2-Step	1-Step	2-Step	1-Step
1977						
1978	-1%	3%	3%	3%	3%	3%
1979	0%	-1%	-3%	-2%	-3%	-2%
1980	3%	-3%	-6%	-6%	-1%	-5%
1981	3%	2%	-1%	-1%	-1%	1%
1982	-5%	-10%	-5%	-6%	-3%	-1%
1983	9%	9%	5%	5%	5%	6%
1984	4%	5%	2%	0%	3%	2%
1985	-1%	-3%	-5%	-3%	-2%	-1%
1986	2%	3%	3%	3%	4%	4%
1987	-1%	2%	2%	2%	2%	2%
1988	2%	2%	1%	1%	2%	2%
1989	-3%	-3%	-4%	-3%	-3%	-2%
1990	6%	4%	1%	0%	-1%	-1%
1991	1%	2%	0%	2%	2%	2%
1992	2%	2%	5%	3%	5%	3%

Table A-3: Count of Observations (Minimum of All Variables)

sector method	TL		LTL-U		LTL-R	
	2-Step	1-Step	2-Step	1-Step	2-Step	1-Step
1977						
1978	39	35	44	38	32	27
1979	39	36	47	44	36	34
1980	41	37	49	47	32	31
1981	21	20	47	46	32	31
1982	35	30	59	58	22	22
1983	34	32	53	52	38	37
1984	38	35	51	50	46	45
1985	42	41	50	49	31	30
1986	39	38	50	50	42	42
1987	37	37	48	48	43	43
1988						
1989	27	25	45	43	35	34
1990	20	17	43	40	32	30
1991	29	25	46	43	37	34
1992	28	24	45	43	42	40

Notes:

- The results for 1988 are found using a smoothing process for reasons discussed in Chapter 2. Hence, there are no observation counts listed for this year
- The counts are the minimum of all relevant variables (ton-miles, miles, labor, capital, fuel). Note that this is only the minimum; for full counts see A.3. The equations are designed so as to use partial productivities, meaning that (for example) a low number of observations for capital will only affect capital productivity, not fuel or labor productivity.

Comments:

- The cumulative results are broadly similar using both methods. The only exception is the truckload sector, where the cumulative MFP's to 1992 are 23% vs. 11%. Note, however, that there are several anomalous years (1980, 1982) where the 1-step method produces low annual MFP estimates. These results were compared to those from two additional methods (equations described below). Labor productivity growth in 1982 is around 10 points lower using the 1-step method than using the other methods, suggesting an anomaly. For this reason and since the 2-step method leverages more information, the 23% seems more reasonable than the 11%.

A.2. Equations Used for Annual MFP Computation

The two equations the results of which are presented in Appendix A.1. are:

Two-Step Median of Differences

$$\frac{\Delta T}{T} = Mdn_i \left(\frac{\Delta Q}{Q} - \frac{\Delta N}{N} \right)_i + \alpha \times Mdn_j \left(\frac{\Delta N}{N} - \frac{\Delta L}{L} \right)_j + \beta \times Mdn_k \left(\frac{\Delta N}{N} - \frac{\Delta K}{K} \right)_k + \gamma \times Mdn_l \left(\frac{\Delta N}{N} - \frac{\Delta F}{F} \right)_l$$

One-Step Median of Differences

$$\frac{\Delta T}{T} = \alpha \times Mdn_m \left(\frac{\Delta Q}{Q} - \frac{\Delta L}{L} \right)_m + \beta \times Mdn_n \left(\frac{\Delta Q}{Q} - \frac{\Delta K}{K} \right)_n + \gamma \times Mdn_p \left(\frac{\Delta Q}{Q} - \frac{\Delta F}{F} \right)_p$$

The two equations above are “median of differences” (M of D) equations. One could alternatively compute the “difference of medians” (D of M), as shown in the following two additional equations:

Two-Step Difference of Medians

$$\begin{aligned} \frac{\Delta T}{T} = & \left[Mdn_i \left(\frac{\Delta Q}{Q} \right)_i - Mdn_i \left(\frac{\Delta N}{N} \right)_i \right] + \alpha \times \left[Mdn_j \left(\frac{\Delta N}{N} \right)_j - Mdn_j \left(\frac{\Delta L}{L} \right)_j \right] + \beta \\ & \times \left[Mdn_k \left(\frac{\Delta N}{N} \right)_k - Mdn_k \left(\frac{\Delta K}{K} \right)_k \right] + \gamma \times \left[Mdn_l \left(\frac{\Delta N}{N} \right)_l - Mdn_l \left(\frac{\Delta F}{F} \right)_l \right] \end{aligned}$$

One-Step Difference of Medians

$$\frac{\Delta T}{T} = \alpha \times \left[Mdn_m \left(\frac{\Delta Q}{Q} \right)_m - Mdn_m \left(\frac{\Delta L}{L} \right)_m \right] + \beta \times \left[Mdn_n \left(\frac{\Delta Q}{Q} \right)_n - Mdn_n \left(\frac{\Delta K}{K} \right)_n \right] + \gamma \times \left[Mdn_p \left(\frac{\Delta Q}{Q} \right)_p - Mdn_p \left(\frac{\Delta F}{F} \right)_p \right]$$

where, in all four equations:

- Variables: T is MFP, Q is final output in ton-miles, N is intermediate output in total miles, L is labor in employees, K is capital in truck tractors, F is fuel in gallon equivalent
- All variables are represented as year-to-year changes, of the form $\Delta Y/Y = (Y_{x+1} - Y_x)/Y_x$, where Y is a generic variable and x is a time period, measured in years, where $x = \{1978-1992\}$
- Mdn is the median operator
- Subscripts: any subscript $z = \{i,j,k,l,m,n,p\}$ refers to qualifying companies that report a pair of variables (i.e. both of them) for successive years. These variable pairs are i- ton-miles and miles, j- miles and labor, k- miles and capital, l- miles and fuel, m- ton-miles and labor; n- ton-miles and capital; p- ton-miles and fuel. Mdn_z indicates the median of all values z
- Weighting factors α , β , and γ are the relative weights of labor, capital and fuel; and $\alpha + \beta + \gamma = 100\%$

Essentially, the “M of D” equations take partial productivities at the company level, and then take the median across all companies. The “D of M” equations work as follows (example reflects the partial productivity of ton-miles w.r.t. labor): Take the median change in ton-miles across all companies that report both ton-miles and labor; take the median change in labor across all companies that report both ton-miles and labor; subtract the two.

The two “D of M” equations produce higher productivity estimates for all sectors (and especially both LTL-U and LTL-R). These results are not presented here because the “D of M” methods are less conceptually sound. There is no link between the input and output changes for individual companies and the methods are influenced by the correlation structures between input changes and output changes at the sector level. However, these methods have been used by the author as a rough gauge of the reasonableness of the primary method for individual years.

Note that all of these methods reflect year-to-year changes at the firm level.

A.3. Detailed Results from Primary (Two-Step Median of Differences) Method

Table A-4: Detailed Productivity Results for TL Sector

	TM- MILE	MILE- LAB	MILE- CAP	MILE- FUEL	LabProd	CapProd	FuelProd	MFP	LabProd- indx	CapProd- indx	FuelProd- indx	MFP- indx	Cum- LabProd	Cum- CapProd	Cum- FuelProd	Cum MFP
1977									102.8	97.5	98.9	100.7				
1978	1%	-4%	1%	2%	-3%	2%	3%	-1%	99.7	99.6	101.6	100.0				
1979	-1%	1%	1%	-1%	0%	0%	-2%	0%	100	100	100	100				
1980	0%	2%	2%	7%	2%	2%	7%	3%	102.2	102.1	106.8	102.9	2%	2%	7%	3%
1981	-1%	4%	4%	-2%	4%	3%	-3%	3%	105.8	105.7	103.8	105.5	6%	6%	4%	5%
1982	-1%	-2%	-6%	-6%	-3%	-7%	-7%	-5%	102.7	98.5	96.8	100.7	3%	-2%	-3%	1%
1983	0%	10%	6%	8%	10%	6%	8%	9%	113.1	104.6	104.9	109.6	13%	5%	5%	10%
1984	1%	3%	4%	1%	4%	5%	1%	4%	117.2	110.1	106.3	113.6	17%	10%	6%	14%
1985	0%	-2%	-1%	3%	-3%	-2%	3%	-1%	114.2	108.4	109.3	112.0	14%	8%	9%	12%
1986	0%	0%	2%	13%	0%	2%	12%	2%	113.8	110.7	123.0	114.5	14%	11%	23%	15%
1987	0%	-3%	1%	3%	-3%	1%	3%	-1%	110.6	112.3	127.0	113.7	11%	12%	27%	14%
1988	0%	2%	2%	2%	2%	2%	2%	2%	112.7	114.9	129.9	116.0	13%	15%	30%	16%
1989	0%	-3%	-1%	-5%	-3%	-1%	-5%	-3%	109.2	113.3	123.8	112.7	9%	13%	24%	13%
1990	0%	8%	7%	-2%	8%	7%	-2%	6%	117.9	121.1	121.5	119.6	18%	21%	22%	20%
1991	0%	1%	2%	-4%	1%	2%	-4%	1%	119.4	124.0	116.5	120.5	19%	24%	16%	21%
1992	0%	3%	-1%	3%	3%	-1%	3%	2%	122.7	122.5	119.8	122.6	23%	22%	20%	23%
1988*	3%	12%	10%	-1%	15%	13%	2%	12%								

Table A-5: Detailed Productivity Results for LTL Sector (LTL-U)

	TM- MILE	MILE- LAB	MILE- CAP	MILE- FUEL	LabProd	CapProd	FuelProd	MFP	LabProd- indx	CapProd- indx	FuelProd- indx	MFP- indx	Cum- LabProd	Cum- CapProd	Cum- FuelProd	Cum MFP
1977									100.2	99.9	97.0	100.0				
1978	2%	1%	2%	0%	3%	4%	2%	3%	103.3	103.5	98.7	103.1				
1979	-1%	-2%	-2%	2%	-3%	-3%	1%	-3%	100	100	100	100				
1980	-4%	-2%	-5%	0%	-5%	-9%	-4%	-6%	94.7	90.9	96.5	94.4	-5%	-9%	-4%	-6%
1981	-3%	3%	2%	0%	-1%	-2%	-3%	-1%	94.1	89.3	93.1	93.5	-6%	-11%	-7%	-7%
1982	-3%	-1%	-6%	2%	-4%	-9%	-2%	-5%	90.1	81.2	91.4	89.1	-10%	-19%	-9%	-11%
1983	1%	5%	6%	8%	5%	7%	8%	5%	94.7	86.7	98.8	94.0	-5%	-13%	-1%	-6%
1984	-1%	2%	3%	2%	2%	2%	2%	2%	96.1	88.8	100.5	95.5	-4%	-11%	0%	-4%
1985	-2%	-4%	-1%	3%	-6%	-3%	1%	-5%	90.1	86.5	101.6	90.3	-10%	-13%	2%	-10%
1986	1%	0%	0%	25%	1%	1%	26%	3%	91.3	87.6	127.8	92.7	-9%	-12%	28%	-7%
1987	0%	1%	4%	0%	1%	4%	-1%	2%	92.5	91.4	127.1	94.2	-7%	-9%	27%	-6%
1988	-1%	0%	0%	2%	0%	0%	0%	0%	92.5	91.4	127.1	94.2	-7%	-9%	27%	-6%
1989	-3%	0%	-3%	-6%	-3%	-6%	-9%	-4%	89.7	86.2	115.8	90.7	-10%	-14%	16%	-9%
1990	-1%	3%	2%	-4%	2%	1%	-5%	1%	91.0	87.1	109.9	91.7	-9%	-13%	10%	-8%
1991	-2%	2%	3%	6%	0%	1%	4%	0%	90.6	88.3	114.4	91.7	-9%	-12%	14%	-8%
1992	1%	5%	3%	4%	6%	3%	5%	5%	95.7	91.0	119.7	96.5	-4%	-9%	20%	-3%
1988*	0%	4%	3%	3%	1%	1%	3%	1%								

Table A-6: Detailed Productivity Results for LTL Sector (LTL-R)

	TM- MILE	MILE- LAB	MILE- CAP	MILE- FUEL	LabProd	CapProd	FuelProd	MFP	LabProd- indx	CapProd- indx	FuelProd- indx	MFP- indx	Cum- LabProd	Cum- CapProd	Cum- FuelProd	Cum MFP
1977									100.8	101.4	98.1	100.7				
1978	1%	2%	2%	1%	3%	3%	2%	3%	103.4	104.2	99.6	103.3				
1979	-1%	-2%	-3%	1%	-3%	-4%	0%	-3%	100	100	100	100				
1980	-2%	1%	-5%	3%	-1%	-7%	2%	-1%	99.3	93.5	101.6	98.8	-1%	-7%	2%	-1%
1981	-4%	3%	0%	1%	-1%	-3%	-3%	-1%	98.3	90.3	98.5	97.4	-2%	-10%	-2%	-3%
1982	-2%	-1%	-7%	4%	-3%	-9%	2%	-3%	95.6	81.9	100.0	94.2	-4%	-18%	0%	-6%
1983	0%	5%	7%	7%	5%	7%	8%	5%	100.5	87.9	107.8	99.4	0%	-12%	8%	-1%
1984	-1%	4%	3%	3%	3%	3%	2%	3%	103.7	90.4	110.0	102.4	4%	-10%	10%	2%
1985	-2%	0%	2%	4%	-2%	0%	3%	-2%	101.3	90.4	112.8	100.6	1%	-10%	13%	1%
1986	1%	2%	1%	25%	3%	2%	26%	4%	104.5	92.4	141.9	104.9	4%	-8%	42%	5%
1987	1%	1%	4%	0%	2%	5%	0%	2%	106.4	97.1	142.1	107.2	6%	-3%	42%	7%
1988	-1%	2%	2%	4%	2%	2%	4%	2%	108.3	98.9	147.5	109.2	8%	-1%	48%	9%
1989	-3%	0%	-3%	-6%	-2%	-6%	-8%	-3%	105.6	93.4	135.4	105.7	6%	-7%	35%	6%
1990	-1%	1%	0%	-4%	0%	0%	-5%	-1%	105.3	93.1	128.2	105.2	5%	-7%	28%	5%
1991	-1%	3%	4%	6%	2%	3%	5%	2%	107.4	95.6	134.6	107.5	7%	-4%	35%	8%
1992	0%	5%	3%	4%	5%	3%	5%	5%	113.2	98.4	140.9	113.0	13%	-2%	41%	13%
1988*	0%	4%	3%	4%	4%	3%	4%	4%								

1988* refers to the results for the year 1988 before application of the smoothing procedure. Note that the smoothed value is the average of the “growth years” after the declines of 1982, i.e. the straight average of the years 1983-1992, except 1988.

Table A-7: Observation Counts by Year and Sector for Primary Productivity Method

	TL				LTL-U				LTL-R					
	TM-MILE	MILE-LAB	MILE-CAP	MILE-FUEL	TM-MILE	MILE-LAB	MILE-CAP	MILE-FUEL	TM-MILE	MILE-LAB	MILE-CAP	MILE-FUEL		
1977					1977					1977				
1978	39	41	44	41	1978	44	44	49	48	1978	33	32	37	37
1979	39	46	48	43	1979	47	49	47	47	1979	36	39	37	38
1980	41	54	53	48	1980	49	55	54	54	1980	32	37	36	38
1981	23	24	23	21	1981	47	51	52	51	1981	32	35	36	35
1982	36	39	40	35	1982	59	62	63	62	1982	22	24	25	25
1983	39	40	40	34	1983	53	55	55	56	1983	38	39	39	40
1984	40	41	41	38	1984	51	54	54	55	1984	46	47	47	48
1985	45	45	44	42	1985	50	52	51	52	1985	31	32	31	32
1986	42	43	43	39	1986	51	51	50	51	1986	43	43	42	43
1987	41	40	41	37	1987	48	48	48	48	1987	43	43	43	43
1988					1988									
1989	27	30	32	31	1989	45	46	45	48	1989	36	36	35	37
1990	20	23	23	23	1990	43	47	45	47	1990	33	34	32	34
1991	29	37	35	35	1991	46	48	47	48	1991	37	38	37	38
1992	28	42	40	39	1992	45	48	49	47	1992	42	44	45	43
1988*	36	32	32	33	1988*	50	49	49	50	1988*	40	39	39	40

A.4. Reduction of LTL-U into LTL-R

Recall that there are different thresholds for defining exclusion from LTL-R. There is a tradeoff because if LTL-R is limited to companies with a zero percentage-point change in % of TL operations, the number of observations is very small (see Chapter 5).

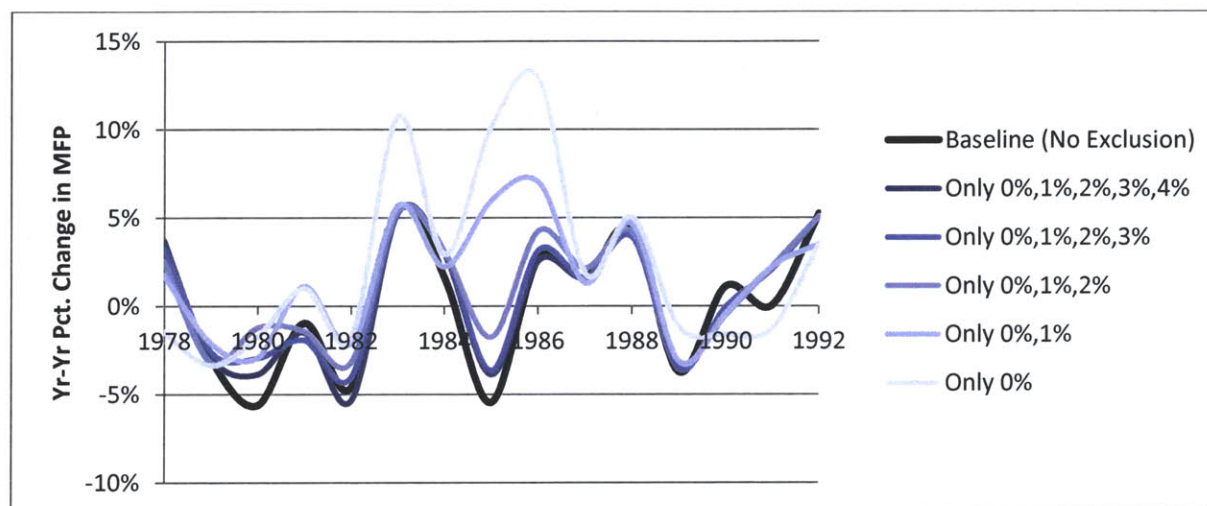


Figure A-1: Annual Multifactor Productivity for Different Exclusion Thresholds for LTL-R Sector

Table A-8: Annual Multifactor Productivity for Different Exclusion Thresholds for LTL-R Sector

	<u>Baseline (No Exclusion) i.e. LTL-U</u>	<u>Only 0%,1%,2%,3%,4%</u>	<u>Only 0%,1%,2%,3%</u>	<u>Only 0%,1%,2%</u>	<u>Only 0%,1%</u>	<u>Only 0%</u>
1977						
1978	3%	4%	3%	3%	2%	-1%
1979	-3%	-3%	-3%	-3%	-2%	-3%
1980	-6%	-4%	-3%	-1%	-3%	-2%
1981	-1%	-1%	-2%	-1%	1%	1%
1982	-5%	-5%	-4%	-3%	-2%	-2%
1983	5%	5%	5%	5%	6%	11%
1984	2%	3%	3%	3%	2%	3%
1985	-5%	-4%	-4%	-2%	6%	10%
1986	3%	3%	3%	4%	7%	13%
1987	2%	2%	2%	2%	1%	2%
1988	4%	4%	4%	4%	5%	5%
1989	-4%	-4%	-4%	-3%	-3%	-1%
1990	1%	0%	0%	-1%	0%	-2%
1991	0%	2%	2%	2%	2%	-1%
1992	5%	5%	5%	5%	3%	3%

Count of Observations

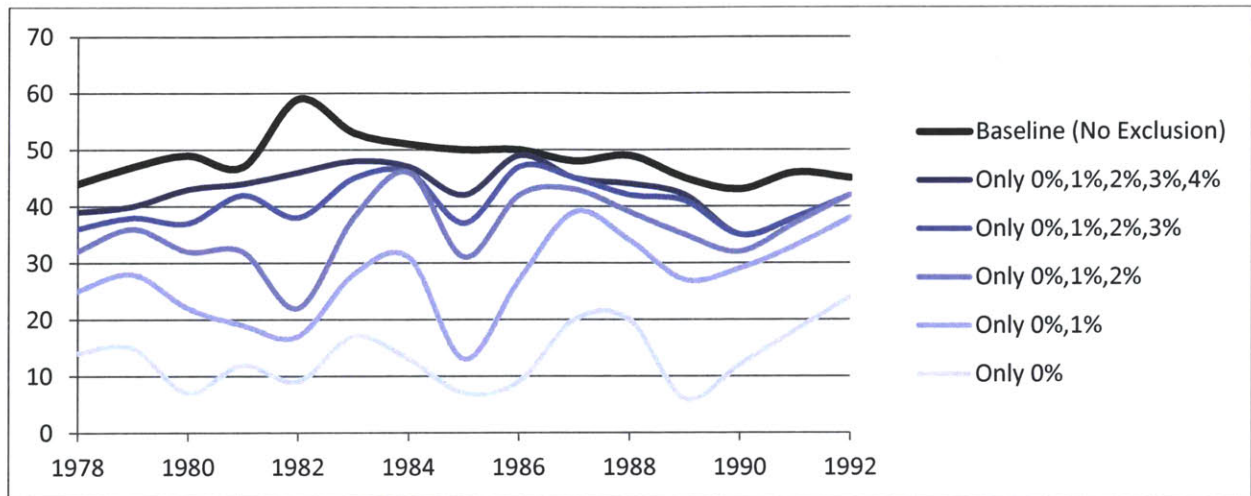


Figure A-2: Observation Counts for Different Exclusion Thresholds for LTL-R Sector

The selection of the threshold as 2% was done on the basis of analysis of convergence of the productivities as the exclusion level was increased. Specifically, as the level of exclusion was increased, the incremental adjustment to MFP for any year should not exceed 2 percentage points or half the cumulative adjustment off the baseline, whichever is larger. For instance, in 1985 productivity suddenly increases from -2% to +6% as the exclusion threshold is tightened; this seems like a case of the median being unduly influenced by small sample size. The two strictest levels of exclusion (0% and 1%) violate the test. The other test for the threshold was to analyze the count of observations. At a 2% threshold (actually 2.5%, with rounding), there are a minimum of 30 observations for every year except one (whereas for the strictest threshold many years have fewer than 10 observations).

One could in principle select a different exclusion threshold for each year, but this was rejected as too prone to analyst error. Another possibility is to adjust using a regression; however, it was not clear that this was a superior approach. The exclusion method is possibly vulnerable to endogeneity (e.g. it is possible the carriers undergoing large operational shifts also are becoming less productive for some other correlated reason), but there is not necessarily a compelling reason to suspect this; and a regression can also suffer from issues of endogeneity if there are missing variables. It is possible that with more extensive data cleaning, the dataset could be used to estimate a regression which would serve as an alternative method of controlling out the effects of operational shifts on LTL productivity.

A.5. Change in Average Distance of Haul

If we divide the total miles traveled by the total tons, we get the average distance traveled per ton of freight. This can stand for length of haul. The results, computed in the same median year-to-year change fashion as productivity, are shown in the table below.

These data are not quite as complete as other parts of the dataset. Note that average distance increases 9% in 1990, but there are only 19 observations (i.e. situations where tons and miles are reported for consecutive years). Overall, it might make more sense to look at how many years length of haul increases or decreases, than to analyze the cumulative index. It appears that the change in length of haul was not substantial, and perhaps somewhat negative (excluding the 1990 data). On the LTL side, there do appear to have been increases in the early 1980s.

Table A-9: Change in Average Length of Haul by Sector

	TL			LTL-R		
	%Δ AvgDist	Cum AvgDist	Count Obs	%Δ AvgDist	Cum AvgDist	Count Obs
1977		97.6				
1978	2.0%	99.5	41	0.0%	100.0	33
1979	0.5%	100	39	0.0%	100.0	36
1980	-0.5%	99.5	41	3.1%	100	32
1981	-0.1%	99.5	23	1.8%	103.1	32
1982	-1.0%	98.5	36	2.4%	105.0	22
1983	-1.3%	97.2	39	0.0%	107.5	38
1984	0.2%	97.4	40	-0.3%	107.5	46
1985	0.0%	97.5	45	0.0%	107.1	31
1986	0.0%	97.4	42	0.6%	107.1	43
1987	0.0%	97.4	41	0.1%	107.7	43
1988	0.7%	98.1		0.1%	107.8	
1989	0.0%	98.1	26	0.0%	107.9	36
1990	9.0%	107.0	19	0.0%	107.9	33
1991	-0.1%	106.9	27	0.2%	108.0	37
1992	-2.0%	104.8	28	0.0%	108.2	42

(Highlighting: 1988 smoothed as elsewhere in this thesis)

Appendix B – Supplementary Results: Unit Cost Decomposition

B.1. Detailed Unit Cost Decomposition Results

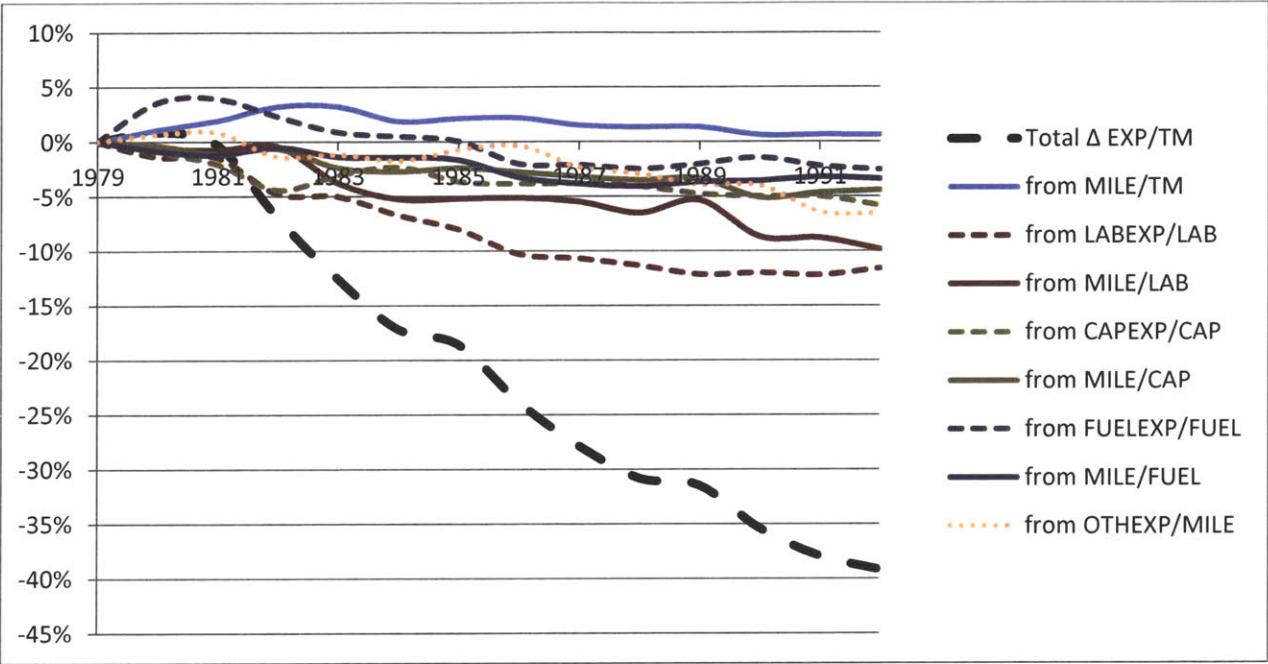


Figure B-1: Detailed Unit Cost Composition (Cumulative) – TL Sector

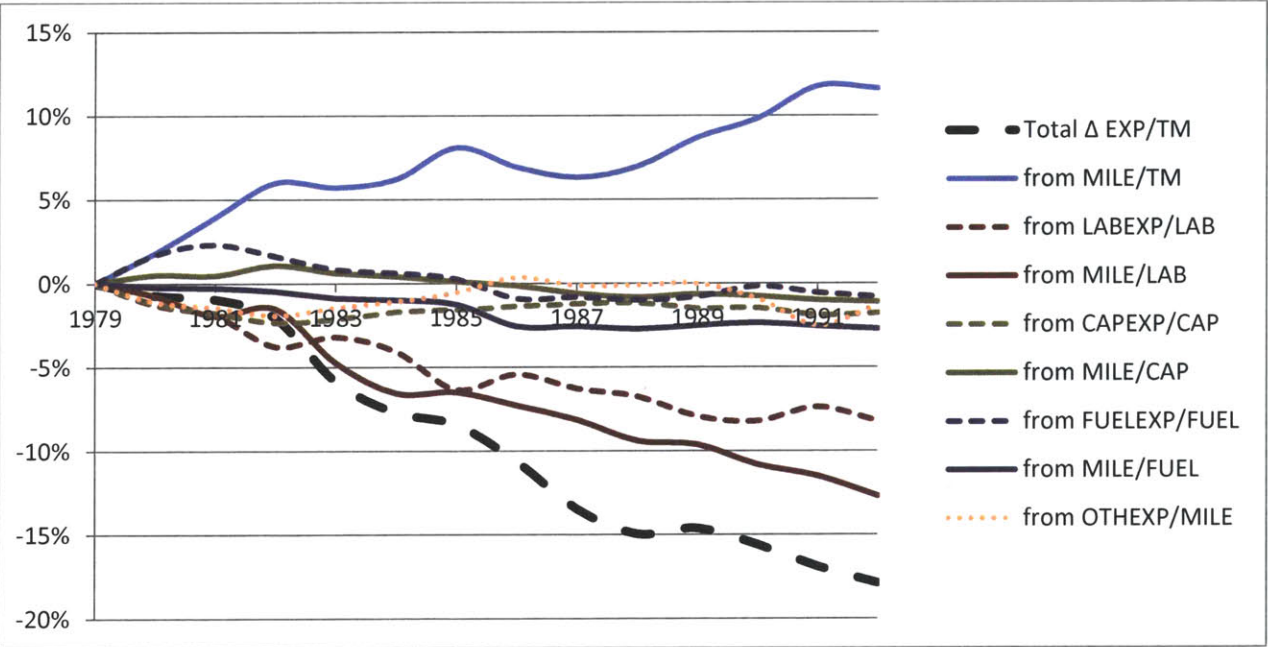


Figure B-2: Detailed Unit Cost Composition (Cumulative) – LTL Sector (LTL-R)

B.2. Example of Decomposition Adjustment

Table B-1: Decomposition Adjustment TL sector

	(a)	(b)	(c)				Dominant	Direc- tion	ϵ boost- tot	$\epsilon(b)$ boost- b	$\epsilon(c)$ boost- c	b- Final	c- Final	(b*c)	Cum Index			
	EXP/TM	EXP/MI	MI/TM	(b*c)	a as pct.	b as pct.									c as pct.	EXP/TM	EXP/MI	MI/TM
1977																		
1978	0.991	1.008	0.992	0.999	-0.9	0.78	-0.84	-0.8	S	0.992	0.996	0.996	1.004	0.988	0.991			
1979	1.026	1.027	1.005	1.033	2.6	2.71	0.55	2.7	S	0.994	0.995	0.999	1.022	1.004	1.026	100	100	100
1980	1.009	0.987	1.000	0.987	0.9	-1.28	0.00	-1.3	W	1.022	1.011	1.011	0.998	1.011	1.009	100.9	99.8	101.1
1981	<i>0.988</i>	<i>0.968</i>	<i>1.006</i>	<i>0.974</i>	<i>-1.2</i>	<i>-3.19</i>	<i>0.58</i>	<i>-3.2</i>	<i>S</i>	<i>1.015</i>	<i>1.013</i>	<i>1.002</i>	<i>0.980</i>	<i>1.008</i>	<i>0.988</i>	<i>99.7</i>	<i>97.8</i>	<i>101.9</i>
1982	0.933	0.923	1.013	0.935	-6.7	-7.73	1.31	-7.7	S	0.999	0.999	1.000	0.922	1.013	0.933	93.1	90.1	103.2
1983	0.940	0.950	1.000	0.950	-6.0	-5.02	0.00	-5.0	S	0.990	0.990	1.000	0.940	1.000	0.940	87.5	84.8	103.2
1984	0.947	0.970	0.990	0.960	-5.3	-3.04	-0.99	-3.0	S	0.986	0.990	0.997	0.960	0.987	0.947	82.8	81.3	101.9
1985	0.983	0.978	1.002	0.981	-1.7	-2.17	0.25	-2.2	S	1.003	1.002	1.000	0.981	1.003	0.983	81.5	79.7	102.1
1986	0.935	0.945	1.000	0.945	-6.5	-5.55	0.05	-5.5	S	0.990	0.990	1.000	0.935	1.000	0.935	76.2	74.6	102.2
1987	0.947	0.987	0.998	0.986	-5.3	-1.26	-0.18	-1.3	S	0.961	0.966	0.995	0.954	0.993	0.947	72.2	71.1	101.5
1988	0.959	0.968	0.999	0.966	-4.1	-3.24	-0.12	-3.2	S	0.992	0.992	1.000	0.960	0.998	0.959	69.2	68.3	101.3
1989	0.991	0.978	1.000	0.978	-0.9	-2.19	0.01	-2.2	S	1.013	1.013	1.000	0.991	1.000	0.991	68.5	67.6	101.3
1990	0.943	0.983	0.998	0.980	-5.7	-1.72	-0.25	-1.7	S	0.962	0.967	0.995	0.950	0.993	0.943	64.6	64.2	100.6
1991	0.960	0.949	1.000	0.949	-4.0	-5.08	0.03	-5.1	S	1.012	1.012	1.000	0.960	1.000	0.960	62.1	61.7	100.6
1992	0.980	0.969	1.000	0.969	-2.0	-3.12	-0.01	-3.1	S	1.011	1.011	1.000	0.980	1.000	0.980	60.8	60.4	100.6

1981- example of decomposition provided in this Appendix B.

Recall that we are assuming a relationship of $A = B \cdot C$ for any point in time (refer to Chapter 5).

We denote the change in A, B and C as a, b and c respectively, such that $aA = bB \cdot cC$.

The problem is that here a, b and c are medians, and $a \neq b \cdot c$ in general. The procedure adjusts b and c so as to force the equality to hold. The only real methodological issue is how much to adjust b relative to c.

Example:

Take the year 1981 for the truckload sector as an example (refer to Table in B.2.)

Step One

For this year, $a = 0.988$, meaning EXP/TM has decreased 1.2% from the previous year (1980).

$b = 0.968$, meaning EXP/MI has decreased 3.2% from the previous year.

$c = 1.006$, meaning MI/TM has increased 0.6% from the previous year.

Note that $b \cdot c \neq a$, as $(0.968)(1.006) = 0.974 \neq 0.988$.

Step Two

In order to ensure internal consistency, we must decrease $b \cdot c$ or increase a. In this thesis a top-down approach is used, meaning the higher level measures are “trusted” more. Therefore we must boost $b \cdot c$ to meet a.

How the residual is allocated depends on whether the movement is to the “strong” (S) or “weak” (W) side. We would hope that it is usually to the strong side. In this case:

- B moves more than C, i.e. $\text{abs}(-3.2\%, +0.6\%) = -3.2$ so b is dominant; B decreases
- a is 0.988, meaning A also decreases
- Since both a and the dominant of {b,c} are to the same direction (down), the movement is to the strong side
- Thus, the residual is allocated per equation Eq. 6.8.

Step Three

The total boost ϵ needs to be $(0.988) / (0.968 \cdot 1.006) = 1.015$.

Then $\epsilon_b = (1.015) \wedge (\text{abs}(-3.19) / [\text{abs}(-3.19) + \text{abs}(0.58)]) = 1.015 \wedge (3.19/3.77) = 1.013$

And $\epsilon_c = (1.015) \wedge (\text{abs}(0.58) / [\text{abs}(-3.19) + \text{abs}(0.58)]) = 1.015 \wedge (0.58/3.77) = 1.002$

(Note that we can use -3.19 and 0.58 for simplicity instead of -3.19% and 0.58%)

Note that $\epsilon = \epsilon_b \cdot \epsilon_c$, as $1.015 = (1.013)(1.002)$.

What is happening is that A decreased by 1.2%, but B*C decreased by 2.6%. We must bring down B and C so that $b*c = a$. Both b and c are being decreased. b is being decreased more, because B changed more than C, and B changed in the same direction as A.

Step Four

The adjusted effect of B on A is: $b* \epsilon_b = (0.968)(1.013) = 0.980$, i.e. B caused A to decrease 2.0%

The adjusted effect of C on A is: $c* \epsilon_c = (1.006)(1.002) = 1.008$, i.e. C caused A to increase by 0.8%

Note that now, $(0.980)(1.008) = (0.988)$, so we have forced the equality.

Step Five

The indexed A, B and C for the previous year (1980) were 100.9, 99.8, and 101.1 respectively.

Then, for 1981:

$$A' = (100.9)(0.988) = 99.7$$

$$B' = (99.8)(0.980) = 97.8$$

$$C' = (101.1)(1.008) = 101.9$$

Note that $A' = B' * C'$, as $(97.8)(101.9)/100 = 99.7$

(the division by 100 is because we have set the base year index to 100; if the index was set to 1, then no normalization would be necessary).

General Comments:

- Note that there is a purchased transportation category, which in this case predominantly reflects use of owner-operators. For many truckload carriers, this is a large component of their costs. Purchased transportation from other modes (rail, air) is included with Other Expenses, but purchased transportation from other motor carriers is distributed among labor, capital, fuel and other expenses following the assumption that the shares of these costs for any given year are the same as for the truckload industry generally.
- The top-down approach used in this thesis is one of several possible methods of ensuring internal consistency. One could alternatively use a bottom-up approach, or some kind of combination. The major objective is to observe the relative impacts of the various factors.