PRODUCTIVITY AND FINANCIAL PERFORMANCE OF U.S. CLASS I RAILROADS

by

SIEW HOON LIM

(Under the direction of C. A. Knox Lovell)

ABSTRACT

This dissertation examines the relationships between productivity and short-run total costs, and short-run profits. The foci of this research are how productivity changes contribute to short-run cost variations over time and across firms, and how positive short-run profit change can be attributed to increased productivity. In the railroad industry, improvements in productivity do not necessarily imply either reductions in short-run total cost or increases in short-run profit. Though numerous studies have attempted to examine railroad productivity in recent decades, the existing economics literature has paid very little attention to these phenomena. Using an unbalanced panel of U.S. Class I railroads for the period of 1986 - 2000, a short-run total cost change decomposition model is used to attribute intertemporal and multilateral cost variation to its causal factors. The intertemporal and multilateral cost decompositions enable us to conduct a benchmarking exercise across firms or through time. In addition, a short-run profit change decomposition model is used to relate short-run profit change to its sources. These models are analyzed using linear programming techniques. The empirical findings are: (i) total cost change varied greatly across railroads; (ii) rail capital had a direct impact on total cost but not on profit in the short run; (iii) the railroad industry experienced significant technical progress over time; (iv) in the cost-efficient benchmarking exercise, the industry benchmarks were cost-efficient because they were large; (v) in both
low-cost and cost-efficient benchmarking exercises, the benchmarking railroads were both technically and allocatively inefficient, they can learn from the industry benchmarks when it comes to cost savings; (vi) positive profit gains can be attributed to improvement in railroad productivity; and (vii) negative profit change can be attributed to falling rail rates and increased input prices.

INDEX WORDS: Sequential DEA, Bennet price indicator, Bennet quantity indicator, frontier, benchmarking exercise
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Dedication

To Zhulu, James and my parents
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Table of Contents

Acknowledgments ................................................................. v

List of Figures ........................................................................ viii

List of Tables ........................................................................ ix

Chapter

1 Introduction ................................................................. 1
  1.1 Motivation and Objectives ........................................... 1
  1.2 An Outline of the Dissertation ..................................... 4

2 Overview of the Railroad Industry ................................. 6
  2.1 Industry Background and History ................................. 6
  2.2 Productivity and Financial Performance ...................... 12
  2.3 Market Structure ....................................................... 16
  2.4 Rail Capital .............................................................. 22

3 Productivity Analysis: A Review of Methodology ............ 24
  3.1 Partial Factor Productivity .......................................... 24
  3.2 Total Factor Productivity ............................................ 25
  3.3 Data Envelopment Analysis (DEA) ............................... 29
  3.4 Econometric Approaches ........................................... 30
  3.5 Conclusions ............................................................ 36

4 Data .................................................................................. 38
5 Intertemporal Cost Change Decomposition and Benchmarking

Exercise: A Short-run Analysis ........................................ 48
5.1 Introduction ......................................................... 48
5.2 The Analytical Framework ......................................... 51
5.3 Intertemporal Short-run Cost-Change Decomposition ...... 53
5.4 Results: Intertemporal Short-run Cost Change Decompo-
sition ................................................................. 63
5.5 Cross-sectional Cost Change Decomposition: Low-cost
and Cost-efficient Benchmarking Exercise ..................... 69
5.6 Results: Cross-sectional Short-run Cost-Gap Decomposi-
tion ................................................................. 72
5.7 Conclusions ......................................................... 78

6 Short-run Profit and Productivity ................................. 80
6.1 Introduction ......................................................... 80
6.2 The Analytical Framework ......................................... 82
6.3 Three-Stage Profit-Change Decomposition .................. 86
6.4 Results .............................................................. 92
6.5 Conclusions ......................................................... 98

7 Closing Remarks ...................................................... 100

Bibliography ............................................................. 104

Appendix

A Supplemental Data Information ................................. 114
B Bennet Indicators .................................................... 116
# List of Figures

1.1 Class I Railroad Performance from 1964 to 2000 .......................... 2  
2.1 Freight Market Share by Ton Miles ....................................... 8  
2.2 Freight Market Share by Ton ............................................ 9  
4.1 Industrial Average: Total Cost and Revenue Ton Miles (1986–2000) .... 45  
4.2 Industrial Average: Total Revenue versus Total Cost (1986–2000) .... 46  
4.3 Profit and Price (1986–2000) ............................................ 46  
5.1 The Decomposition of Short-run Cost Change ................................ 50  
5.2 The decomposition of the quantity effect into a productivity effect and an activity effect ........................................... 57  
5.3 The decomposition of the productivity effect into a technical efficiency effect, an allocative efficiency effect and a technical change effect ............... 59  
6.1 The Decomposition of Short-run Profit Change .......................... 82  
6.2 The Decomposition of the Quantity Effect ............................... 89  
B.1 Cost of Living vs. Standard of Living .................................... 117
### List of Tables

2.1 Freight Market Share (Intercity Ton Miles) ........................................ 14
4.1 Class I Railroads 1986 – 2000 .............................................................. 38
4.2 Input and Output Variables ................................................................. 40
4.3 Descriptive Statistics ........................................................................... 42
5.1 The Intertemporal Short-run Cost Change Decomposition ...................... 66
5.2 DEA Benchmarking Exercise: Cost Efficiency Scores of Railroads .......... 73
5.3 Short-run Cost Gap Decomposition Using the Low-cost Benchmark ......... 75
5.4 Short-run Cost Gap Decomposition Using the Low-cost and Cost-efficient Benchmark ................................................................. 77
6.1 The Short-run Profit Change Decomposition ......................................... 93
Chapter 1

Introduction

1.1 Motivation and Objectives

The railroad industry has played a central role in U.S. economic developments. However, due to its economic characteristics, the railroad industry became the first industry in the U.S. that was subject to government regulation. After decades of financial distress, failures and bankruptcies, U.S. railroads experienced a historical milestone in 1980 – partial deregulation made possible by the Staggers Act. Today, in the face of shrinking market share, rising rail costs and falling rail rates, the success and sustainability of the U.S. railroad industry and individual railroads hinge largely upon increased productivity.

According to the American Association of Railroads (AAR), railroads have achieved higher levels of productivity since passage of the Staggers Act. ¹ Nevertheless, higher productivity does not necessarily imply increased profit, nor does it imply reductions in cost. Figure 1.1 displays clearly that, while productivity and output have been on the rise, revenue (in real terms) has been sliding since 1981. This raises the question of what factors can possibly explain the divergence of railroad productivity and revenue. More importantly, given the decrease in revenue over time, what does improved productivity mean to the railroad industry when it comes to profitability?

We will see in Chapters 2 and 3 that few railroad productivity studies have linked productivity to financial performance, and most of these studies were conducted on international

¹Here, productivity is measured in terms of revenue ton-miles per constant dollar of operating expense, where a revenue ton-mile means the movement of a ton of freight one mile for revenue.
railroads. McGeehan [69] uses a translog variable cost function to determine the cost structure and productivity growth of the Irish rail company. Waters and Street [86] examine the linkages between total factor productivity (TFP) and financial performance of the Australian National Railways. Waters and Tretheway [87] construct a productivity study by comparing the TFP and total price performance (TPP) of Canadian railroads. Hensher, Daniels and Demellow [54] conduct a productivity analysis of state-owned Australians railroads. They attribute variations in TFP to changes in operating and managerial environments. Using data for 19 European countries from 1961 to 1988, Gathon and Pestieau [48] examine the relations between railroad performance and railroad managements and regulations. Salerian [77] uses the logarithmic version of Fisher’s Ideal index to decompose profit into productivity and price effects using the Australian National Railways data set.

Figure 1.1: Class I Railroad Performance from 1964 to 2000.
Prior to railroad deregulation in the U.S., railroad research focused mainly on productivity. Caves, Christensen and Swanson [28] use a translog variable cost function to examine railroad productivity from 1955 to 1974. Caves, Christensen and Swanson [29] compare the productivity of highly regulated U.S. railroads and the less-regulated Canadian railroads for the same period. Grabowski and Mehdian [49] use a production frontier to measure the revenue inefficiency of railroads from 1951 to 1981. Chapin and Schmidt [31] apply data envelopment analysis to measure the efficiency of Class I railroads since deregulation. In fact, only a handful of studies have linked either management characteristics or performance to productivity of U.S. railroads in the periods following deregulation. Friedlaender, Berndt and McCullough [46] investigate the relationship between railroad performance and managerial effectiveness and railroad characteristics in the deregulated environment. Berndt et al. [18] examine the effects of deregulation on rail costs. But there was no direct analysis of railroad profit in these studies.

Friedlaender and Spady [44] perform thorough examinations of the impact of infrastructure investments and abandonments on costs and profitability. They find that, in a partial equilibrium context, when output levels and rail rates are held constant, a ceteris paribus reduction in way and structure capital or a ceteris paribus reduction in low-density route-miles leads to considerable cost savings. Nevertheless, in a general equilibrium context, when output levels and rail rates are allowed to change in a competitive market structure, infrastructure profitability is significantly reduced.

In two separate, yet similar, studies, Martland [66] and Martland [67] try to connect changes in productivity to changes in railroad activity and financial performance of U.S. railroads for the periods from 1973 to 1983 and from 1966 to 1995, respectively. In these studies, outputs and inputs were measured in financial terms. Martland [66] identifies eight factors that increased productivity and six factors that reduced productivity. Though railroads had managed to reduce the cost of production, much of the cost savings was offset by the factors that reduced productivity. Over the period 1973–1983, the productivity-enhancing factors
barely outweighed the productivity-reducing factors. Thus, Martland concludes that annual profit changes were attributable to relative changes in output and input prices. Martland [67] finds that, although the increase in productivity was impressive, most of the railroad cost savings were passed along to shippers in the form of reduced rail rates which, in turn, lowered financial returns. He speculated about the possibility of declining railroad productivity in the coming decades, and about the potentially large, downward price pressures that would put the industry into another financial predicament.

The findings of Friedlaender and Spady [44], Martland [66], and Martland [67] deserve a lot of attention. Friedlaender and Spady [44] focused on the relation between railroad financial performance and railroad infrastructure, but fell short of incorporating railroad productivity into their models. Martland’s studies connected financial performance to productivity, but suffered from a lack of sound economic theory.

The main objective of this research is to investigate the linkage between productivity and financial performance. Specifically, I will analyze the relationship between productivity change and total cost change, and profit change. Because previous research had shown that overcapitalization was a key factor leading to non-optimal railroad operations, I decided to conduct a short-run analysis. As a result, I am able to examine how physical capital affects the financial performance of railroads in the short run.

1.2 An Outline of the Dissertation

In Chapter 2, I will provide an overview of the U.S. railroad industry, including a review of the productivity change and financial performance of railroads before and after deregulation. Chapter 3 provides a review of various methods that have been used in railroad productivity research, e.g. partial factor productivity (PFP), total factor productivity (TFP), data envelopment analysis (DEA), and various econometrics approaches. Chapter 4 provides a discussion of the data and variable definitions I used. In Chapter 5, an empirical model is used to explore the sources of short-run total cost changes and to investigate the relation
between cost change and productivity change. In Chapter 6, another empirical model is used to examine how short-run profit changes can be attributed to changes in productivity in the railroad industry. Chapter 7 provides closing remarks.
Chapter 2

Overview of the Railroad Industry

2.1 Industry Background and History

Since the late 1970s, many countries have experienced the need to restore the financial and market performance of their railroads. Most privatization studies have shown that inefficiency and financial crises are the common factors that lead to state-owned railroad restructuring. Besides the availability of modern technology effectively used by trucking, water and air competitors, the rising service expectations of both shippers and passengers are reasons for railroad restructuring in recent decades.

In the U.S., major railroad restructuring took place between the 1970s and the 1980s. The Staggers Act was enacted in 1980 to partially deregulate railroads and, according to the Association of American Railroads (AAR), the railroad industry experienced significant productivity improvement and increased financial performance since then. The Staggers Rail Act was designed to achieve the following legislative goals: (i) to generate adequate revenue for the railroads, (ii) to provide regulatory protection to captive shippers for whom reasonable rail rates are not available due to the absence of effective competition, (iii) to relax regulatory constraints for railroads under effective competition, and (iv) to enhance revenue of financially distressed railroads (Tye [84] & [85]).

Currently, U.S. freight railroads are classified into five categories - Class I, regional, local railroads, switching, and terminal carriers. Class I railroads have the largest revenues and local railroads the smallest. Class I railroads have to meet substantial reporting requirements of regulators. In 2003, the Surface Transportation Board (STB) Class I threshold was an annual operating revenue of $272.0 million. This threshold is indexed to a base of $250
million in 1991 and adjusted annually in accordance with changes in the “Railroad Freight Rate Index” published by the Bureau of Labor Statistics.\(^1\) Nine Class I railroads reported to the STB in 1999, eight in 2000, and only seven in 2002. These seven railroads represent 2 percent of the total number of railroads in the U.S. However, Class I railroads account for 71 percent of the industry’s operating mileage, 88 percent of its labor, and 91 percent of its freight revenue. Currently, over 90 percent of the 560 freight railroads operating in the U.S. are privately owned. The Class I railroads in 2002 are: The Burlington Northern and Santa Fe Railway, CSX Transportation, Grand Trunk Corporation, Kansas City Southern Railway, Norfolk Southern Combined Railroad Subsidiaries, Soo Line Railroad, and Union Pacific Railroad.

In 2001, there were 34 regional railroads, 314 local railroads, and 215 switching and terminal carriers. Regional railroads operate at least 350 miles of road and/or have operating revenue between $40 million and the Class I threshold. Local railroads are line-haul railroads that are smaller than regional railroads. They operate less than 350 miles of road and earn less than $40 million per year. Switching and terminal carriers are railroads that, regardless of their revenue, provide switching and/or terminal services. They perform pick-up and delivery services within a specified area for one or more connecting line-haul carriers.

Currently, the vast majority of rail tracks are owned by freight railroads. Amtrak, the sole intercity passenger railroad in the U.S., pays fees to freight railroads for the use of railroad tracks, and Amtrak itself owns about 750 miles of railroad from Boston to Washington, DC. Commuter and light rail systems also negotiate with freight railroads for permission to use existing tracks.

Depending upon how a freight market is defined, the market share of railroads compared to other modes of transportation varies substantially. As shown in Figures 2.1 and 2.2, in

---

\(^1\)The Interstate Commerce Commission (ICC) changed the minimum freight revenue required to be considered a Class I railroad from $5 million in 1965, to $10 million in 1976, $50 million in 1978, and $92 million in 1988. The STB Class I threshold was annual operating revenue of $259.4 million in 1998 and $258.5 million in 1999. Typically, a declassification from Class I status occurs when a railroad falls below the applicable threshold for three consecutive years.
2001 the market share of railroads was 42 percent, which is the largest in the transportation industry, if freight output is measured as movement of one ton of goods per mile (or ton-mile), and 26 percent, which is smaller than that of trucking, if freight output is defined as tons of goods moved.²

![Ton-Miles Pie Chart]

Figure 2.1: Freight Market Share by Ton Miles

In the past ten years, the fastest growing railroad service has been intermodal transportation, which involves movements “of truck trailers or containers by rail and at least one other mode of transportation” [7]. In 2004 alone, intermodal volume on U.S. railroads reached 10 million trailers and containers.

Over its more than 170 years of history, the U.S. freight railroad industry has played an important role in economic development. The first railroad was chartered by the state of Maryland in 1827. In 1887, Congress passed the Interstate Commerce Act, creating the Interstate Commerce Commission (ICC) to regulate railroads and other interstate carriers.³ Under the Interstate Commerce Act, railroads were not allowed to set or alter prices;

²Sources: AAR [4].
³According to the AAR, the ICC is “a U.S. government agency which was responsible for regulatory oversight of certain aspects of the railroad industry, including railroad mergers and acquisitions, abandonments, and tariffs for certain commodities. The ICC was succeeded by the Surface Transportation Board on January 1, 1996.”
they were compelled to provide services to light-density, low-demand areas with extended service hours. Their extensive mileage and maintenance costs created financial problems for railroads.

In the post-World War I era, increasing competition from other transportation modes and stringent federal regulation started a process of railroad decline that continued for decades. By 1920, regulations had developed to control the construction and abandonment of rail lines, rail mergers, conditions of service, car supply, and rates. The rail rates proposed by the railroads were not based upon the actual costs of service incurred. Rail companies were not free to make rate adjustments, and proposed rates were subject to the ICC’s approval. The Great Depression devastated the rail industry. Rail operating revenue decreased 50 percent from $6.2 billion in 1928 to $3.1 billion in 1933.

In the 1940s, most railroads were in deep financial chaos. Although a surge in war-related traffic brought temporary relief, by 1949 rail ton-miles had fallen 28 percent. Passenger
revenue declined even more. Throughout the 1950s and 1960s, railroads lost much of the high-value freight traffic to the trucking industry. The growing competition from trucking and increased government funding for the construction of interstate highways and inland waterway systems, as well as huge losses in passenger operations, led to railroad bankruptcies, service abandonment, deferred maintenance, and financial deterioration.

During the 1970s, railroads lacked the financial capability to maintain their tracks. Railroad’s speed and reliability declined because of dangerous track conditions. By 1980, the rail share of intercity freight had fallen from 75 percent in the 1920s to 38 percent [5].

Winston (1993) finds that rail rates regulated by the ICC for commodities were generally inefficient, and union-negotiated labor-input restrictions also prevented the railroads from operating efficiently. High fixed costs of production (e.g. tracks, network structure, and stations) created barriers to entry, and the incumbents were not allowed to exit unprofitable markets. This led to financial losses and low rates of return on investment.

Railroads also faced competition from other modes of transportation. The new Interstate Highway System, which was largely completed in the 1970s, enabled motor carriers to take over parts of freight shipments from railroads. The airline industry, assisted by government subsidies for airport construction and other infrastructure, also took away a large number of rail passengers.

In 1970, a quasi-nationalized rail company, Amtrak, was created by Congress to relieve railroads of the burden of the financial losses associated with operating intercity passenger trains. In spite of that, many rail companies were financially distressed by the mid-1970s. The collapse of the Penn Central rail line in June 1970 prompted a widespread interest in deregulation.

In 1973, the Regional Rail Reorganization (3-R) Act was crafted to remedy a transportation crisis in 17 midwestern and northeastern states following the bankruptcy of Penn Central. The United States Railway Association (USRA) was created to prepare a plan for a new regional rail system. The new system, later named Consolidated Rail Company
(Conrail), began operations in 1976 by consolidating the bankrupt rail companies in the Northeast. Meanwhile, USRA was authorized to designate unprofitable routes for abandonment, and recommended the elimination of almost 6000 miles of Northeast rail lines in 1976. The USRA also chose properties to be turned over to Conrail, and provided interim financial support to the bankrupt companies before the transfer. In addition, the government guaranteed settlement to the creditors of the bankrupt rail companies. The 3-R Act continued to provide income protection to rail workers. It required Conrail to offer jobs to all employees of its predecessor companies. However, this policy proved ineffective. Congress and the President then agreed on passage of the Railroad Revitalization and Regulatory Reform (4-R) Act (Wilner, [88], Beshers and Seidenstat [19]).

Railroad deregulation began with the 4-R Act of 1976, and was followed by the Staggers Rail Act of 1980, which aimed to transform this sector into a more competitive market structure. The 4-R Act reestablished the USRA as an independent agency with the authority to develop comprehensive business and financial plans, granted the rail carriers greater rate flexibility, established new abandonment criteria, and encouraged mergers, consolidations and joint use of facilities. The Staggers Act broadened the limitations of rate regulation in the 4-R Act. It permitted railroads to custom-design transportation packages at mutually agreed upon rates. The ICC was also ordered to process abandonment requests more rapidly (Wilner [88]). The Act enabled railroads to set rail rates as long as railroads did not engage in predatory pricing. Railroad mergers were also made possible under the Staggers Act. The Act also legalized shipper-carrier contracts or private negotiations between railroads and shippers over rail rates, services, and volumes of shipments. The Staggers Act started a financial recovery for the entire rail industry that continues through to the present (Wilner [88], Beshers and Seidenstat [19]).
2.2 Productivity and Financial Performance

Before the full effects of the Staggers Act could be determined, Levin [61] felt that some degree of intermodal competition must be maintained because the intensity of competition was a critical determinant of the price levels, profits, and deadweight losses. Railroad mergers would distort such competition. The railroad industry’s financial viability could only be achieved if rail rates increased substantially. In other words, prices must exceed marginal cost, since marginal cost pricing would generate insufficient return to capital to assure long-run viability. Levin calculated a set of Ramsey prices that would minimize the deadweight loss and achieve an 8 percent rate of return, which was assumed to be the lower bound on profits required for long-run viability. Financial viability would imply a static deadweight loss of approximately $1 billion annually. This amount was relatively small compared with the subsidy required to cover full costs if prices were regulated to equal marginal cost.

Boyer [21] found that rail rates had, indeed, risen slightly after deregulation. This conclusion is inconsistent with most studies, but Boyer’s finding lacks robustness because of the short yearly time series data (from 1970 to 1985) he used in the ordinary least squares (OLS) regression. Moreover, deregulation was positive but statistically insignificant in the same OLS regression, in which rail revenue was the dependent variable. Interestingly, other railroad transportation studies have shown positive consequences of deregulation.

The AAR reports that, in the past twenty years, the railroad industry’s operating revenue has increased sufficiently to cover all of its operating costs. Additionally, according to the U.S. Bureau of Labor Statistics, the railroad industry is near the top of all U.S. industries in terms of productivity gains over the past two decades. Since Staggers, railroads have achieved enormous productivity gains with respect to nearly every rail input. According to the AAR, between 1980 and 2001 “rail labor productivity rose 360 percent, locomotive productivity rose 132 percent, track productivity rose 138 percent, and fuel efficiency rose 71 percent” [8]. In each case, productivity improvement in the post-Staggers era were two to three times higher than in the pre-Staggers era.
Prior to the Staggers Act, the ICC regulated the maximum and minimum rates for all rail shipments. Railroads could not practice differential pricing. Since regulated rail rates were often not related to costs and demand, railroads could not operate efficiently and neither could they compete with other modes. Railroads had to endure lengthy and costly regulatory proceedings to adjust individual rail rates. Hence, railroads usually resorted to across-the-board, general rate changes as costs changed. As a result, rail rates tended to reflect historical costs, rather than current costs. Regulated rates often tended to ignore changes in operating practices and traffic flows. Since individual railroads were prevented from independently pricing their services, there was less incentive for productivity growth, innovation and cost reductions.

The Staggers Act freed railroads to price their services in the open market place, with regulation remaining only when railroads did not face effective competition. Railroads responded to such change by increasing productivity in order to compete more effectively. According to the AAR, most productivity gains have been passed on to shippers in the form of lower rates. Real revenue per ton-mile (RPTM) has fallen 60 percent in the 20 years since then.\(^4\) Similarly, large rate reductions have occurred for commodities such as coal, grain and chemicals, which are shipped mainly by railroads. From 1981 to 2001, real rail rates for coal fell 62 percent, while electricity prices declined less than half as quickly. Railroads also haul vast quantities of auto parts and accessories, as well as some 70 percent of finished vehicles from auto plants. Since 1981, real rail rates for motor vehicle traffic have fallen 35 percent. From 1981 to 2001, real rail rates for wheat fell 54 percent, corn rates fell 41 percent, and soybean rates were reduced 53 percent.

Table 2.1 is taken from Wilner [88], and shows the freight market share of different intercity transport modes. The market share of rail decreased from 74.9 percent in 1929 to 37.5

\(^4\)RPTM is used as a proxy for rail rates because it measures both the actual payments made by rail shippers and the bases for which the rates are assessed - weight and distance. Although it can be affected by changes in length of haul, commodity mix, equipment ownership, and other shipment characteristics, studies have shown a reduction in RPTM represents a reduction in rail rates. RPTM had been used in most research studies to represent rail rates.
percent in 1980, and rose to 40.6 percent in 1995, while the market share of trucks rose from 3.2 to 27.2 percent between 1929 and 1995. The rapid development of the trucking industry in the 1950s changed the market-dominant position of railroads. The market share of inland water, which includes the Great Lakes, has been below 15 percent since 1993.

Following passage of the Staggers Act, railroads were free to merge, change prices and abandon unprofitable markets. They were also allowed to make long-term contracts with shippers. This led to substantial price declines and improved services in the rail sector (Bailey [10]). By constructing measures of intermodal and intramodal competition, MacDonald [65] found that, since passage of the Staggers Act, rail rates fell as railroad competition for shipment of corn, soybeans and wheat increased. But this effect may vary with respect to water competition. That is, nearby water competition may restrain railroads from setting prices, even though there may be just a single railroad. Consequently, the effects of inter-railroad competition on rates increased when there was little or no water competition.

<table>
<thead>
<tr>
<th>Year</th>
<th>Rail</th>
<th>Truck</th>
<th>Inland</th>
<th>Pipelines</th>
<th>Air</th>
</tr>
</thead>
<tbody>
<tr>
<td>1929</td>
<td>74.9%</td>
<td>3.2%</td>
<td>17.4%</td>
<td>4.4%</td>
<td>0.0%</td>
</tr>
<tr>
<td>1940</td>
<td>61.3%</td>
<td>10.0%</td>
<td>19.1%</td>
<td>9.6%</td>
<td>0.0%</td>
</tr>
<tr>
<td>1944</td>
<td>68.6%</td>
<td>5.4%</td>
<td>13.8%</td>
<td>12.2%</td>
<td>0.0%</td>
</tr>
<tr>
<td>1950</td>
<td>56.2%</td>
<td>16.3%</td>
<td>15.4%</td>
<td>12.2%</td>
<td>0.0%</td>
</tr>
<tr>
<td>1955</td>
<td>49.5%</td>
<td>17.5%</td>
<td>17.0%</td>
<td>16.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>1960</td>
<td>44.1%</td>
<td>21.7%</td>
<td>16.8%</td>
<td>17.4%</td>
<td>0.1%</td>
</tr>
<tr>
<td>1970</td>
<td>39.8%</td>
<td>21.3%</td>
<td>16.5%</td>
<td>22.3%</td>
<td>0.2%</td>
</tr>
<tr>
<td>1980</td>
<td>37.5%</td>
<td>22.3%</td>
<td>16.4%</td>
<td>23.6%</td>
<td>0.2%</td>
</tr>
<tr>
<td>1990</td>
<td>37.7%</td>
<td>25.4%</td>
<td>16.4%</td>
<td>20.2%</td>
<td>0.3%</td>
</tr>
<tr>
<td>1993</td>
<td>38.1%</td>
<td>27.7%</td>
<td>14.7%</td>
<td>19.1%</td>
<td>0.4%</td>
</tr>
<tr>
<td>1994</td>
<td>39.1%</td>
<td>27.8%</td>
<td>14.6%</td>
<td>18.1%</td>
<td>0.4%</td>
</tr>
<tr>
<td>1995</td>
<td>40.6%</td>
<td>27.2%</td>
<td>14.1%</td>
<td>17.7%</td>
<td>0.4%</td>
</tr>
</tbody>
</table>

Sources: Frank N. Wilner (1997), adapted from Association of American Railroads (1962 and 1995)

Under the Staggers Act, railroads can alter prices depending on the location and destination. Since marginal cost pricing is inherently difficult in the rail industry, firms charged
higher rail rates, especially for captive shippers who had no easy alternative to using the railroads. In spite of this, McFarland [68] found that railroad deregulation did not lead to monopoly pricing. Therefore, he concluded that there was no justification for increased regulation in rail rates.

Since 1981, the rail sector has witnessed a large number of mergers. Many observers feared that the decrease in the number of competitors (increase in market concentration) would result in higher rail rates. Nevertheless, Ellig [39] observed that, as the number of competitors decreased, rail rates actually declined. But this does not necessarily mean that mergers always lead to lower prices. MacDonald [65] found that railroad mergers that increased market concentration led to rate increases. However, the number of rail companies nationwide was not a good indication of the degree of market concentration. Since individual railroads did not cover the entire country, their operations were concentrated in certain geographical regions. Hence, mergers of rail companies that did not compete in the same region did not reduce competition.

Berndt et al. [18] found that deregulation led to significant cost declines for Class I railroads from 1974 to 1986, and only a small fraction of the reduction was attributed to mergers. This finding was also echoed by Chapin and Schmidt [31]. Wilson [89] studied the effects of rail deregulation on the prices of 34 different commodity classifications over a period of 17 years. He showed that the majority of commodity prices rose initially due to small cost saving and increased market power under deregulation. But by 1988, most commodity prices decreased because of the long-term cost efficiency gained through deregulation. Wilson and Wilson [90] also found that there have been both nominal and real reductions in rail rates since 1980, ranging from 40 to 71 percent across commodities.

Chapin and Schmidt [31] applied data envelopment analysis to measure the efficiency of Class I railroads. They found that when firms used network of track as output and collected
usage fees from other railroads, mergers increased technical efficiency, but reduced scale efficiency; and many merged firms were larger than the efficient scale.\footnote{As mentioned earlier in the chapter, passenger railroads pay fees to freight railroads for the use of rail tracks owned by freight railroads. Hence, rail track was considered as a form of output to the freight railroads by Chapin and Schmidt.}

Bereskin \cite{bereskin} examined the effects on railroad costs of four hypothetical or potential transcontinental railroad mergers - Burlington Northern Santa Fe (BNSF) and CSX, BNSF and Norfolk Southern (NS), Union Pacific (UP) and CSX, and UP and NS. He found that, under each of the hypothetical merger scenarios, the merged railroad that had higher track mileage and greater total traffic also had lower estimated costs per unit of traffic. He also found that transcontinental mergers were expected to yield lower operating costs.

Although there has been a considerable increase in concentration in the U.S. rail industry following the regulatory reform, rail rates have been falling in the presence of intermodal competition (from truck and water modes). Congress passed the Motor Carrier Act in 1980, making entry much easier and leaving more price freedom for the trucking industry as well. In addition to falling rail rates, the rail industry has achieved substantial productivity improvements, and has enhanced its service quality in the past twenty years.

2.3 Market Structure

\textit{The economic characteristics of the rail industry make it a natural target for government intervention, yet also render it particularly difficult to regulate in the public interest.} \textemdash Kessides, Willig \cite{kessides}

Rail output is a service rather than a product. Hence, it is not storable, and shippers and passengers participate in the production process. In general, rail output can be classified into two groups: revenue output and available output. Revenue output refers to for revenue rail service, which is rail service demanded. A common measure of revenue output for freight railroads is revenue ton-mile. Available output refers to rail service supplied. A common measure of available output for freight railroads is freight train-mile. According to Oum and...
Yu [71], the use of available output may be justified if one wants to measure managerial efficiency in the presence of government control. However, if one wants to identify the effect of regulations or government control, revenue output measures would be more appropriate output indicators, since high efficiency measured in available output may imply that the railroad is efficient even though it supplies a lot of useless capacity, such as empty trains or cars.

Rail inputs are often lumpy or indivisible. Railroad infrastructure such as tracks may also be considered an output when other railroads pay a fee to the track owner (which sometimes is also a rail-service provider) for the use of tracks. On the other hand, railroad infrastructure may be either privately or publicly owned. In retrospect, rail infrastructure and services can be dealt with in different ways, and the structural pattern in the rail industry can be defined in terms of the degree of vertical relationship between infrastructure and services: (1) vertical integration, (2) competitive access, and (3) vertical separation (Campos and Cantos [24]).

Vertical integration is the traditional structure of the rail industry, where a single entity owns all the infrastructure facilities and provides services. Perry [75] states that there are three determinants of vertical integration: (1) technological economies, (2) transactional economies, and (3) market imperfections. Under technological economies, if a firm integrates with another upstream firm, less of the intermediate inputs may be needed to produce the same amount of output in the downstream process. Vertical integration may also arise from transactional economies. Transaction costs are associated with the process of exchange, and are different from production costs. The major determinant of vertical integration in the rail industry is asset specificity. Vertical integration in response to technological or transactional economies would, in general, increase welfare (Perry [75]). The advantage of vertical integration is the elimination of market imperfections (e.g. the double marginalization problem), since prior to integration, neither of the two firms has the incentive to take into account the adverse effects of their pricing behavior on the other (Salop [78]). Both Economides [38] and Salop [78] claimed that vertical integration can improve coordination in services between
the two formerly unintegrated firms, and hence improve service quality and reduce costs. A railroad which owns and operates its own facilities and vehicles is also known as a monolithic railroad. Kessides and Willig [58] found that state-owned monolithic railroads were less responsive to the needs of shippers and were inefficient. Similarly, privately owned monolithic railroads that were exposed to excessive government control may lose their incentive for efficiency and for market responsiveness.

Competitive access refers to the existence of an operator who maintains and ensures the availability of rail facilities to other operators. The access to the facilities must be fair and equal. The ultimate challenge is to price access to infrastructure in an efficient manner. Access pricing may create entry barriers. This problem arises in the rail industry when a single vertically integrated firm controls the supply of rail facilities to its competitors. Thus, there are incentives for the private integrated firm to set high infrastructure prices to raise its rivals’ costs. On the other hand, it could be that the regulator may set access prices too low to favor new entrants.

The problems of setting access prices may also arise in the case of vertical separation. Vertical separation is characterized by the ownership of rail facilities that are completely separated from other rail operations. Infrastructure can be treated as a natural monopoly. Services, on the other hand, can be treated as any other competitive economic activity. They can be provided by multiple competing operators or by a single firm under a license agreement. Even though such vertical separation can resolve some of the natural monopoly problems, the rail industry is still a capital-intensive sector with asset indivisibilities. For instance, capital units such as tracks and stations can be expanded in discrete and indivisible increments, but the demand for rail services may change only in small units, thus resulting in excess capacity. Separation of rail facilities from services also results in the entry of more than one operator on a single route. In profitable routes, this system would improve efficiency of the industry by allowing direct competition among operators. The main problem of this vertical unbundling is the potential loss of economies of scope, and the separated system may
lead to a prohibitive rise in transaction costs and increased complexity of the institutional framework due to contract negotiation. Vertical separation may also cause a reduction of interest in investment by the infrastructure owner when there is only one potential buyer or route operator, and the infrastructure owner has less bargaining power. However, this problem is less relevant the greater is the competition in the market.

Most countries have chosen to retain public ownership of infrastructure. Infrastructure can remain in public hands while the private sector provides rail services. Rothengatter [76] argued that vertical separation of infrastructure and rail services is essential for the European rail industry. Countries like France and Germany have established state-owned enterprises to manage the rail infrastructure. Fair access to rail infrastructure can remove entry barriers that might potentially reduce competition (Campos and Cantos [24]). In Sweden, the Transport Policy Act of 1988 divided the state’s rail asset between two state-owned enterprises, Statens Järnvägar (SJ), the Swedish State Railways, and Banverket (BV), the National Rail Administration. SJ operates like a private company and enjoys a monopoly for freight transport over the entire rail system and for passenger services over most of the system. BV is responsible for the railroad infrastructure. Although SJ pays for using the infrastructure, BV is heavily subsidized. The restructuring in Sweden is unique, because it did not involve privatization (Kopicki and Thompson [59]).

In the U.S., some commuter rail systems own all or part of the rail right-of-way. Certain tracks have been directly purchased from freight railroads. However, it is more common for commuter rail systems to negotiate with freight railroads for permission to rent right-of-way owned by freight railroads. Joint use of rail tracks allows the track owners to reduce the average cost per user. But joint use can make it difficult to allocate costs among the different types of users, or to determine the marginal cost of each type. Rothengatter [76] argued that the privatization policy in the U.S. rail industry is impracticable in Europe. He believed that if the European railroads were to follow the U.S. example, the European railroads would lose
their market share to roads and other transportation modes, and the negative environmental impact of increased road transport is large.

Thompson [80] suggested that ownership of rail infrastructure can be separated from operations, and such separation helps reduce unit cost. The more traffic a rail line carries, the lower is the unit costs. Besides, separation of infrastructure from operations also creates intramodal competition. However, the critical issues remaining are capacity management and infrastructure pricing. Incomplete information and lack of control across borders can reduce a railway’s ability to manage capacity. Moreover, pricing infrastructure in a transparent, efficient and nondiscriminatory manner is another challenge to the regulators.

Due to economies of scale and large sunk costs, railroads have marginal costs that are lower than their average costs. Thus, marginal cost pricing does not generate enough revenue to cover costs. Since railroads incur substantial fixed costs, the larger the size of the railroad company, the greater efficiency the company can achieve due to economies of scale. Hence, it is widely assumed that railroads which involve a large infrastructure network are examples of natural monopoly. Besides the transportation industry, regulated industries like electric utilities, gas utilities, telecommunications have also experienced this common problem.

The theory of contestable markets, which clarifies the concept of natural monopoly in terms of a sub-additive cost function, was developed and advanced by Baumol, Bailey and Willig [14], Panzar and Willig [74], and Baumol, Panzar and Willig [15]. According to Baumol [13], a natural monopoly refers to one or both of the following two circumstances:

- subadditivity of the cost function, which refers to an industry in which multifirm production is more costly than production by a single firm.

- sustainability of monopoly in an industry in which entrants are not able to survive even in the absence of the monopolist’s predatory behavior.
Contestable markets refer to markets which have substantial attributes of natural monopoly but are characterized by free and easy entry and exit. Although the cost-minimizing market structure contains a single seller - a “contestable monopolist”, the seller does not have monopoly power due to potential entry and competition (Bailey [10]). Besides this, a time lag exists in the entrant’s ability to exit, such that the entrants are able to “hit and run”, meaning the entrants are able to enter the market to earn profits above competitive levels, and yet manage to leave the market before any retaliatory actions are taken by the incumbents (Bailey and Baumol [11]). In fact, a market that is not competitive may function well as long as it is structurally contestable. In summary, under the theory of contestable markets, no excess profits can be earned by firms, and firms that are inefficient cannot survive market competition. Moreover, predatory pricing becomes unprofitable to firms, and cross-subsidization becomes economically impractical (Bailey [10]). Kessides and Willig [58] state “if an industry is contestable, then it is best left on its own devices with no government interference, even if it is composed of a very small number of large firms. Impediments to entry and exit, not concentration or scale of operations alone, are primary sources of interference with the public-interest workings of the invisible hand.”

According to Kessides and Willig [58], contestability analysis shows that high fixed costs and the consequent economies of scale need not cause excessive profits or prices or any predatory behaviors associated with market power. Contestability theory shows that it is the presence of sunk costs rather than economies of scale that affect market performance. This theory provides an improved set of guidelines for proper regulatory interference in the structure and conduct of railroads. These guidelines include: (1) permit freedom of pricing and operations on rail services that face effective competition, (2) permit a railroad to set prices in response to demand and marginal cost differences, and to enter into voluntary contracts with shippers that have specifically tailored terms, conditions, commitments and compensation schemes, and (3) control the prices that a railroad sets to “captive shippers,” over whom the railroad has monopoly power, by the stand-alone costs of the shipper’s service
and by the stipulation that the railroad’s rates do not generate earnings that persistently exceed the railroad’s replacement costs, including a competitive returns on capital.  

Additionally, contestability offers a framework for the analysis of issues pertaining to the vertical structure of the rail industry. In the rail industry, sunk costs are only clustered in certain areas of its operation, such as tracks, way and structures which are mainly in upstream production. Contestability theory suggests the idea of unbundling firms vertically in order to separate the part of the industry that needs to be regulated from those that do not, based upon their degrees of competition and contestability. Setting apart the portions of operation which involve heavy sunk costs enables the government to effectively target and impose appropriate regulations on the portion(s) that needs to be regulated. In this way, contestability suggests a flexible case-by-case regulatory approach. (Bailey [9], Kessides and Willig [58]).

2.4 Rail Capital

As discussed earlier, network or route abandonments were impossible during the pre-Staggers era, and studies in the 70s and 80s have unequivocally concluded that excess capacity creates considerable financial burden to the railroad industry. When evaluating the social costs of railroad regulation in the 1960s, Friedlaender [43] found that considerable cost savings could occur if railroads were given the freedom to cut back on capital input use and hence reduce the costs of excess capacity.

Keeler [56] agreed that track abandonment could create substantial savings for the railroad industry; local governments that opposed track abandonments should either take over the service or subsidize the railroads. He felt that track abandonment may not be easy for railroads, given the indivisibilities of rail capital. Caves, Christensen and Swanson [29] also

\[\text{The stand-alone cost is the cost of serving a shipper or a group of shippers alone, as if the shipper or its group were isolated from the railroads’ other customers. In other words, the stand-alone cost is the minimum cost of a possibly hypothetical alternative to the service provided by the incumbent railroad. It serves as a surrogate for competition and a simulated competitive price (Kessides and Willig [58]).}\]
found that the existence of excess capacity in network structure had hindered the economic performance of U.S. railroads. Because route abandonment was prohibited prior to deregulation, the existence of excess capacity had increased both the fixed and variable costs of railroads.

Waters and Tretheway [87] found that Canadian railroads experienced relatively low total factor productivity growth compared to American railroads in the 1980s because U.S. railroads were given the freedom to abandon unprofitable routes and to reduce other inputs. Given the falling rail rates and limited output growth, the only way to generate productivity gains is by reducing input use. Tretheway, Waters and Fok [82] also drew the conclusion that reducing track and capital inputs is essential for the viability and productivity growth of railroads. When comparing the productivity of major Australian railroads, Hensher, Daniels and Demellow [54] found that the capital stock was statistically significant and negatively related to railroad productivity.

As a result of considerable industrial failures, route abandonment became one of the central ingredients of the Stagger Act because overcapitalization appeared to be the most common problem faced by railroads. Unfortunately, Friedlaender et al. [45] reported that, even years after passage of the Staggers Act in 1980, overcapitalization persisted in the railroad industry despite the legislative goal to free railroads from being tied to unprofitable routes and services. Hence, one of the objectives of my research is to explore the role of capital in determining the productivity growth and financial performance of railroads.
Historically, railroad transportation has attracted the attention of researchers from different disciplines like economics, management science and engineering. Most railroad research has been motivated by both academic and policy questions, and a substantial literature has appeared on a variety of economic aspects of railroad transportation, for examples, rates and costs, impacts on the economy, efficiency, pricing of rail infrastructure, and so forth. (Winston [91]). In the past three decades, productivity studies of North American railroads were conducted by researchers who had not only contributed substantially to the methodological advancement of operations research, but also provided important policy implications for governments or regulatory authorities worldwide.

Winston [91] and Oum, Waters and Yu [72] conducted thorough literature surveys on transportation economics and railroad transportation. Thus, the focus of this chapter is to provide an overview of railroad productivity studies and a review of some of the popular research techniques.

3.1 Partial Factor Productivity

There have been numerous productivity or efficiency studies of railroads. Partial factor productivity (PFP) is a commonly used measure of productivity and efficiency, and it takes the form of a ratio: \( \frac{\text{Output}}{\text{Input}} \). The ratios “output per worker”, “freight per train-mile”, or “passenger per train-mile” are some examples of the PFP measures used in railroad research. These measures are widely used by public and private agencies in reporting transportation statistics. PFP measures are different from “total factor productivity” measures, because
the latter are output-input ratios that take into account all outputs and all inputs. The advantage of using total factor productivity measures is the avoidance of imputing gains to one input (or one output) that are really attributable to some other inputs (or outputs). For example, a gain in output resulting from an increase in a fixed input may be mistakenly attributed to labor even though labor performance deteriorated during the time period being observed (Cooper, Seiford and Tone [33]). Therefore, in addition to PFP indexes, the total factor productivity measures are used often in railroad research.

3.2 Total Factor Productivity

Total factor Productivity (TFP) compares total outputs with total inputs, and a TFP index is the ratio of an aggregate output index to an aggregate input index. In fact, there are different ways of measuring TFP, and the TFP indexes may vary as a result of aggregation problems (Diewert [34]).

A useful starting point to analyze TFP indexes is to consider the bilateral Törnqvist TFP measure proposed by Christensen and Jorgenson [32]:

\[
\ln(TFP_k/TFP_l) = \sum_i \left( \frac{R_{ik} + R_{il}}{2} \right) \ln(Y_{ik}/Y_{il}) - \sum_i \left( \frac{S_{ik} + S_{il}}{2} \right) \ln(X_{ik}/X_{il}), \tag{3.1}
\]

where \(X\) and \(Y\) represent the input and output indexes respectively, \(S\) and \(R\) are the corresponding input cost share and output revenue share, the \(k\) and \(l\) subscripts denote two adjacent periods, and the \(i\) subscript denotes the individual inputs or outputs. If the price of rail output equals its marginal cost, and if production exhibits constant returns to scale, then the output revenue shares are estimates of the elasticities of total cost. \(^1\)

However, Caves, Christensen and Swanson [27] pointed out that equation (3.1) is not relevant for the railroad industry because rail rates (or output prices) do not reflect marginal costs and the railroad industry does not necessarily exhibit constant returns to scale. Thus,

\(^1\)For the most recent application, see Estache, González and Trujillo [40].
they proposed a new measurement of TFP by using estimated output cost elasticities, instead of revenue shares as output weights:

\[
\ln(\frac{TFP_k}{TFP_l}) = \sum_{i}^m \left[ \frac{1}{2} \left( \frac{\partial \ln C}{\partial \ln Y_i} \right)_k + \frac{1}{2} \left( \frac{\partial \ln C}{\partial \ln Y_i} \right)_l \right] \ln(\frac{Y_{ik}}{Y_{il}}) \\
- \sum_{i}^n \left( \frac{S_{ik} + S_{il}}{2} \right) \ln(\frac{X_{ik}}{X_{il}}). 
\] (3.2)

The actual cost shares are the input weights. They are estimates of cost elasticities with respect to factor prices, and they remain the same as in equation (3.1) because rail factor markets are unregulated. The elasticities of cost with respect to the outputs are unobservable, but they can be estimated from cross-section cost-function regressions.

Caves, Christensen and Swanson [27] found that energy consumption declined sharply in the early 1950s as a result of the replacement of steam locomotives by more energy-efficient diesel locomotives and, on average, labor input accounted for about 50 percent of total cost between 1951 and 1974. During the same period, average annual productivity growth for the railroad industry was 1.5 percent.

In another paper, Caves and Christensen [25] used the TFP measure in equation (3.2) to compare the postwar productivity performance of the state-owned Canadian National (CN) and the privately-owned Canadian Pacific (CP) Railroads. They found that both CN and CP performed well under market competition, and that the productivity growth of CN was approximately equal to that of CP. This result has important implications because previous privatization studies had supported the notion that public ownership in a noncompetitive environment led to the poor economic performance of state-owned enterprises. Caves and Christensen’s ([25], p. 974) findings clearly show that “public ownership is not inherently less efficient than private ownership,” and the negative aspects of public ownership can be overcome by effective market competition.
Another common TFP measure in the railroad productivity literature is the multilateral Törnqvist TFP index proposed by Caves, Christensen and Diewert [26]. It is written as:

\[
\ln(\text{TFP}_k/\text{TFP}_l) = \sum_i \left( \frac{R_{ik} + \bar{R}_i}{2} \right) \ln\left( \frac{Y_{ik}}{\bar{Y}_i} \right) - \sum_i \left( \frac{R_{il} + \bar{R}_i}{2} \right) \ln\left( \frac{Y_{il}}{Y_i} \right) - \sum_i \left( \frac{S_{jk} + \bar{S}_j}{2} \right) \ln\left( \frac{X_{jk}}{\bar{X}_j} \right) + \sum_i \left( \frac{S_{jl} + \bar{S}_j}{2} \right) \ln\left( \frac{X_{jl}}{X_j} \right),
\]

(3.3)

where \( k \) and \( l \) denote two adjacent periods as before; \( Y_i \) and \( X_j \) are the quantities of output \( i \) and input \( j \) respectively; \( R_i \) is the revenue share of output \( i \); \( S_j \) is the cost share of input \( j \); \( \bar{R}_i \) is the revenue share of output \( i \) averaged across all firms and time periods; \( \bar{S}_j \) is the cost share of input \( j \) averaged across all firms and time periods, and \( \ln\bar{Y}_i \) and \( \ln\bar{X}_j \) are the geometric means of output \( i \) and input \( j \), respectively, averaged across all firms and time periods. The advantage of this index is that it satisfies the desired transitivity property, meaning that it allows us to make multilateral comparisons (between firms and over time). This superlative, multilateral index is therefore strongly preferred for comparisons based on cross-section or panel data. However, this index may not be more desirable than a chain-linked, bilateral index in a time-series context because of the chronological order of observations. Another disadvantage is that the index needs to be recalculated each time an additional year is included since values calculated from previous years will vary [26].

In two related studies, Freeman et al. [42] and Tretheway, Waters and Fok [82] used equation (3.3) to examine the productivity performance of Canadian railroads (CN and CP). After calculating the TFP measures, they adopt the procedure used by Caves, Christensen and Tretheway [30] of regressing the TFP index on a number of factors, such as output and network variables, to decompose TFP differences into a number of sources. Both studies showed that CP achieved a slightly higher productivity growth than CN, but the difference was statistically insignificant. However, CN’s financial performance was substantially below
that of CP, and TFP growth for both CN and CP was below the average TFP growth for U.S. railroads over the same period.

Hensher, Daniels and Demellow [54] applied equation (3.3) to analyze the productivity of five major public railroads in Australia – New South Wales, Victoria, Queensland, South Australia and Western Australia, from 1971/72 to 1991/92. The railroads’ performance varied depending upon whether the demand-side TFP or the supply-side TFP was used. After obtaining gross measures of TFP, Hensher, Daniels and Demellow regressed both the supply-side and demand-side TFP measures on a number of technological-change and managerial-change variables. They found that the railroads in South Australia and Queensland performed well above the other railroads in the country as a result of good management practices.

The use of TFP as a productivity measure is widely accepted. But because productivity growth does not automatically imply strong financial performance, TFP in itself is insufficient to measure firms’ overall performance [86]. Thus, Waters and Street [86] studied a range of performance measures and examined the linkages between the total factor productivity (TFP) and total price performance (TPP) of the Australian National Railways. Waters and Tretheway [87] also examined the linkages between productivity, prices and financial performance of CN and CP. TPP is the growth of input prices relative to the growth of output prices. Hence, the TPP index is written as:

\[ TPP = \frac{TC/X}{TR/Y}, \]  

where TC and TR represent total (economic) cost and total revenue, respectively. TPP is related to TFP since \( TFP = Y/X \) and, therefore

\[ TPP = TFP \cdot \frac{TC}{TR}, \]

or

\[ \frac{TR}{TC} = \frac{TFP}{TPP}. \] (3.5)

Thus, TPP is equal to TFP if a firm’s revenues equal its costs. The ratio \( TR/TC \) is an indicator of a firm’s profitability and is linked to TFP growth relative to TPP growth. If the
change in TFP is greater than that of TPP, then the firm’s profitability improves as a result of the productivity gain. However, if a firm’s productivity gains are not able to offset rising input prices, or if the change is TFP is less than that of TPP, then the firm’s profitability decreases.

Using equation (3.5) and following the indexing procedure introduced by Caves, Christensen and Diewert [26], as described by equation (3.3), Waters and Treheway [87] found that the Canadian railroads’ TPP had exceeded TFP since the early 1980s because railroads’ revenues did not keep up with cost increases even after adjusting for productivity gains.

Waters and Treheway found that the rise in the input price index in the 1980s could be attributed to increases in fuel, labor and capital service prices, while rail rates (output prices) remained sticky even in nominal terms. Hence, they suggested that for a mature industry, such as the North American railroad industry, with limited prospects for output growth, the main source of productivity gains is input reductions.

In an extension of Waters and Street [86], Salerian [77] used the logarithmic version of Fisher’s Ideal index to decompose profit into productivity and prices effects using the Australian National Railways data set. He found that there had been a small decrease in profit because the cost index increased more than the revenue index. Additionally, profitability decreased because the TFP improvement was offset by a decrease in the aggregate index of output price divided by input price.

3.3 Data Envelopment Analysis (DEA)

One of the operations research techniques that has been applied to the measurement and analysis of railroad productivity is a linear programming approach called Data Envelopment Analysis (DEA) models. The DEA model constructs a non-parametric, piece-wise frontier over the data. Using linear programming techniques, the frontier is calculated so that it envelops the data as tightly as possible. Lovell [63] provides an overview of some useful DEA models and analyzes these models in terms of their ability to measure efficiency.
Oum and Yu [71] applied a two-stage DEA approach to compare the economic efficiency of railway systems in nineteen OECD countries. In the first stage, efficiency scores were first obtained from the solution to a DEA linear programming problem. In the second stage, the DEA scores were expressed in logarithmic form and regressed on a set of explanatory variables, including the subsidy-to-cost ratio and the degree of managerial autonomy, in a Tobit model. The authors found that heavily subsidized railroads tended to be less efficient than other railroads. Additionally, railroads with a higher degree of managerial autonomy tended to perform better since their managements can respond more quickly to new circumstances and were more accountable for the railroad’s success or failure.

Chapin and Schmidt [31] also employed a two-stage DEA approach similar to that of Oum and Yu’s [71] to measure the efficiency of U.S. railroads following deregulation. They found that railroads’ efficiency had improved since deregulation but not as a result of mergers. Merged firms did not perform better than firms that did not merge. Mergers had, indeed, created larger-than-efficient-sized firms, and nearly half of these firms experienced decreasing returns to scale.

The two-stage procedure used by Oum and Yu [71] and Chapin and Schmidt [31], which is ubiquitous in the operations research literature, is not without problems. Simar and Wilson [79] explicitly point out that the inferences drawn from the regression analysis (in the second stage) are fragile because of the complicated, unknown serial correlation among the estimated efficiencies, and the correlation between the explanatory variables and the error term. Fortunately, these difficulties can be overcome by the “double bootstrap procedure” proposed by Simar and Wilson.

3.4 **Econometric Approaches**

The econometric approach is more common in railroad productivity research than indexing procedures, and it involves the estimation of firms’ cost and production functions. The estimated cost and production functions are then used to evaluate the economic performance
and productivity change of individual railroads and the industry as a whole. Borts [20] discussed a series of problems that arise when estimating a cost function for the rail industry. For example, eastern U.S. railroads had higher traffic density and experienced increasing costs, while southern and western railroads had persistent overcapitalization problems as a result of increasing returns. Thus, Borts dealt with the problem by stratifying the firms (observations) by region and size, and estimating a stratified cost function.

Harris [53] found that conventional cost function estimations contain general problems like inadequate cost accounting methods in measuring rail output production, improperly disaggregated accounting data, such as the division of costs between passenger and freight services, and so on. He proposed a total-cost equation:

$$TC = \beta_0 + \beta_1 RTM + \beta_2 RFT + \beta_3 MR + \epsilon,$$  \hspace{1cm} (3.6)

where TC represents total cost, RTM represents revenue ton miles, RFT denotes revenue freight tons, MR denotes miles of road, and $\epsilon$ is the error term. The variables RTM and RFT are measures of rail output. Miles of road (MR) is the actual number of miles of routing a railroad is required to serve by law. It is used as a measure of a firm’s capacity or economies of density.

The estimation of equation (3.6) is problematic by ordinary least squares because of heteroscedasticity. Thus, Harris transformed the variables and created a dummy variable URB to account for the higher costs of operations in urban areas. The new model is defined as

$$AC = \frac{TC}{RTM} = \gamma_0 + \gamma_1 \frac{RFT}{RTM} + \gamma_2 \frac{RFT}{RTM} URB + \gamma_3 \frac{MR}{RTM} + \gamma_4 \frac{MR}{RTM} URB + \mu.$$  \hspace{1cm} (3.7)

The empirical results showed that the cost of rail service on light-density lines was much higher than the cost on high-density lines. Hence, Harris concluded that railroads should be allowed to raise rates on light-density lines and to reduce rates on high-density lines.

Keeler [56] argued that, because of overcapitalization, estimating a long-run cost function of railroad is inappropriate since railroads cannot freely adjust all of their inputs to minimize
cost. Assuming a Cobb-Douglas production functions, Keeler minimized

$$TC = r_T T + r_R R + r_E E + r_L L,$$

(3.8)

where $T$ represents track miles, $R$ represents rolling stock investment, $E$ represents energy or fuel consumption, and $L$ represents labor. The $r$’s represent the respective input prices. The short-run cost minimization problem can be solved through the Lagrange-multiplier method.

Caves, Christensen and Swanson [28] [29] used a multiproduct variable cost function to estimate railroad productivity growth. Productivity change can be viewed as a shift in the structure of production. A variable cost function was used because the authors believed that railroads were in disequilibrium with respect to their capital stock. Thus, they assumed that firm minimizes variable costs subject to some levels of quasi-fixed inputs. The generalized translog multiproduct variable cost function is specified as

$$
\ln VC = \alpha_0 + \alpha_{t1} D_{t1} + \alpha_{t2} D_{t2} + \sum_i Y_i (\alpha_i + \alpha_{t1i} D_{t1} + \alpha_{t2i} D_{t2}) \\
\qquad + K (\alpha_K + \alpha_{t1K} D_{t1} + \alpha_{t2K} D_{t2}) + \sum_i \ln P_i (\beta_i + \beta_{t1i} D_{t1} + \beta_{t2i} D_{t2}) \\
\qquad + \frac{1}{2} \sum_i \sum_j \delta_{ij} Y_i Y_j + \frac{1}{2} \delta_{KK} K^2 + \frac{1}{2} \sum_i \sum_j \gamma_{ij} \ln P_i \ln P_j \\
\qquad + \sum_i \sum_j \rho_{ij} Y_i \ln P_j + \sum_j \rho_{Kj} K \ln P_j + \sum_j \theta_{Kj} KY_j, 
$$

(3.9)

where $VC$ is variable cost, the variables denoted by $D$ are the binary variables for periods 1 and 2 that enable the structure of production to differ from that of period 0. \(^2\) These binary variables interact with output, capital and variable input prices. $Y_i$ is the Box-Cox transformation of output $y_i$, $Y_i = (y_i^\lambda - 1)/\lambda$, and $K$ are the Box-Cox transformation of capital $k$, where $K = (k^\lambda - 1)/\lambda$. The $P_i$ are variable input prices. The authors impose symmetry restrictions on the $\gamma_{ij}$ and $\delta_{ij}$. Additionally, they imposed linear restrictions on

\(^2\)In Caves, Christensen and Swanson [29], an additional binary variable for country was introduced to the model such that the production structure of one country (the base country) can be compared to that of another.
the parameters to satisfy the requirement of homogeneity of degree one in input prices. Thus,

\[ \sum \beta_i = 1, \]
\[ \sum \beta_{tt} = 0, \]
\[ \sum \beta_{t2i} = 0, \]
\[ \sum_j \gamma_{ij} = 0 \forall i, \]
\[ \rho_{Kj} + \sum_j \rho_{ij} = 0. \]  \hfill (3.10)

Equation (3.9) can be solved as a multivariate regression system by adding variable cost shares using Shephard’s Lemma.

Caves, Christensen and Swanson [28] found that productivity growth between 1955 to 1974 averaged approximately 2 percent per year. When comparing the economic performance of U.S. and Canadian railroads, Caves, Christensen and Swanson [29] found that the less-regulated Canadian railroads had higher productivity growth. It was believed that overcapitalization had hindered the economic performance of U.S. railroads. Because U.S. railroads were prohibited from abandoning unprofitable routes, they bore the financial burden of operating on these routes. The problem of excess capacity had led to increases in both fixed and variable costs of U.S. railroads.

Berndt et al. [18] estimated a translog single-output variable cost function similar to equation (3.9). Additionally, the authors assumed error-component structures in the cost equation and its associated input-share equations. The equation system was estimated using the three-stage least squares and maximum likelihood estimation.

McGeehan [69] also applied a model similar to equation (3.9) to evaluate the production structure and productivity growth of the Irish railroad. He found that over the period 1973-1983, the Irish railroad experienced steady productivity growth. During the same period, substantial economies of density were present in its operations, suggesting that unit costs increased less than proportionately as output increased given a fixed level of capacity or network. As a result of new investment and changes in freight handling, the size of the
workforce was reduced considerably. Additionally, capital stock and fuel consumption were also reduced as outputs increased, resulting in productivity growth and lower average cost.

Braeutigam, Daughety and Turnquist [22] developed a “hybrid” cost model by incorporating the average speed of shipment as a proxy for service quality. The underlying assumption was that the speed of service is an important determinant of rail costs. The speed of service was then related to technological parameters generated through engineering process functions. The short-run cost function was specified in translog form. The results show an increase in average speed of shipment led to a statistically significant decrease in short-run variable cost.

Traditional econometric methods do not reflect the fact that firms are not necessarily on their cost or production frontiers. To remedy this shortcoming, the stochastic frontier method was proposed by Aigner, Lovell and Schmidt [1], and Meeusen and van den Broeck [70]. Lovell [64] reviews developments in the econometric approach to efficiency analysis and provides interesting empirical examples of the stochastic frontier models. The stochastic production frontier is defined as

\[
\ln(y_i) = x_i'\beta + v_i - u_i, \tag{3.11}
\]

where \(v_i\) denote the random error representing the effects of random shocks, and \(u_i\) is a non-negative random variable that measures the distance between each firm’s actual output and the output frontier.

Grabowski and Mehdian [49] used the production frontier method to measure the revenue efficiency of the U.S. railroad industry for the period 1951-1981. The frontier was estimated using corrected ordinary least squares (COLS). The results show that the main source of revenue inefficiency was operating under decreasing returns to scale when the scale of operation was larger than optimal.

Using a set of panel data for 19 European railroads over the period 1961-1988, Gathon and Perelman [47] estimated a factor requirement frontier to evaluate technical efficiency. This model is different from the usual production frontier, because labor consumption is used
as the dependent variable, and rail outputs (for both passenger and freight), technology (or electrification rate), a trend variable, and degree of autonomy (an index for managerial freedom) are used as explanatory variables. They found that managerial freedom was negatively correlated with technical inefficiency, suggesting that firms with less managerial freedom perform less well than firms with more managerial freedom. Technology, as expected, contributed negatively to labor technical inefficiency.

In a related study, Gathon and Pestieau [48] decomposed productive efficiency into managerial efficiency and regulatory efficiency using the displaced ordinary least squares approach. They first estimated a production frontier under an unregulated environment:

\[
\ln y_i = \alpha + \beta \ln x_i + \epsilon_i, \quad (3.12)
\]

where the error term \( \epsilon_i \sim \mathcal{N}(0, \sigma^2_\epsilon) \). They then incorporated differences in autonomy by correcting the error term and estimating:

\[
\epsilon_i = \delta + \gamma \text{AUTONOMY}_i + \eta_i. \quad (3.13)
\]

The variable AUTONOMY is an index of the regulatory environment. Hence, a production frontier is obtained when \( \eta_i \) is at its maximum. Both managerial efficiency and regulatory efficiency can be derived from the frontier and equation (3.13). The results indicate that firms’ performance varied under different regulatory environments and levels of managerial autonomy. Firms’ technical inefficiency may be a result of regulatory inefficiency which was beyond managements’ control.

In recent years, several other railroad productivity studies have been conducted using econometric approaches, including Banös-Pino et al. [12], Kennedy and Smith [57], and Loizides and Tsionas [62].

\footnote{According to Gathon and Perelman [47], labor expenses account for about 90 percent of the variable cost throughout the entire period and for all railroads. This implies that input substitutability is very limited.}
3.5 Conclusions

Conventional econometric approaches and indexing procedures are popular research techniques used in evaluating railroad productivity. However, some of these techniques are subject to limitations. Short-run total-cost and variable-cost functions were used in place of long-run cost functions to reflect the inflexibility of rail inputs like capital stock. The two-stage DEA approach may seem attractive, but the inferences drawn from the regression analysis in the second stage are fragile. Hence, the resulting conclusions of these studies are suspect. In spite of these problems, most productivity studies of railroads have provided important and policy-relevant findings that enable regulators and managements to evaluate and improve the performance of railroad transportation.

The railroad industry in the U.S. has experienced a substantial economic make-over since passage of the Staggers Act. Studies in the pre-deregulation era suggested that railroad inefficiency and management slack were direct results of regulations that prohibited railroads from making optimal operations decisions. In general, railroads operating under strict regulatory environments perform poorer financially and operationally than railroads with more managerial autonomy. Railroads bear a substantial financial burden by operating inefficiently, as required by law, at excess capacity. State-owned railroads can overcome technical inefficiency if they operate in a competitive environment. Research has also shown that rail input prices have been on the rise with labor input accounting for most of the variable costs, but rail rates, on the other hand, have been sticky (in nominal terms) or falling (in real terms). Given the limited output growth, researchers believe that the main source of productivity gains have been input reduction.

Previous studies have emphasized analyzing productivity changes of railroads under different regulatory settings, and how productivity can be improved if certain institutional factors are changed. These studies, with the exception of Waters and Tretheway [87], Waters and Street [86], and Salerian [77], did not explicitly evaluate the linkages between productivity and financial performance and the divergence of productivity and profitability. These
linkages are important for the railroad industry and the economy in which it operates and serves. In Chapters 4 and 5, we will examine these linkages, and provide explanations for this divergence.
Due to mergers, bankruptcies, and declassifications throughout the period 1986 – 2000, the panel data set used in this research study is unbalanced. Table 4.1 shows the Class I railroads in our data set.

Table 4.1: Class I Railroads 1986 – 2000

<table>
<thead>
<tr>
<th>Co. Id</th>
<th>Abbrev.</th>
<th>Railroads</th>
<th>Years of Obs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ATSF</td>
<td>Atchison, Topeka &amp; Santa Fe Railway Co.</td>
<td>1986 – 1995</td>
</tr>
<tr>
<td>2</td>
<td>BN</td>
<td>Burlington Northern Inc.</td>
<td>1986 – 1995</td>
</tr>
<tr>
<td>3</td>
<td>BNSF</td>
<td>The Burlington Northern &amp; Santa Fe R. Co.</td>
<td>1996 – 2000</td>
</tr>
<tr>
<td>4</td>
<td>CNW</td>
<td>Chicago &amp; North Western Transportation Co.</td>
<td>1986 – 1994</td>
</tr>
<tr>
<td>5</td>
<td>CR</td>
<td>Consolidated Rail Corp.</td>
<td>1986 – 1998</td>
</tr>
<tr>
<td>6</td>
<td>CSX</td>
<td>CSX Transportation</td>
<td>1986 – 2000</td>
</tr>
<tr>
<td>7</td>
<td>DRGW</td>
<td>Denver &amp; Rio Grande Western R.R. Co.</td>
<td>1986 – 1993</td>
</tr>
<tr>
<td>8</td>
<td>FEC</td>
<td>Florida East Coast R. Co.</td>
<td>1986 – 1991</td>
</tr>
<tr>
<td>9</td>
<td>GTW</td>
<td>Grand Trunk Western R.R. Co.</td>
<td>1986 – 2000</td>
</tr>
<tr>
<td>12</td>
<td>KCS</td>
<td>Kansas City Southern R. Co.</td>
<td>1986 – 2000</td>
</tr>
<tr>
<td>13</td>
<td>MKT</td>
<td>Missouri-Kansas-Texas R.R. Co.</td>
<td>1986 – 1987</td>
</tr>
<tr>
<td>14</td>
<td>NS</td>
<td>Norfolk Southern Corporation</td>
<td>1986 – 2000</td>
</tr>
<tr>
<td>15</td>
<td>SLSW</td>
<td>St. Louis Southwestern R. Co.</td>
<td>1986 – 1989</td>
</tr>
<tr>
<td>16</td>
<td>SOO</td>
<td>Soo Line R.R. Co.</td>
<td>1986 – 2000</td>
</tr>
<tr>
<td>17</td>
<td>SP</td>
<td>Southern Pacific Transportation Co.</td>
<td>1986 – 1996</td>
</tr>
<tr>
<td>18</td>
<td>UP</td>
<td>Union Pacific R.R. Co.</td>
<td>1986 – 2000</td>
</tr>
</tbody>
</table>

The data set was obtained mainly from the Analysis of Class I Railroads (abbreviated as *the Analysis*) from 1986 to 2000, which is an abstract of the annual R-1 Report all Class I
railroads are required to file with the Surface Transportation Board (STB) beginning 1996, or its predecessor, the Interstate Commerce Commission (ICC) before 1996) [3].

Despite being classified as Class I, the size of these railroads varied greatly. In 2000, Burlington Northern Santa Fe (BNSF) produced approximately 34 percent of the industry’s output (revenue ton miles), Union Pacific (UP) produced 33 percent, CSX Transportation (CSX) produced 15 percent, and Norfolk Southern (NS) produced 14 percent, while smaller railroads such as Illinois Central (IC), Soo Line (SOO), Kansas City Southern (KCS) and Grand Trunk Western (GTW) each produced less than 2 percent of the industry’s output. Moreover, the volume of inputs used by these railroads varied greatly with UP hiring 30 percent of the railroad workers, BNSF 24 percent, CSX and NS each 20 percent, and the rest of the railroads each hiring less than 2 percent of industry labor in 2000.

Currently, both Canadian National Railway (CN) and Canadian Pacific Railway (CP) own three U.S. Class I railroads. Grand Trunk Western (GTW) and Illinois Central (IC) are owned by CN, and Soo Line (SOO) by CP. Table 4.2 displays the input and output variables and their units of measurement.

Revenue ton mile is used as the output measure for this analysis. It is the preferred measure because it reflects the amount of output that was actually demanded by shippers. Output price or rail rate is measured by freight revenue per ton mile.

Labor input is measured by the average number of employees, including company executives, professionals and union workers. Energy input is measured by gallons of diesel oil

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1 Although the pre-1986 Analysis is available (from 1979), the data reported are either incomplete or erroneous. Supplemental data are available in Appendix A.

2 With the exceptions of CNW and UP, passenger and commuter rail services are provided mostly by AMTRAK and local transit agencies. Passenger rail output data are not available from the Analysis. However, certain input quantity data (e.g., energy, labor, locomotives, miles of track operated) are inclusive of passenger rail, and except energy, these data are not disaggregated. This does not raise a concern because passenger rail services provided by Class I railroads used only a small portion of the overall rail inputs. For example, energy used by passenger rail accounted for about 1 percent or less of the total consumption of diesel oil of all Class I railroads except CNW. Freight rail service has been used as the single output produced by railroads in other studies, see [18] and [31].
Table 4.2: Input and Output Variables

<table>
<thead>
<tr>
<th>Variables</th>
<th>Units of Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Output Quantity:</strong></td>
<td></td>
</tr>
<tr>
<td>Freight Revenue Output</td>
<td>Revenue ton miles (RTM)(^a)</td>
</tr>
<tr>
<td><strong>Output Price:</strong></td>
<td></td>
</tr>
<tr>
<td>Price per RTM</td>
<td>Freight revenue per ton mile</td>
</tr>
<tr>
<td><strong>Variable Input Quantities:</strong></td>
<td></td>
</tr>
<tr>
<td>Labor</td>
<td>Average number of employees</td>
</tr>
<tr>
<td>Energy</td>
<td>Fuel consumption (gallons of diesel oil)</td>
</tr>
<tr>
<td>Materials</td>
<td>Expenditures on input materials divided by the Rail Material Price Index (^b)</td>
</tr>
<tr>
<td><strong>Variable Input Prices:</strong></td>
<td></td>
</tr>
<tr>
<td>Labor</td>
<td>Average annual salary of all employees</td>
</tr>
<tr>
<td>Energy</td>
<td>Price per gallon of diesel</td>
</tr>
<tr>
<td>Material</td>
<td>Rail Material Price Index</td>
</tr>
<tr>
<td><strong>Fixed Input Quantities:</strong></td>
<td></td>
</tr>
<tr>
<td>Way and Structure (W&amp;S)</td>
<td>Miles of track operated</td>
</tr>
<tr>
<td>Rolling Stocks:</td>
<td></td>
</tr>
<tr>
<td>– Locomotives</td>
<td>Number of locomotives</td>
</tr>
<tr>
<td>– Freight cars</td>
<td>Number of freight cars</td>
</tr>
<tr>
<td><strong>Fixed Input Prices:</strong></td>
<td></td>
</tr>
<tr>
<td>Way and Structure (W&amp;S)</td>
<td>(Annual W&amp;S depreciation)/(Miles of track operated)</td>
</tr>
<tr>
<td>Rolling Stocks:</td>
<td></td>
</tr>
<tr>
<td>– Locomotives</td>
<td>(Annual locomotive depreciation)/(Number of locomotives)</td>
</tr>
<tr>
<td>– Freight cars</td>
<td>(Annual Fr. car depreciation)/(Number of freight cars)</td>
</tr>
</tbody>
</table>

\(^a\) AAR definition: the movement of a ton of freight one mile for revenue.

\(^b\) computed by the AAR, base year=1977 [2].
consumed. Material is obtained by dividing input material expenditures by the Rail Material Price Index. The price of labor is measured by the average annual salary paid to workers. The price of energy is measured by the price of diesel oil per gallon. The price of material is the Rail Material Price Index published by the AAR with base year 1977 [2].

Way and Structure are measured by miles of track operated by the railroads. Rolling stocks consist of locomotives and freight cars. The average rental price of a locomotive is annual locomotive depreciation divided by the number of locomotives. The price of a freight car is measured by annual freight car depreciation divided by the number of freight cars. The price of way and structure is measured by the annual way and structure depreciation divided by miles of track. 3

The descriptive statistics of the variables are displayed in Table 4.3 on the following three pages. The annual means and standard deviations of all variables for years 1986 through 2000 are reported.

Total cost, total revenue and profit in Table 4.3 were computed using the price and quantity information in the same table. Note that the term profit refers to economic profit instead of accounting profit. The short-run total cost and profit functions will be discussed in detail in Chapters 5 and 6, respectively.

Figure 4.1 shows the industry-wide averages of total cost and revenue ton miles from 1986 through 2000. As we can see from both Table 4.3 and Figure 4.1, even though the number of railroads decreased from 16 in 1986 to 8 in 2000, average annual revenue ton miles (output) increased almost every year. In fact, both rail cost and output more than doubled from 1986 to 2000. Hence, the upward-sloping trends of cost and output can be observed in Figure 4.1. However, since rail cost did not increase as fast as rail output over these years, cost per revenue ton mile (or average total cost) was falling.

3Due to data constraints, the computations of the quantity and price indexes of capital are simplified by using capital depreciations, since depreciation is part of railroad annual operating expenses. However, these prices are, by no means, the actual prices paid for any piece of capital equipment in any year.
Table 4.3: Descriptive Statistics

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Profit ($ mil) Mean</td>
<td>684.630</td>
<td>785.303</td>
<td>939.981</td>
<td>945.740</td>
<td>1032.481</td>
</tr>
<tr>
<td>Profit ($ mil) SD</td>
<td>760.766</td>
<td>826.907</td>
<td>937.698</td>
<td>947.171</td>
<td>963.373</td>
</tr>
<tr>
<td>Total Revenue ($ mil)</td>
<td>1571.375</td>
<td>1602.103</td>
<td>1797.622</td>
<td>1805.101</td>
<td>1958.206</td>
</tr>
<tr>
<td>Total Revenue ($ mil) SD</td>
<td>1517.949</td>
<td>1582.415</td>
<td>1696.475</td>
<td>1708.870</td>
<td>1760.105</td>
</tr>
<tr>
<td>Total Cost ($ mil) Mean</td>
<td>886.745</td>
<td>816.800</td>
<td>857.641</td>
<td>859.361</td>
<td>925.726</td>
</tr>
<tr>
<td>Total Cost ($ mil) SD</td>
<td>791.415</td>
<td>765.250</td>
<td>771.413</td>
<td>774.359</td>
<td>805.762</td>
</tr>
<tr>
<td>RTM (mil) Mean</td>
<td>53961.702</td>
<td>58729.071</td>
<td>65945.561</td>
<td>67589.399</td>
<td>73854.931</td>
</tr>
<tr>
<td>RTM (mil) SD</td>
<td>56249.461</td>
<td>62824.121</td>
<td>68885.602</td>
<td>71307.501</td>
<td>73989.051</td>
</tr>
<tr>
<td>Price per RTM Mean</td>
<td>0.031</td>
<td>0.030</td>
<td>0.030</td>
<td>0.030</td>
<td>0.030</td>
</tr>
<tr>
<td>Price per RTM SD</td>
<td>0.009</td>
<td>0.010</td>
<td>0.010</td>
<td>0.010</td>
<td>0.010</td>
</tr>
<tr>
<td>Locomotives Mean</td>
<td>1296.313</td>
<td>1226.438</td>
<td>1309.667</td>
<td>1292.067</td>
<td>1373.714</td>
</tr>
<tr>
<td>Locomotives SD</td>
<td>1133.444</td>
<td>1062.313</td>
<td>1092.920</td>
<td>1090.817</td>
<td>1106.779</td>
</tr>
<tr>
<td>Freight Cars Mean</td>
<td>44503.375</td>
<td>42240.125</td>
<td>43088.533</td>
<td>41733.333</td>
<td>42908.571</td>
</tr>
<tr>
<td>Freight Cars SD</td>
<td>49168.916</td>
<td>46004.158</td>
<td>44012.969</td>
<td>42141.263</td>
<td>40650.718</td>
</tr>
<tr>
<td>Way &amp; Struct (F1) Mean</td>
<td>16094.750</td>
<td>15310.875</td>
<td>15903.733</td>
<td>15497.933</td>
<td>16022.499</td>
</tr>
<tr>
<td>Way &amp; Struct (F1) SD</td>
<td>14079.641</td>
<td>13598.159</td>
<td>13814.119</td>
<td>13393.585</td>
<td>13054.867</td>
</tr>
<tr>
<td>Labor (V1) Mean</td>
<td>17055.188</td>
<td>15420.063</td>
<td>15636.467</td>
<td>15169.867</td>
<td>15438.857</td>
</tr>
<tr>
<td>Labor (V1) SD</td>
<td>15882.241</td>
<td>14501.256</td>
<td>14085.150</td>
<td>13821.495</td>
<td>13439.179</td>
</tr>
<tr>
<td>Diesel (V2) Mean</td>
<td>187.272</td>
<td>191.804</td>
<td>211.322</td>
<td>211.979</td>
<td>223.260</td>
</tr>
<tr>
<td>Diesel (V2) SD</td>
<td>177.990</td>
<td>184.766</td>
<td>198.922</td>
<td>200.769</td>
<td>206.075</td>
</tr>
<tr>
<td>Material (V3) Mean</td>
<td>750857.610</td>
<td>789784.354</td>
<td>926256.741</td>
<td>910419.669</td>
<td>871531.949</td>
</tr>
<tr>
<td>Material (V3) SD</td>
<td>702921.236</td>
<td>772085.308</td>
<td>881285.656</td>
<td>906556.370</td>
<td>785622.020</td>
</tr>
<tr>
<td>WF1 Mean</td>
<td>16137.701</td>
<td>15224.506</td>
<td>15567.701</td>
<td>16176.990</td>
<td>14385.254</td>
</tr>
<tr>
<td>WF1 SD</td>
<td>8021.818</td>
<td>6825.543</td>
<td>7527.510</td>
<td>12129.931</td>
<td>9501.761</td>
</tr>
<tr>
<td>WF2 Mean</td>
<td>2116.525</td>
<td>791.814</td>
<td>793.709</td>
<td>785.358</td>
<td>737.600</td>
</tr>
<tr>
<td>WF2 SD</td>
<td>2409.339</td>
<td>262.448</td>
<td>304.561</td>
<td>356.818</td>
<td>364.818</td>
</tr>
<tr>
<td>WF3 Mean</td>
<td>6360.919</td>
<td>4806.901</td>
<td>5101.229</td>
<td>4983.795</td>
<td>5445.326</td>
</tr>
<tr>
<td>WF3 SD</td>
<td>5142.928</td>
<td>1991.592</td>
<td>1890.502</td>
<td>1402.348</td>
<td>1869.492</td>
</tr>
<tr>
<td>V1 Mean</td>
<td>36524.875</td>
<td>38174.188</td>
<td>39703.667</td>
<td>40457.467</td>
<td>40793.143</td>
</tr>
<tr>
<td>V1 SD</td>
<td>3449.022</td>
<td>3719.830</td>
<td>3406.025</td>
<td>3360.748</td>
<td>2969.706</td>
</tr>
<tr>
<td>V2 Mean (per gal)</td>
<td>0.498</td>
<td>0.536</td>
<td>0.497</td>
<td>0.560</td>
<td>0.689</td>
</tr>
<tr>
<td>V2 SD (per gal)</td>
<td>0.031</td>
<td>0.021</td>
<td>0.021</td>
<td>0.020</td>
<td>0.032</td>
</tr>
<tr>
<td>V3 Mean (index)</td>
<td>1.416</td>
<td>1.339</td>
<td>1.397</td>
<td>1.471</td>
<td>1.527</td>
</tr>
<tr>
<td>V3 SD (index)</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td># of railroads</td>
<td>16</td>
<td>16</td>
<td>15</td>
<td>15</td>
<td>14</td>
</tr>
<tr>
<td>---------------------------</td>
<td>--------</td>
<td>--------</td>
<td>--------</td>
<td>--------</td>
<td>--------</td>
</tr>
<tr>
<td><strong>Profit</strong></td>
<td>992.927</td>
<td>1124.643</td>
<td>1156.265</td>
<td>1394.692</td>
<td>1550.708</td>
</tr>
<tr>
<td>($ mil)</td>
<td>917.946</td>
<td>982.591</td>
<td>987.519</td>
<td>1085.360</td>
<td>1236.229</td>
</tr>
<tr>
<td><strong>Total Revenue</strong></td>
<td>1921.727</td>
<td>2110.923</td>
<td>2148.142</td>
<td>2490.856</td>
<td>2843.939</td>
</tr>
<tr>
<td>($ mil)</td>
<td>1731.750</td>
<td>1767.598</td>
<td>1775.345</td>
<td>1879.223</td>
<td>2118.896</td>
</tr>
<tr>
<td><strong>Total Cost</strong></td>
<td>928.801</td>
<td>986.281</td>
<td>991.877</td>
<td>1096.164</td>
<td>1293.230</td>
</tr>
<tr>
<td>($ mil)</td>
<td>821.802</td>
<td>794.133</td>
<td>796.575</td>
<td>800.367</td>
<td>898.442</td>
</tr>
<tr>
<td><strong>RTM</strong></td>
<td>74205.375</td>
<td>82060.068</td>
<td>85331.459</td>
<td>100058.409</td>
<td>118698.879</td>
</tr>
<tr>
<td>(mil)</td>
<td>74483.142</td>
<td>75891.984</td>
<td>77939.995</td>
<td>85849.083</td>
<td>104745.109</td>
</tr>
<tr>
<td><strong>Price per RTM</strong></td>
<td>0.029</td>
<td>0.028</td>
<td>0.027</td>
<td>0.028</td>
<td>0.028</td>
</tr>
<tr>
<td><strong>Locomotives</strong></td>
<td>1339.714</td>
<td>1416.231</td>
<td>1428.154</td>
<td>1573.667</td>
<td>1741.909</td>
</tr>
<tr>
<td>(F1)</td>
<td>1093.199</td>
<td>1061.102</td>
<td>1066.922</td>
<td>1060.853</td>
<td>1258.898</td>
</tr>
<tr>
<td><strong>Freight Cars</strong></td>
<td>41462.214</td>
<td>42522.077</td>
<td>41202.462</td>
<td>45099.417</td>
<td>48273.273</td>
</tr>
<tr>
<td>(F2)</td>
<td>39195.513</td>
<td>36568.118</td>
<td>34994.715</td>
<td>34002.530</td>
<td>36043.489</td>
</tr>
<tr>
<td><strong>Way &amp; Struc</strong></td>
<td>15698.143</td>
<td>16383.923</td>
<td>16057.846</td>
<td>17227.917</td>
<td>18755.818</td>
</tr>
<tr>
<td>(F3)</td>
<td>12862.068</td>
<td>12300.931</td>
<td>12021.822</td>
<td>11615.511</td>
<td>12760.137</td>
</tr>
<tr>
<td><strong>Labor (V1)</strong></td>
<td>14741.857</td>
<td>15185.769</td>
<td>14809.692</td>
<td>15830.167</td>
<td>17110.455</td>
</tr>
<tr>
<td>SD</td>
<td>12783.530</td>
<td>12243.263</td>
<td>11876.739</td>
<td>11618.043</td>
<td>12401.526</td>
</tr>
<tr>
<td><strong>Diesel (V2)</strong></td>
<td>208.294</td>
<td>231.876</td>
<td>238.186</td>
<td>278.580</td>
<td>317.195</td>
</tr>
<tr>
<td>(mil of gals)</td>
<td>195.373</td>
<td>197.763</td>
<td>203.667</td>
<td>222.137</td>
<td>260.041</td>
</tr>
<tr>
<td><strong>Material</strong></td>
<td>759482.612</td>
<td>775125.781</td>
<td>736998.963</td>
<td>787141.488</td>
<td>780503.685</td>
</tr>
<tr>
<td>(V3)</td>
<td>665682.205</td>
<td>614479.965</td>
<td>577398.063</td>
<td>579678.415</td>
<td>590368.105</td>
</tr>
<tr>
<td><strong>W_{F1}</strong></td>
<td>15121.338</td>
<td>15647.533</td>
<td>14956.720</td>
<td>15933.327</td>
<td>18927.296</td>
</tr>
<tr>
<td>SD</td>
<td>11363.289</td>
<td>12048.208</td>
<td>12240.715</td>
<td>13462.729</td>
<td>12527.670</td>
</tr>
<tr>
<td><strong>W_{F2}</strong></td>
<td>726.404</td>
<td>675.707</td>
<td>642.129</td>
<td>659.588</td>
<td>1135.553</td>
</tr>
<tr>
<td>SD</td>
<td>370.947</td>
<td>322.452</td>
<td>314.616</td>
<td>321.624</td>
<td>1465.927</td>
</tr>
<tr>
<td><strong>W_{F3}</strong></td>
<td>6180.318</td>
<td>5663.943</td>
<td>6016.719</td>
<td>6166.367</td>
<td>15249.427</td>
</tr>
<tr>
<td>SD</td>
<td>2530.736</td>
<td>1753.696</td>
<td>1918.847</td>
<td>1877.945</td>
<td>16287.097</td>
</tr>
<tr>
<td><strong>W_{V1}</strong></td>
<td>42172.500</td>
<td>45624.308</td>
<td>46253.923</td>
<td>47533.083</td>
<td>49034.909</td>
</tr>
<tr>
<td>SD</td>
<td>3358.571</td>
<td>3801.173</td>
<td>3501.145</td>
<td>4061.186</td>
<td>4565.943</td>
</tr>
<tr>
<td><strong>W_{V2}</strong></td>
<td>0.674</td>
<td>0.628</td>
<td>0.623</td>
<td>0.606</td>
<td>0.592</td>
</tr>
<tr>
<td>(per gal)</td>
<td>0.039</td>
<td>0.023</td>
<td>0.039</td>
<td>0.055</td>
<td>0.026</td>
</tr>
<tr>
<td><strong>W_{V3}</strong></td>
<td>1.676</td>
<td>1.798</td>
<td>1.855</td>
<td>1.913</td>
<td>1.924</td>
</tr>
<tr>
<td>(index)</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td><strong># of railroads</strong></td>
<td>14</td>
<td>13</td>
<td>13</td>
<td>12</td>
<td>11</td>
</tr>
<tr>
<td>--------------------------</td>
<td>------------</td>
<td>------------</td>
<td>------------</td>
<td>------------</td>
<td>------------</td>
</tr>
<tr>
<td>Profit Mean (§ mil)</td>
<td>1772.852</td>
<td>2000.659</td>
<td>1933.005</td>
<td>2166.052</td>
<td>2164.497</td>
</tr>
<tr>
<td>(§ mil) SD</td>
<td>1527.777</td>
<td>1877.571</td>
<td>1825.667</td>
<td>2187.481</td>
<td>2133.028</td>
</tr>
<tr>
<td>Total Revenue Mean (§ mil)</td>
<td>3188.757</td>
<td>3591.611</td>
<td>3582.975</td>
<td>3900.560</td>
<td>4135.169</td>
</tr>
<tr>
<td>Total Cost Mean (§ mil)</td>
<td>1415.905</td>
<td>1590.952</td>
<td>1649.970</td>
<td>1734.508</td>
<td>1970.672</td>
</tr>
<tr>
<td>RTM Mean (mil)</td>
<td>135597.483</td>
<td>149880.649</td>
<td>152977.982</td>
<td>174201.401</td>
<td>183245.032</td>
</tr>
<tr>
<td>Price Per SD</td>
<td>0.027</td>
<td>0.028</td>
<td>0.027</td>
<td>0.025</td>
<td>0.025</td>
</tr>
<tr>
<td>Locomotives Mean (F1)</td>
<td>1960.500</td>
<td>2222.222</td>
<td>2288.111</td>
<td>2577.375</td>
<td>2546.750</td>
</tr>
<tr>
<td>Freight Cars Mean (F2)</td>
<td>52125.900</td>
<td>54444.556</td>
<td>55762.444</td>
<td>63167.750</td>
<td>61036.125</td>
</tr>
<tr>
<td>Way &amp; Struc Mean (F3)</td>
<td>20623.600</td>
<td>22194.111</td>
<td>21978.000</td>
<td>24981.875</td>
<td>24883.125</td>
</tr>
<tr>
<td>Labor(V1) Mean (V1)</td>
<td>18180.900</td>
<td>19775.667</td>
<td>19802.444</td>
<td>21162.125</td>
<td>21045.000</td>
</tr>
<tr>
<td>Diesel (V2) Mean (V2)</td>
<td>358.771</td>
<td>398.061</td>
<td>403.867</td>
<td>448.908</td>
<td>463.657</td>
</tr>
<tr>
<td>Material Mean (mil of gals)</td>
<td>834305.426</td>
<td>927436.375</td>
<td>894307.718</td>
<td>913259.311</td>
<td>920640.459</td>
</tr>
<tr>
<td>(V3) SD</td>
<td>698622.524</td>
<td>921059.539</td>
<td>854146.666</td>
<td>931119.561</td>
<td>944048.578</td>
</tr>
<tr>
<td>W_{F1} Mean</td>
<td>19078.630</td>
<td>15687.846</td>
<td>18536.582</td>
<td>16371.588</td>
<td>16913.037</td>
</tr>
<tr>
<td>W_{F2} Mean</td>
<td>673.411</td>
<td>618.514</td>
<td>709.288</td>
<td>648.599</td>
<td>693.014</td>
</tr>
<tr>
<td>W_{F3} Mean</td>
<td>266.799</td>
<td>308.296</td>
<td>305.602</td>
<td>271.429</td>
<td>289.740</td>
</tr>
<tr>
<td>W_{V1} Mean</td>
<td>51531.700</td>
<td>51442.444</td>
<td>55536.778</td>
<td>54863.375</td>
<td>59279.250</td>
</tr>
<tr>
<td>W_{V2} Mean</td>
<td>0.674</td>
<td>0.666</td>
<td>0.527</td>
<td>0.560</td>
<td>0.879</td>
</tr>
<tr>
<td>(per gal) SD</td>
<td>0.036</td>
<td>0.039</td>
<td>0.057</td>
<td>0.033</td>
<td>0.062</td>
</tr>
<tr>
<td>W_{V3} Mean</td>
<td>1.935</td>
<td>1.969</td>
<td>1.991</td>
<td>1.987</td>
<td>1.981</td>
</tr>
<tr>
<td># of railroads</td>
<td>10</td>
<td>9</td>
<td>9</td>
<td>8</td>
<td>8</td>
</tr>
</tbody>
</table>

The standard deviations of total cost change were large. This is due to the fact that Class I railroads varied greatly in terms of size.

Figure 4.2 presents the industrial averages of total revenue and total cost of Class I railroads in nominal terms from 1986 through 2000. In Figure 4.2, both total revenue and
total cost had been rising. However, since total revenue was more than total cost and rose at a faster rate than did total cost, the gap between total revenue and total cost became larger. This tells us that profit had been rising in those years shown in Figure 4.3 on the following page.

In Table 4.3, industry-wide profit rose from $700 million in 1986 to $2 billion in 2000. Interestingly, in spite of rising profit, rail rates had been decreasing in the same period (see Figure 4.3). The sources of year-to-year profit change are what we wish to uncover using the decomposition model discussed in Chapter 6. We will see later that, given falling rail rates and rising input prices, railroads’ success has depended largely on productivity gains.

Table 4.3 shows that rail output (RTM) nearly quadrupled, from about 54 billion in 1986 to 183 billion revenue ton miles in 2000. It also varied greatly across railroads due to variations in the size of the firms and their operations. The standard deviations of output price were small, indicating that rail rates did not vary much across railroads.

Figure 4.1: Industrial Average: Total Cost and Revenue Ton Miles (1986–2000)
Figure 4.2: Industrial Average: Total Revenue versus Total Cost (1986–2000)

Figure 4.3: Profit and Price (1986–2000)
The number of locomotives increased nearly 100 percent over these years, while the annual depreciation per locomotive stayed about the same in nominal terms. The number of freight cars also increased from 44,500 in 1986 to 61,000 in 2000, but the annual depreciation per freight car fell from $2,100 in 1986 to less than $700 in 2000. This means that, in real terms, the capital prices for both locomotive and freight car were falling. Besides locomotives and freight cars, way and structure (miles of track) rose substantially, suggesting that increased demand for output triggered increases in fixed input use. Initially, the depreciation of a mile of track was about $6,400 in 1986. In 1995, the depreciation per mile of track peaked at $15,000, but fell to $8,300 in 2000. Notice that, in almost every year, the standard deviations of fixed input quantities were relatively close to the means, whereas the standard deviations of fixed input prices were relatively small compared to the means. This implies that capital prices were less dispersed than capital quantities across firms.

Labor quantity increased from roughly 17,000 in 1986 to 21,000 in 2000. The price of labor \( W_{11} \) increased over time from about $36,500 in 1986 to nearly $60,000 in 2000. Rail salaries are higher than the salary of average American workers, and are the second highest in the transportation industry, behind the average salary of pipelines workers. According to the National Transportation Statistics 2002, the average annual wage for a U.S. worker in 2000 was about $38,800, while the average wage of a worker in the transportation industry was $38,400, and the average wage of a pipelines worker was $66,500 [23].

Diesel consumption increased steadily over time, but fuel prices appeared to be volatile. Like other input prices, the standard deviations of fuel prices were relatively small, implying that railroads faced about the same energy prices in any given year.

In general, input quantities varied tremendously across railroads due to large variations in the size of firms and their operations. However, input prices did not vary much across firms, but they did vary through time, suggesting that railroads faced similar input prices. The standard deviations of the material price index are zero because the same annual, industry-wide indexes were used for all firms in every year.
Chapter 5

Intertemporal Cost Change Decomposition and Benchmarking Exercise: A Short-run Analysis

5.1 Introduction

The economic approach to index number theory and productivity measurement is based on a ratio concept. This causes no particular difficulties for economists because they are used to this approach. However the ratio approach is not one that the business and accounting community finds natural; a manager or owner of a firm is typically interested in analyzing profit differences rather than ratios. Thus interest centers on decomposing cost, revenue or profit changes into price and quantity (or volume) effects. — W.E. Diewert, [37]

Railroad research in recent decades has focused on rail rates, rail cost and rail production before and after the major deregulation in 1980. As we have seen in Chapters 2 and 3, most of these studies examined whether changes in management structure, mergers, and deregulation had led to cost savings and railroad productivity change, and whether shippers and consumers as a whole had enjoyed lower rail rates as a result of market competition. Researchers have come up with different econometric models to estimate rail cost and production functions, both long-run and short-run, but only a handful of these studies examined the linkage between rail cost change and productivity.

In this chapter, an empirical model is used to explore the sources of short-run railroad cost change and to investigate the relation between cost change and productivity. Unlike the usual econometric modeling of rail cost, this model is adapted from the approach found
in Grifell-Tatjé and Lovell [51]. And unlike the conventional economic approaches to index number theory and productivity measurement, this technique uses Bennet input price and quantity indicators, and is capable of decomposing both intertemporal and cross-sectional total cost change. Sequential DEA is used to improve the robustness of the results since the number of railroads during this time period is small and declining. More importantly, the advantage of using sequential DEA is that it allows the current-period technology to be constructed from input and output quantity data for all railroads represented in all periods prior to and including the current period [50].

In this chapter, short-run cost is used in place of long-run cost in the model. Short-run cost is important in the present context because not all rail inputs can be freely varied during a given time period. For example, railroads are not free to optimally adjust their capacity, and so they might not be operating along their long-run cost frontier.\(^1\) Hence, railroads minimize cost for a certain production level by changing only the variable inputs. Moreover, structures and equipment are fixed inputs which railroad management cannot easily vary during a given time period. On the other hand, labor, energy and material are variable inputs in railroad operations that can be adjusted relatively easily. In light of this, a capital (or fixed-input) effect is also added to the cost-change decomposition. The cost frontier in this model is piecewise linear and nonparametric as opposed to the nonlinear, parametric, translog cost frontiers in other studies. A three-stage decomposition of short-run cost change is conducted as shown in Figure 5.1.

The short-run cost change is divided into a variable-input component and a fixed-input component. The variable-input component consists of a (variable) price effect and a (variable) quantity effect. The fixed-input component consists of a capital or fixed input effect, of course. In other words, this technique attributes short-run total cost change to a price effect, a quantity effect and a capital effect. The price effect identifies the cost variation attributable exclusively to variation in variable input prices. The quantity effect identifies

\(^1\)see Friedlaender and Spady [44]
the cost variation attributable to variation in variable input use. The capital effect identifies the cost variation attributable to variation in fixed input use.

In the second stage of the decomposition, the quantity effect is decomposed into a productivity effect and an activity effect. The productivity effect identifies the cost variation attributable to changes in productivity. The activity effect identifies the cost variation attributable to variation in the volume of production.

In the third stage, the productivity effect is decomposed into a technical efficiency effect, an allocative efficiency effect and a technical change effect. In the cross-sectional context, the technical change effect is absent since we are only dealing with a within-period decomposition. In the cross-sectional decomposition analysis, a low-cost railroad and a cost-efficient railroad are chosen as the benchmarks for comparison. All these effects are evaluated at a Benet price or quantity indicator. A set of unbalanced panel data on U.S. class I railroads for the period 1986–2000 is used.

The results of the intertemporal analysis show that variable input prices play a major role in short-run cost changes in almost all time periods. A large proportion of the price effect is
attributed to changes in the price of labor. Energy prices were volatile over the entire period, but they did not contribute much to cost increases, except for the periods 1988–1990 and 1999–2000. The railroad industry experienced significant technical progress over this time frame. The capital effect was a crucial factor in determining changes in total cost. We observe that, in any given period, a negative capital effect was followed by a decrease in total cost, and a positive capital effect was followed by an increase in total cost. This suggests that, in the short-run, an increase in capital expenditure would cause the short-run cost to rise. These results are consistent with earlier studies of rail abandonment.

In the cross-sectional study, it is interesting that, except for 1996, the cost-efficient railroads also had the lowest short-run average total cost in the industry from 1995 to 2000. A within-period benchmarking exercise was conducted from 1995 through 2000. In any given year, the cost-efficient benchmark (or the “role model”) railroad outperformed other railroads because it was large. The benchmarking railroads (or the “challengers”) were less efficient both technically and allocatively, and both of these effects are within management’s control. Additionally, the benchmarking railroads had higher costs despite the fact that they also faced relatively lower input prices from 1997 through 1999. Subsequently, the benchmarking railroads can learn from the benchmark when it comes to cost savings.

The rest of this chapter is organized as follows. The next section provides the analytical framework of the model. Sections 5.3 and 5.5 provide a more thorough description of the intertemporal and cross-sectional decomposition techniques. The results of the intertemporal analysis appear in section 5.4. Section 5.6 presents the results of the cross-sectional analysis. Section 5.7 concludes with a summary.

5.2 The Analytical Framework

Let \( X = (X_1, X_2, \ldots, X_N) \geq 0 \) represent the input quantity vector and \( Y = (Y_1, Y_2, \ldots, Y_M) \geq 0 \) represent the output quantity vector. Let \( W = (W_1, W_2, \ldots, W_N) > 0 \) be the input price
vector and $P = (P_1, P_2, \ldots, P_M) > 0$ be the output price vector. Since we are interested in only the cost side of the producer’s activities, output prices are ignored.

In a long-run analysis, the producer’s input set is defined as

$$L(Y) = \{X : (X \text{ can produce } Y)\}, \quad (5.1)$$

which is assumed to be closed and convex, and to satisfy strong disposability of inputs. The input set $L(Y)$ represents the set of all input vectors, $X$, which can produce the output vector $Y$. The lower bound of the input set is the input isoquant given by

$$I(Y) = \{X : X \in L(Y), \lambda X \notin L(Y), \lambda < 1\}. \quad (5.2)$$

Note that an input vector $X$ must be within its input set $L(Y)$. However, it does not need to belong to its input isoquant $I(Y)$.

The input distance function is given as

$$D(Y, X) = \max\{\theta : X/\theta \in L(Y)\}. \quad (5.3)$$

The distance $D(Y, X)$ is equal to 1 if $X$ belongs to the input isoquant $I(Y)$. If $X$ belongs to the input set of $Y$, $X \in L(Y)$, then $D(Y, X) \geq 1$.

The cost frontier is defined by

$$C(Y, W) = \min_X \{W^T X : X \in L(Y)\} = \min_X \{W^T X : D(Y, X) \geq 1\}. \quad (5.4)$$

In a short-run analysis, $X$ is partitioned into two components, $X = (X_v, X_f)$, where $X_v$ represents a subvector of variable inputs and $X_f$ is a subvector of fixed inputs; $W$ is also partitioned into two components $W = (W_v, W_f)$, where $W_v$ and $W_f$ are the associated input prices for variable and fixed inputs, respectively.

The producer’s short-run input set represents the set of all variable input vectors, $X_v$, which can produce the output vector $Y$ in the short run, given the fixed output vectors, $X_f$. It is defined as

$$L(Y|X_f) = \{X_v : (X_v \text{ can produce } Y|X_f)\}. \quad (5.5)$$
The lower bound of the short-run input set is the short-run input isoquant given by

\[ I(Y|X_f) = \{x_v : x_v \in L(Y|X_f), \lambda x_v \notin L(Y|X_f), \lambda < 1 \}. \tag{5.6} \]

The short-run input distance function is given as

\[ D(Y, x_v|X_f) = \max \{\theta : x_v/\theta \in L(Y|X_f)\}. \tag{5.7} \]

The distance \( D(Y, x_v|X_f) \) is equal to 1 if \( x_v \) belongs to the input isoquant \( I(Y|X_f) \). If \( x_v \) belongs to the input set of \( Y, X \in L(Y|X_f) \), then \( D(Y, x_v|X_f) \geq 1 \).

The dual to the short-run input distance function is the short-run variable cost frontier. The short-run variable cost frontier gives the minimum variable cost required to produce output vector \( Y \) with variable input price vector \( W_v \) and with fixed inputs \( X_f \) and the prevailing technology. The short-run variable cost frontier is defined as

\[
VC(Y, X_f, W_v) = \min_{x_v} \{(W_v^T x_v) : x_v \in L(Y|X_f)\}
= \min_{x_v} \{(W_v^T x_v) : D(Y, x_v|X_f) \geq 1\}, \tag{5.8}
\]

where \( VC(Y, X_f, W_v) \) is nondecreasing in \( Y \) and nondecreasing, concave and homogeneous of degree one in \( W_v \). If the producer is both technically and allocatively efficient, \( VC = VC(Y, X_f, W_v) \).

### 5.3 Intertemporal Short-run Cost-Change Decomposition

The Grifell-Lovell [51] technique decomposes cost changes into a price effect and a quantity effect. The model here adds a twist to the Grifell-Lovell model by using short-run cost and by introducing a capital effect.

Consider the short-run cost frontier defined as:

\[
TC = VC(Y, X_f, W_v) + W_f X_f
= W_v x_v(Y, X_f, W_v) + W_f X_f. \tag{5.9}
\]
Totally differentiate (5.9) to obtain

\[
dTC = X_v dW_v + W_v dX_v + X_f dW_f + W_f dX_f, \tag{5.10}
\]

where the first term on the right hand side is a price effect, the second term is a quantity effect, and the last two terms comprise a capital effect. The conventional method of performing a cost-change decomposition considers only the price and quantity components.\(^2\)

By applying the short-run cost frontier, we are able to introduce a capital component. The capital component is important in the present context.\(^3\) Thus, by isolating the capital effect from the variable price and quantity effects, we are able to measure the role of capital in rail cost changes.

Through the application of sequential Data Envelopment Analysis (DEA), indicators instead of indexes are used to measure these effects.\(^4\) The Laspeyres [60] and Paasche [73] indexes are ubiquitous in the statistical world. The Fisher Quantity and Price Indexes [41] and the Törnqvist indexes are also commonly seen. The Laspeyres index uses base-period weights. The Paasche index uses the current-period weights to define the index. Fisher [41] suggests taking the geometric mean of the two indexes to obtain the Fisher ideal index, and Törnqvist defines another index using a weighted geometric mean of the indexes. Quantity indexes may be defined using these price indexes. As common as these indexes may be, they are not without problems. According to Diewert [35], the Laspeyres and Paasche indexes do not satisfy the circularity test and fail the country or time reversal test. The Fisher Index is also intransitive, and the Törnqvist index fails both the circularity test and the monotonicity test.

---

\(^2\) Revenue and profit change decompositions into price and quantity effects are also common in the literature.

\(^3\) Refer to Chapters 2 and 4 for a discussion of the role of rail capital and the impact of overcapitalization on financial performance.

\(^4\) Indexes are based on ratios, and indicators, on the other hand, are based on differences. See Diewert [36]. The Stochastic Frontier approach can also be used to obtain indicators or indexes. However, due to data constraints, a nonparametric (DEA) approach is used.
Diewert [36] advocates the use of an alternative approach, due to Bennet [16], which uses differences rather than ratios. Bennet’s price and quantity indicators are simply the arithmetic mean of the Laspeyres and Paasche indicators. Details of Bennet’s indicators are provided in Appendix B.

Grifell and Lovell [51] use Bennet’s price and quantity indicators for the cost-change decompositions because, as shown by Diewert [36], the Bennet indicators satisfy nineteen tests, including continuity of prices and quantities, identity tests for prices and quantities, the bounding test, monotonicity, invariance to changes in the units of measurement, linear homogeneity in prices and quantities, and time reversal, among others.

Using Bennet’s method, we can decompose the short-run cost change in the following ways. For the intertemporal model, the short-run cost change between periods $t$ and $t+1$ can be decomposed as:

$$TC^{t+1} - TC^t = (W_v^{t+1}X_v^{t+1} - W_v^tX_v^t) + (W_f^{t+1}X_f^{t+1} - W_f^tX_f^t)$$

$$= \frac{1}{2}(X_v^t + X_v^{t+1})^T(W_v^{t+1} - W_v^t) \quad \text{Price Effect}$$

$$+ \frac{1}{2}(W_v^t + W_v^{t+1})^T(X_v^{t+1} - X_v^t) \quad \text{Quantity Effect}$$

$$+ \left\{ \frac{1}{2}(W_f^t + W_f^{t+1})^T(X_f^{t+1} - X_f^t) + \right.$$}

$$\frac{1}{2}(X_f^t + X_f^{t+1})^T(W_f^{t+1} - W_f^t) \right\} \quad \text{Capital Effect} \quad (5.11)$$

The price effect of the short-run cost change is the variable input price change evaluated at a Bennet input quantity indicator. The quantity effect of the short-run cost change is the variable input quantity change evaluated at a Bennet variable input price indicator. The capital-effect component consists of two parts – the fixed input quantity change evaluated at a Bennet fixed input price indicator, and the fixed input price change evaluated at a Bennet fixed input quantity indicator.

The quantity effect, itself, consists of two components: a productivity effect indicating the impact on short-run cost of a change in productivity, and an activity effect indicating the impact on short-run cost of a change in the scale of the firm’s operations. In other words,
a productivity effect measures the path resulting from a shift in the cost frontier, and an activity effect reflects movement along the cost frontier.

The price effect indicates the impact on short-run cost of a change in variable input prices from $W^t_v$ to $W^{t+1}_v$, by holding variable input usage fixed. On the other hand, the quantity effect shows the impact on cost of the change in variable input usage from $(X^t_v)$ to $(X^{t+1}_v)$, holding variable input prices fixed. A capital effect reflects the impact on short-run cost of changes in capital usage, holding capital prices fixed, and of a change in the prices of capital, holding capital fixed.

The quantity effect ($QE = \frac{1}{2}(W^t_v + W^{t+1}_v)^T[(X^{t+1}_v - X^B_v) - (X^t_v - X^E_v)]$) between period $t$ and period $t + 1$ decomposes as:

$$QE = \frac{1}{2}(W^t_v + W^{t+1}_v)^T[(X^{t+1}_v - X^B_v) - (X^t_v - X^E_v)] \quad \text{Productivity Effect}$$

$$+ \frac{1}{2}(W^t_v + W^{t+1}_v)^T(X^B_v - X^E_v) \quad \text{Activity Effect}$$

(5.12)

Figure 5.2 illustrates the decomposition of the quantity effect into a productivity effect, and $VC^t(Y, X^t_f, W^t_v)$ and $VC^{t+1}(Y, X^{t+1}_f, W^{t+1}_v)$ are the short-run variable cost frontiers for period $t$ and period $t + 1$ respectively. $VC^t$ is drawn in such a way that it is located above $VC^{t+1}$. The implicit assumption here is that technical progress has occurred between period $t$ and period $t + 1$ despite the fact that $W^{t+1}_v$ may be greater than or equal to $W^t_v$. These two assumptions, however, are not necessary in the model. If short-run variable costs lie above the frontiers, there is inefficient variable input use for that period. The point $X^B_v$ is a cost minimizing variable input vector for $(Y^{t+1}, X^{t+1}_f, W^{t+1}_v)$ and period $t + 1$ technology. Thus $X^B_v = \nabla_{W^{t+1}_v} VC^{t+1}(Y^{t+1}, X^{t+1}_f, W^{t+1}_v)$. Similarly, $X^E_v$ is a cost-minimizing variable input vector for $(Y^{t}, X^{t+1}_f, W^{t+1}_v)$ and period $t + 1$ technology. Thus $X^E_v = \nabla_{W^{t+1}_v} VC^{t+1}(Y^{t}, X^{t+1}_f, W^{t+1}_v)$.

The productivity effect measures the excess cost of operating above the period $t + 1$ short-run variable cost frontier $VC^{t+1}(Y, X^{t+1}_f, W^{t+1}_v)$ in period $t + 1$, less the excess cost of
Figure 5.2: The decomposition of the quantity effect into a productivity effect and an activity effect.
operating above the period \( t + 1 \) short-run variable cost frontier \( VC^{t+1}(Y, X^t, W^t) \) in period \( t \). Both excess costs are evaluated at a Bennet input price indicator. If the productivity effect reduces short-run variable cost from period \( t \) to period \( t + 1 \), then \( \frac{1}{2}(W^t + W^{t+1})^T(X^t - X^E) > \frac{1}{2}(W^t + W^{t+1})^T(X^{t+1} - X^B) \), and the productivity effect reduces short-run cost, \textit{ceteris paribus}. If the productivity effect increases short-run variable cost from periods \( t \) to \( t + 1 \), then \( \frac{1}{2}(W^t + W^{t+1})^T(X^t - X^E) < \frac{1}{2}(W^t + W^{t+1})^T(X^{t+1} - X^B) \), and the productivity effect increases short-run cost, \textit{ceteris paribus}.

The activity effect measures the impact on short-run cost between periods \( t \) and \( t + 1 \) of changes in the size of rail production from \( X^t \in I^{t+1}(Y^t|X^t) \) to \( X^{t+1} \in I^{t+1}(Y^{t+1}|X^{t+1}) \). The excess cost is also evaluated at a Bennet input price indicator. If the activity effect reduces short-run variable cost from period \( t \) to period \( t + 1 \), then \( \frac{1}{2}(W^t + W^{t+1})^T(X^B - X^E) \) is less than zero, and short-run cost is reduced. If the activity effect contributes positively to short-run variable cost, then \( \frac{1}{2}(W^t + W^{t+1})^T(X^B - X^E) \) is greater than zero, and short-run cost is increased.\(^5\)

The productivity effect has two components – a cost-efficiency component and a technical-change component. The cost efficiency change component can be decomposed into a technical efficiency effect and an allocative efficiency effect. Figure 5.3 helps us visualize these effects.

Clearly, in Figure 5.3 \( X^t_v \) is technically inefficient, since \( X^C_v = \theta^t X^t_v \in I^t(Y^t|X^t) \), where \( \theta^t = [D^t(Y^t, X^t_v)|X^t_j]^{-1} < 1 \). However, we also observe that \( X^C_v \) is allocatively inefficient for \( W^t \), because too much \( X_{v1} \) and too little \( X_{v2} \) are used, compared to the cost-efficient variable input vector \( X^A_v \). Besides this, input vector \( X^{t+1}_v \) is also technically inefficient, since \( X^D = \theta^{t+1} X^{t+1}_v \in I^{t+1}(Y^{t+1}|X^{t+1}) \), where \( \theta^{t+1} = [D^{t+1}(Y^{t+1}, X^{t+1}_v)|X^{t+1}_j]^{-1} < 1 \). However,

\(^5\)Note that the activity effect resembles some form of a scale measure per se, but it is by no means a returns-to-scale measure. This is because returns-to-scale is a long-run concept. In the short run, output can be changed only by changing the amounts of some, but not all, inputs. The response of output to changes in the mix of variable and fixed inputs used is called “returns to variable proportions”. See Jehle and Reny [55]. The activity effect measures the change in variable inputs, weighted by a Bennet input price indicator in the short run. It does not measure the percentage change in cost with respect to the percentage change in output in the long run, nor does it measure changes in output when all inputs are changed in the same proportion.
Figure 5.3: The decomposition of the productivity effect into a technical efficiency effect, an allocative efficiency effect and a technical change effect.

\( X^D_v \) is allocatively inefficient for \( W_v^{t+1} \), because too much \( X_v^1 \) and too little \( X_v^2 \) are used, compared to the cost-efficient variable input vector \( X^B_v \).

The productivity effect (PE) in equation 5.12 decomposes as:

\[
PE = \frac{1}{2}(W_v^t + W_v^{t+1})^T[(X_v^{t+1} - X_v^B) - (X_v^t - X_v^E)] \\
= \frac{1}{2}(W_v^t + W_v^{t+1})^T[(X_v^{t+1} - X_v^D) - (X_v^t - X_v^C)] \quad \text{TE Effect} \\
+ \frac{1}{2}(W_v^t + W_v^{t+1})^T[(X_v^D - X_v^B) - (X_v^C - X_v^A)] \quad \text{AE Effect} \\
+ \frac{1}{2}(W_v^t + W_v^{t+1})^T(X_v^E - X_v^A) \quad \text{Tech. Chg. Effect}
\]

(5.13)

The technical efficiency effect of (5.13) measures the impact on short-run variable cost, and hence the impact on short-run total cost, of the change in technical efficiency between
periods $t$ and $t+1$. The allocative efficiency effect of (5.13) measures the impact on short-run variable cost, and hence the impact on short-run total cost, of the change in allocative efficiency between periods $t$ and $t+1$. Both effects are evaluated at a Bennet input price index. The sum of these two effects is the cost-efficiency component and is equal to $[(X_{v}^{t+1} - X_{v}^{E}) - (X_{v}^{t} - X_{v}^{A})]$.

As for the technical change effect in (5.13), it is clear from Figure 5.3 that the cost-efficient input vector $X_{v}^{A} \in I^{t}(Y^{t}|X_{f}^{t})$, and therefore $W_{v}^{TT}X_{v}^{A} = VC^{t}(Y^{t}, X_{f}, W_{v}^{t})$. Moreover, the cost-efficient input vector $X_{v}^{E} \in I^{t+1}(Y^{t}|X_{f}^{t+1})$, and so $W_{v}^{t+1T}X_{v}^{E} = VC^{t+1}(Y^{t}, X_{f}^{t+1}, W_{v}^{t+1})$. The movement from $X_{v}^{A}$ to $X_{v}^{E}$ indicates the impact on short-run variable cost, and hence short-run total cost, of any positive technical change. The technical change effect is evaluated at a Bennet input price indicator. This effect can be observed in Figures 5.2 and 5.3.

We are now ready to implement the intertemporal cost-change decomposition. Information on $(Y^{t}, X_{v}^{t}, W_{v}^{t})$ and $(Y^{t+1}, X_{v}^{t+1}, W_{v}^{t+1})$ can be observed. However, the decomposition also requires that the unobserved input quantity vectors $X_{v}^{A}, X_{v}^{B}, X_{v}^{C}, X_{v}^{D}$ and $X_{v}^{E}$ be identified. Using the sequential DEA technique, we are able to obtain each of the unobserved input quantity vectors. Because the number of railroads declines every year, the use of sequential DEA improves the robustness of the results by incorporating, as a reference set, the previous years’ railroads into the analysis [83]. For examples, the short-run variable cost frontier for 1993 uses all railroads from 1986 to 1993 as its reference set, the short-run variable cost frontier for 1994 uses all railroads represented from 1986 to 1994 as its reference set, and so on. Additionally, the advantage of using sequential DEA is that it allows the current-period technology to be constructed from input and output quantity data for all railroads represented in all periods prior to and including the current period. Subsequently, technologies once used are not forgotten, and remain available for adoption.

Suppose we have $t$ time periods and that in time period $s$ we have $I_{s}$ railroads, $s = 1, \ldots, t$. We assume that the railroads use $n = 1, \ldots, N$ inputs to produce $m = 1, \ldots, M$ outputs. Let $Y^{t}$ and $X^{t}$ be the $M \times 1$ output quantity vector and the $N \times 1$ input quantity vector.
for railroad $\zeta$ in period $t$ respectively. Also, let $Y_{\zeta}^s$ be the sequential $M \times s$ matrix of $M$ outputs produced and $X_{\zeta}^s$ be the $N \times s$ matrix of $N$ inputs used by railroads in each of periods $s = 1, \ldots, t$. Subsequently, let $Y^s = \{Y^1, \ldots, Y_{\zeta}^s, \ldots, Y^t\}$ be an $M \times \sum_{s=1}^{t} I_s$ matrix of $M$ outputs produced by all $I_s$ railroads in each of periods $s = 1, \ldots, t$. Let $X^s = \{X^1, \ldots, X_{\zeta}^s, \ldots, X^t\}$ be an $N \times \sum_{s=1}^{t} I_s$ matrix of $N$ inputs used by $I_s$ railroads in each of periods $s = 1, \ldots, t$. Note that the matrices $Y^s$ and $X^s$ include output and input quantity data for all railroads represented in periods 1 through $t$. Hence, the matrices are sequential.

We can compute the technical efficiency effect in (5.13) by identifying input quantity vectors $X^C_v$ in period $t$ and $X^D_v$ in period $t + 1$. Since $X^C_v$ is a radial contraction of $X^t_v$, $X^C_v = \theta^C X^t_v = X^t_v/D^t(Y^t, X^t_v|X^t_f)$, where $\theta^C \leq 1$. The scalar $\theta^C$ can be determined by solving the following linear programming problem:

\[
\begin{align*}
[D^t(Y^t, X^t_v|X^t_f)]^{-1} &= \min_{\theta^C, \lambda^s} \theta^C \\
\text{subject to} \quad &\theta^C X^C_v \geq \lambda^s X^s_v, \\
&\lambda^s Y^s \geq Y^t_v, \\
&\lambda^s \geq 0, \\
&\sum_{i} \lambda^i = 1, \quad i = 1, \ldots, \sum_{s=1}^{t} I_s.
\end{align*}
\]

(5.14)

The constraints of this linear program guarantee that $X^C_v = \theta^C X^t_v \in I^t(Y^t_v|X^t_f)$.

Since $X^D_v$ is a radial contraction of $X^t+1_v$, $X^D_v = \theta^D X^t+1_v = X^t+1_v/D^{t+1}(Y^{t+1}, X^t+1_v|X^{t+1}_f)$, with $\theta^D \leq 1$. Similarly, the scalar $\theta^D$ can be determined as the solution to the following linear programming problem:

\[
\begin{align*}
[D^{t+1}(Y^{t+1}, X^t+1_v|X^t_f)]^{-1} &= \min_{\theta^D, \lambda^{s+1}} \theta^D \\
\text{subject to} \quad &\theta^D X^{t+1}_v \geq \lambda^{s+1} X^{s+1}_v, \\
&\lambda^{s+1} Y^{s+1} \geq Y^{t+1}_v, \\
&\lambda^{s+1} \geq 0, \\
&\sum_{i} \lambda^i = 1, \quad i = 1, \ldots, \sum_{s=1}^{t} I_{s+1}.
\end{align*}
\]

(5.15)
The constraints of this linear program guarantee that $X_v^D = \theta^D X_v^{t+1} \in I^{t+1}(Y^{\zeta^{t+1}} \mid X_f^{\zeta^{t+1}})$.

The allocative efficiency effect in (5.13) can be computed by identifying the unobserved input quantity vectors $X_v^A$ in period $t$ and $X_v^B$ in period $t+1$. The input quantity vector $X_v^A$ minimizes the short-run variable cost of producing output $Y^t$, when variable input prices are $W^t_v$ with period $t$ technology. Thus, $X_v^A$ can be identified by solving the cost-minimization linear program:

$$VC^t(Y^\zeta^t, X_f^\zeta^t, W_v^\zeta^t) = \min_{X_v, \lambda^s} W_v^{\zeta^tT} X_v$$
subject to $X_v \geq \lambda^s X_v^*$,
$$\lambda^s Y^s \geq Y^\zeta^t,$$
$$\lambda^s \geq 0,$$
$$\sum_i \lambda^{is} = 1, \quad 1, \ldots, \sum I_s. \quad (5.16)$$

The constraints of this program guarantee that $W_v^{\zeta^tT} X_v^A = VC^t(Y^\zeta^t, X_f^\zeta^t, W_v^\zeta^t)$.

Similarly, since $X_v^B$ minimizes the short-run variable cost of producing $Y^{t+1}$ output when input prices are $W_v^{t+1}$ and with period $t + 1$ technology, $X_v^B$ can be identified by solving the linear programming problem:

$$VC^{t+1}(Y^{\zeta^{t+1}}, X_f^{\zeta^{t+1}}, W_v^{\zeta^{t+1}}) = \min_{X_v, \lambda^{s+1}} W_v^{\zeta^{t+1T}} X_v$$
subject to $X_v \geq \lambda^{s+1} X_v^{s+1}$,
$$\lambda^{s+1} Y^{s+1} \geq Y^{\zeta^{t+1}},$$
$$\lambda^{s+1} \geq 0,$$
$$\sum_i \lambda^{is+1} = 1, \quad i = 1, \ldots, \sum I_{s+1}. \quad (5.17)$$

The constraints of this program guarantee that $W_v^{\zeta^{t+1T}} X_v^B = VC^{t+1}(Y^{\zeta^{t+1}}, X_f^{\zeta^{t+1}}, W_v^{\zeta^{t+1}})$.

Finally, the technical change effect can be computed by identifying input quantity vectors $X_v^A$ and $X_v^E$. Given the input quantity vector $X_v^B$ as the solution to the linear programming problem above, we can also compute the activity effect in (5.12).
Since the input quantity vector \( X_E \) minimizes the short-run variable cost of producing output \( Y_t \) when input prices are \( W_{t+1} \) and with period \( t+1 \) technology, \( X_E \) can be identified as the solution to the linear programming problem:

\[
VC_{t+1}(Y^\zeta_t, X_f^\zeta_{t+1}, W_v^\zeta_{t+1}) = \min_{X_v, \lambda_{t+1}} W_{v}^\zeta_{t+1} X_v
\]

subject to \( X_v \geq \lambda_{s+1} X_v^s_{t+1} \),

\[
\lambda_{s+1} Y_{s+1} \geq Y^\zeta_t,
\]

\[
\lambda_{s+1} \geq 0,
\]

\[
\sum_i \lambda_{is+1} = 1, \quad i = 1, \ldots, \sum_{s=1}^t I_{s+1}, \quad (5.18)
\]

The constraints of this program guarantee that \( W_v^\zeta_{t+1} X_v^\zeta E = VC_{t+1}(Y^\zeta_t, X_f^\zeta_{t+1}, W_v^\zeta_{t+1}) \).

Since there are \( I \) firms in time period \( t \), we need to solve the five linear programming problems \( I_t \) times in order to obtain the five unobserved input quantity vectors \( X_A, X_B, X_C, X_D \) and \( X_E \). These unobserved input quantity vectors are combined with the observed input quantity vectors \( X_v^t \) and \( X_v^{t+1} \) and the observed input price vectors \( W_v^t \) and \( W_v^{t+1} \) to decompose the quantity effect of the observed short-run cost change. In other words, based upon the observed and unobserved input quantity and price vectors, the decomposition of short-run cost change can be implemented by solving (5.11) through (5.13).

### 5.4 Results: Intertemporal Short-run Cost Change Decomposition

Using the observed price and quantity data in Chapter 4, the five unobserved input quantity vectors \( X_A, X_B, X_C, X_D \) and \( X_E \) can be obtained by solving the five linear programming problems in equations (5.14) through (5.18). The values of these vectors are inserted into the intertemporal short-run cost change decompositions (5.11), (5.12) and (5.13). The results are displayed on Table 5.1.

There are huge variations in short-run cost change in each time period. For example, in the 1986-1987 period the mean short-run cost change was −$70 million, but the standard
deviation was nearly twice as much. More stunningly, the mean short-run cost change in the 1995-1996 period was −$9 million, but the standard deviation was a striking $133 million.

The capital effect played a crucial role in these short-run cost changes. In 1990-1991, the capital effect was about $15 million, while the cost change was only $3 million. In 1994-1995, the capital effect ($72 million) accounted for 80 percent of the cost change ($90 million), while the price and quantity effects accounted for only 19 percent and 0.6 percent respectively. On the other hand, a negative capital effect led to decrease in cost. For example, in 1986-1987, the -$50 million capital effect, the -$60 million quantity effect and the $40 million price effect led to an average cost decrease of $70 million. In 1995-1996, the negative capital and quantity effects combined outweighed the positive price effect, causing short-run cost to fall by $9 million. In most time periods, the positive price effect was offset by the negative quantity effect, leaving the capital effect the sole important determinant of railroads’ short-run cost changes. In fact, in any given year, the capital effect and the cost change moved in the same direction. In other words, when the capital effect was negative, short-run cost fell; and when the capital effect was positive, short-run cost rose. This implies that capital expenditure has a direct impact on short-run cost. Railroads incurring large capital expenditures are likely to face a cost increase in the short run. This may be due to the aging of physical units of freight railroads that led to high depreciation. According to the Bureau of Transportation Statistics [23], in 2000 43 percent of Class I railroads locomotive fleet were built before 1980, and 21 percent were built in the 1980’s. The opposite signs of the price and quantity effects indicate that railroads adjust variable input usage according to changes in variable input prices since railroads tend to be price takers in input markets.

The price effect was positive in almost every period. Not surprisingly, a large proportion of this effect can be attributed to the price of labor. The price of energy, on the other hand, accounted for a smaller fraction of the price effect except for the 1988-1989, 1989-1990 and 1999-2000 periods. A positive price effect constitutes an increase in costs. In 1999-2000, the
price effect alone accounted for 91 percent of the observed cost increase. During this period, changes in energy price accounted for about 60 percent ($143 million) of the increase in cost.

The quantity effect accounted for 90 percent of the cost increase in 1998-1999, but less than 1 percent in 1999-2000. The dramatic change in 1999-2000 was due to the enormous increase in energy price. In fact, the quantity effect was small because the positive activity effect was almost completely absorbed by the negative productivity effect.

The activity effect and the productivity effect had opposite signs in every period except 1996-1997. The activity effect was positive in every period except for the 1996-1997 and 1997-1998 periods. The positive activity effect implies that railroads increased their production. This result can be verified by the increased amount of revenue ton miles (output) and variable inputs discussed in Chapter 4.

The productivity effect had a negative sign in every period except for 1997-1998. A negative productivity effect implies a lowering of costs by increased productivity. In most time periods, the strong negative productivity effect outweighed the positive activity effect, resulting in a negative quantity effect and a lowering of costs. In some instances, such as the 1993-1994, 1994-1995, 1998-1999 and 1999-2000 periods, relatively large positive activity effects outweighed negative productivity effects, leading to a positive quantity effect and an increase in costs.

The technical efficiency and allocative efficiency effects were volatile, with signs changing over time. From the 1996-1997 period to the 1999-2000 period, the allocative efficiency effect was positive, implying that variable inputs were allocated inefficiently in those time periods. The technical efficiency effect also had a positive impact on short-run cost change during these same time periods except 1999-2000. The technical change effect was negative in every time period. This means that railroads had experienced significant technical progress over time, which in turn reduced their short-run costs. Hence, the driving force behind the negative productivity effect was technical progress. As a result of computerization and innovation, railroads were able to improve their service quality and to cut costs.
Table 5.1: The Intertemporal Short-run Cost Change Decomposition

<table>
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<td>5.479</td>
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<td>0.227</td>
<td>5.789</td>
<td>14.665</td>
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<tr>
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<td>SD 125.727</td>
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<td>22.988</td>
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<td>15</td>
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<td>14</td>
</tr>
</tbody>
</table>

**Quantity Effect**

|                      | SD 44.045    | 21.204       | 19.498       | 22.532       | 27.140       |
| Productivity Effect  | Mean -83.566 | -42.435      | -27.632      | -43.481      | -43.943      |
|                      | SD 87.041    | 47.689       | 34.713       | 42.869       | 42.814       |

**Productivity Effect**

| Technical Efficiency Effect | Mean 28.203 | -2.311 | 8.431 | -43.729 | -12.562 |
|                            | SD 75.786   | 27.155 | 36.931 | 56.661  | 73.610  |
| Allocative Efficiency Effect | Mean -60.461 | -17.478 | -30.302 | 6.423 | -14.715 |
|                             | SD 110.437 | 25.742 | 36.021 | 38.044 | 77.479 |
| Technical Change Effect    | Mean -51.908 | -22.646 | -5.760 | -6.175 | -16.665 |
|                            | SD 53.918   | 27.420 | 8.936  | 3.566  | 20.587  |

**Individual Price Effect**

<p>| Labor                  | Mean 29.919 | 27.277 | 5.092 | 4.737 | 32.371 |
|                       | SD 36.118   | 32.401 | 18.383 | 7.685 | 42.019 |
| Material              | Mean -0.059 | 0.051 | 0.068 | 0.052 | 0.122 |</p>
<table>
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<td>$ mil</td>
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<tr>
<td>Mean</td>
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<td>13</td>
<td>12</td>
<td>11</td>
<td>10</td>
</tr>
</tbody>
</table>

**Quantity Effect**

| Activity Effect       | Mean   |        |        |        |        |
|                      |        | 16.856 | 22.394 | 42.497 | 63.521 |
|                      | SD     | 22.684 | 28.412 | 38.194 | 123.349|
| Productivity Effect  | Mean   | -38.316| -35.660| -39.682| -63.004|
|                      | SD     | 37.029 | 42.126 | 64.563 | 109.902|

**Productivity Effect**

| Technical Efficiency Effect | Mean |        |        |        |        |
|                            |      | -3.882 | -36.685| -13.814| 7.022  |
|                            | SD   | 64.596 | 64.737 | 53.369 | 36.348 |
| Allocative Efficiency Effect | Mean | -17.204| 11.633 | 7.846  | 8.837  |
|                            | SD   | 63.145 | 40.199 | 49.941 | 30.443 |
| Technical Change Effect    | Mean | -17.229| -10.609| -33.714| -78.863|
|                            | SD   | 8.232  | 13.511 | 36.951 | 110.055|

**Individual Price Effect**

| Labor                  | Mean   |        |        |        |        |
|                       |        | 34.072 | 15.600 | 24.804 | 18.073 |
|                       | SD     | 27.623 | 41.693 | 40.413 | 26.723 |
| Energy                | Mean   | -8.932 | -0.353 | -8.065 | -1.372 |
|                       | SD     | 7.722  | 6.026  | 9.024  | 2.991  |
| Material              | Mean   | 0.097  | 0.043  | 0.046  | 0.009  |
|                       | SD     | 0.078  | 0.034  | 0.034  | 0.007  |
|----------------------|---------------|---------------|---------------|---------------|
|                      | $ mil         | $ mil         | $ mil         | $ mil         |
| (Cont’d)             |               |               |               |               |
| TC Change            | Mean 13.873   | 59.018        | 98.896        | 236.164       |
|                      | SD 46.368     | 114.955       | 196.827       | 267.581       |
|                      |               |               |               |               |
| Capital Effect       | Mean 14.009   | 23.051        | 21.801        | 18.729        |
|                      | SD 21.758     | 25.470        | 27.461        | 21.713        |
|                      |               |               |               |               |
| Price Effect         | Mean 22.038   | 34.467        | -13.026       | 216.002       |
|                      | SD 42.053     | 96.768        | 62.597        | 257.678       |
|                      |               |               |               |               |
| Quantity Effect      | Mean -22.174  | 1.499         | 90.121        | 1.433         |
|                      | SD 30.800     | 53.164        | 183.924       | 110.293       |
|                      | # of railroads | 9             | 9             | 8             | 8             |
|                      |               |               |               |               |
| Activity Effect      | Mean -20.637  | -2.101        | 153.325       | 50.766        |
|                      | SD 105.406    | 57.525        | 219.939       | 74.475        |
|                      |               |               |               |               |
| Productivity Effect  | Mean -1.537   | 3.600         | -63.205       | -49.333       |
|                      | SD 83.862     | 64.066        | 302.090       | 71.994        |
|                      |               |               |               |               |
| Technical Efficiency | Mean 3.004    | 18.110        | 30.791        | -10.537       |
|                      | SD 69.058     | 49.756        | 50.442        | 64.690        |
|                      | Allocative Efficiency Effect | Mean 12.949 | 38.159 | 32.490 | 28.452 |
|                      | SD 39.585     | 105.861       | 89.880        | 87.296        |
|                      | Technical Change Effect | Mean -17.490 | -52.669 | -126.486 | -67.247 |
|                      | SD 29.315     | 100.659       | 250.915       | 69.775        |
|                      | Individual Price Effect |               |               |               |               |
| Labor                | Mean 21.758   | 76.902        | -10.248       | 73.223        |
|                      | SD 43.139     | 98.881        | 44.097        | 104.660       |
| Energy               | Mean 0.249    | -42.245       | -2.774        | 142.785       |
|                      | SD 12.688     | 41.876        | 28.480        | 158.448       |
| Material             | Mean 0.032    | 0.020         | -0.004        | -0.006        |
|                      | SD 0.031      | 0.020         | 0.004         | 0.006         |
In a nutshell, short-run cost changes varied substantially across railroads. In any given years, if the price and quantity effects offset each other, then the capital effect became the sole determinant of cost changes. Typically, the price effect raised costs except for 1998–1999, when the cost of labor fell. This means that variable input prices were increasing. In fact, changes in labor costs accounted for most of the price effect. The railroad industry has experienced significant technical progress over time. The negative productivity effect suggests that improved railroad productivity helped reduce costs. The quantity effect reduced costs, except for these periods, when the activity effect outweighed the productivity effect. The positive activity effect tells us that railroads naturally incurred higher costs as a result of increased output.

5.5 Cross-sectional Cost Change Decomposition: Low-cost and Cost-efficient Benchmarking Exercise

The beauty of the Grifell-Lovell model [51] is that it not only allows us to conduct an intertemporal decomposition, it also enables us to implement a benchmarking exercise in a cross-sectional manner. Firms often are not only interested in learning from their lessons in the past. It is in the firm’s manager’s interest to compare itself against an industrial benchmark so as to improve the firm’s performance and to adjust the firms’ strategy.

Suppose there are \( i = 1, \ldots, I \) firms as before, but now we consider just a single time period. The time subscript is hence omitted. Grifell-Tatjé and Lovell call the cross-sectional cost change a “cost gap” or “cost variance”. Thus, the following decomposition is called a short-run cost gap decomposition. The main purpose of such a decomposition is to decompose the short-run cost difference of a firm, \( TC_\zeta \), where \( \zeta \in I \) as before, and a benchmark firm, \( TC^* \). Grifell-Tatjé and Lovell suggest two possibilities for selecting a benchmark (“role model”) firm. The first one being the firm that has the lowest cost per unit of output (average cost) in the sample. They call this a “low-cost benchmark”. The second possibility is to select the benchmark that is cost-efficient, and thus is located on the cost frontier. They call this
the “cost-efficient benchmark”. In this section, $\zeta$ is the benchmarking (“challenger”) firm and is associated with period $t$, and the benchmark firm “*” is associated with period $t+1$ in the intertemporal model and in Figures 5.2 and 5.3. Since we are only conducting a within-period decomposition, there is but one short-run cost frontier. It makes sense that the technical change effect is, therefore, absent in the cross-sectional model. 

Note that the benchmarking firm has observed short-run cost $W^\zeta_v X^\zeta_v + W^\zeta_f X^\zeta_f \geq TC(Y^\zeta, X^\zeta_f, W^\zeta_v)$, and the low-cost benchmark has observed short-run cost $W^*_v X^*_v + W^*_f X^*_f \geq TC(Y^*, X^*_f, W^*_v)$. The low-cost benchmark need not be cost-efficient. However, it is possible that the low-cost benchmark is also cost-efficient, or vice versa.

Based upon the intertemporal model, we can construct a cross-sectional decomposition in the following way. The cost gap is defined as:

$$TC^\zeta - TC^* = (W^\zeta_v X^\zeta_v - W^*_v X^*_v) + (W^\zeta_f X^\zeta_f - W^*_f X^*_f)$$

$$= \frac{1}{2} (X^\zeta_v + X^*_v)^T (W^\zeta_v - W^*_v) \quad \text{Price Effect}$$

$$+ \frac{1}{2} (W^*_v + W^\zeta_v)^T (X^\zeta_v - X^*_v) \quad \text{Quantity Effect}$$

$$+ \left\{ \frac{1}{2} (W^*_f + W^\zeta_f)^T (X^\zeta_f - X^*_f) + \right. $$

$$\left. \frac{1}{2} (X^*_f + X^\zeta_f)^T (W^\zeta_f - W^*_f) \right\} \quad \text{Capital Effect} \quad (5.19)$$

The price effect measures the contribution of the variable input price differences between the two firms to the cost gap.

The quantity effect measures the impact on the cost gap of differences in variable input use. The quantity effect can also be decomposed into an activity effect and a productivity effect. The activity effect is defined as:

$$\frac{1}{2} (W^\zeta_v + W^*_v)^T (X^A_v - X^B_v), \quad \text{Activity Effect} \quad (5.20)$$

which measures the contribution of the difference between the cost-efficient size of the two firms to the short-run cost gap. If the firm is cost-efficient, which implies that the benchmark
has $X^*_v = X^*_v = X^*_v$, then (5.20) becomes

$$\frac{1}{2} (W^\zeta_v + W^*_v)^T (X^A_v - X^*_v).$$

(5.21)

The productivity effect consists of a technical efficiency effect and an allocative efficiency effect. The technical efficiency effect is given by:

$$\frac{1}{2} (W^\zeta_v + W^*_v)^T [(X^\zeta_v - X^C_v) - (X^*_v - X^D_v)]. \quad \text{Technical Efficiency Effect} \quad (5.22)$$

The technical efficiency effect measures the contribution of the difference between the technical inefficiency of the two firms to the short-run cost gap. If the firm is cost-efficient, then (5.22) simplifies to

$$\frac{1}{2} (W^\zeta_v + W^*_v)^T [(X^\zeta_v - X^C_v)].$$

(5.23)

The allocative efficiency effect is simply:

$$\frac{1}{2} (W^\zeta_v + W^*_v)^T [(X^C_v - X^A_v) - (X^*_v - X^B_v)], \quad \text{Allocative Efficiency Effect} \quad (5.24)$$

which measures the contribution of the difference between the allocative inefficiency of the two firms to the short-run cost gap. Accordingly, if the firm is cost-efficient, then (5.24) simplifies to

$$\frac{1}{2} (W^\zeta_v + W^*_v)^T [(X^C_v - X^A_v)].$$

(5.25)

Finally, the capital effect measures the impact on the cost gap of differences in fixed input use. This within-period model requires both the observed data $(Y^\zeta_v, X^\zeta_v, W^\zeta_v)$ and $(Y^*_v, X^*_v, W^*_v)$, and the unobserved input quantity vectors $X^A_v, X^B_v, X^C_v$ and $X^D_v$. These unobserved input quantity vectors can be identified by solving a within-period version of the linear programming problems (5.14), (5.15), (5.16) and (5.17). We then substitute these solutions for the four effects to produce a cross-sectional short-run cost-gap decomposition.
5.6 Results: Cross-sectional Short-run Cost-Gap Decomposition

A benchmarking exercise can be conducted by implementing the cross-sectional decompositions of short-run cost. Recall that the technical change effect is absent since we are constructing a within-period decomposition. Hence, we only need to identify four unobserved input quantity vectors $X^A_v, X^B_v, X^C_v$ and $X^D_v$ by solving the four associated linear programming problems with the observed price and quantity data in Chapter 4. The values of these unobserved input quantity vectors are inserted into the cross-sectional decomposition equations as described in section 5.5.

Table 5.2 shows the cost efficiency scores of each railroad from 1995 to 2000. Railroads are considered cost-efficient if they achieve a cost efficiency score of 1. The unweighted average industry cost efficiency scores are below 0.6. Burlington Northern & Santa Fe (BNSF) was cost-efficient from 1996 to 2000. Union Pacific (UP) was cost-efficient in 1995 and 1996, but its cost efficiency score fell to 0.910 in 1997, and continued to drop below 0.8 thereafter. BNSF and UP are the two largest railroads in the industry. Grand Trunk Western (GTW), a subsidiary of Canadian National, was cost-inefficient prior to 2000. From 1995 to 1998, Consolidated Rail (Conrail) had the lowest cost efficiency scores among its peers and it was subsequently acquired.

Conrail was a result of the Regional Rail Reorganization (3-R) Act in 1973, tailored to remedy a transportation crisis in 17 midwestern and northeastern states following the bankruptcy of Penn Central. It began operations in 1976 by consolidating the bankrupt railroads in the Northeast. Subsequently, Conrail was required to offer jobs to all employees of its predecessor companies. The creation of Conrail did not resolve the financial turmoil of the rail industry. Conrail stock was acquired by Norfolk Southern (NS) and CSX in 1997. Interestingly, the efficiency scores for both NS and CSX began to fall after the two eastern railroads took over Conrail.

In this analysis, a cost-efficient benchmark and a low-cost benchmark is chosen for each year. In 1995, Burlington Northern (BN) was both the low-cost and cost-efficient railroad.
Table 5.2: DEA Benchmarking Exercise: Cost Efficiency Scores of Railroads

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</thead>
<tbody>
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<td>Atchison, Topeka &amp; Santa Fe</td>
<td>0.741</td>
<td>–</td>
<td>–</td>
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<td>–</td>
<td>–</td>
</tr>
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<td>Burlington Northern</td>
<td>1.000</td>
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<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Burlington Northern &amp; Santa Fe a</td>
<td>–</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>Consolidated Rail b</td>
<td>0.433</td>
<td>0.490</td>
<td>0.515</td>
<td>0.503</td>
<td>–</td>
<td>–</td>
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<tr>
<td>CSX</td>
<td>0.572</td>
<td>0.589</td>
<td>0.618</td>
<td>0.621</td>
<td>0.529</td>
<td>0.511</td>
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<td>Grand Trunk Western</td>
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<td>0.774</td>
<td>0.856</td>
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<td>0.538</td>
<td>0.483</td>
<td>0.491</td>
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<td>0.760</td>
<td>0.758</td>
<td>0.775</td>
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<td>–</td>
<td>–</td>
<td>–</td>
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<td>Union Pacific</td>
<td>1.000</td>
<td>1.000</td>
<td>0.910</td>
<td>0.767</td>
<td>0.776</td>
<td>0.770</td>
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<td>0.597</td>
<td>0.589</td>
<td>0.579</td>
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<tr>
<td>Weighted Industry Average d</td>
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<td>0.840</td>
<td>0.794</td>
<td>0.794</td>
<td>0.779</td>
</tr>
</tbody>
</table>

a The merger of the Burlington Northern (BN) and the Atchison, Topeka, and Santa Fe Railway Company (ATSF) occurred in 1995.

b During 1998, CSX and Norfolk Southern (NS) were approved to operate the routes and assets of Consolidated Rail.

c Southern Pacific Transportation (SP) merged into UP in late 1996.

d Scores weighted by individual railroads’ revenue ton miles divided by the average industry revenue ton miles.
Hence, only one benchmarking exercise was conducted for 1995 using BN as the low-cost and cost-efficient benchmark. After the merger of BN and Atchison, Topeka & Santa Fe (ATSF), BNSF (the merged firm) remained cost-efficient in 1996, but was not low-cost. On the other hand, Soo Line (SOO) was the low-cost firm (having the lowest average total cost) for that year but was not cost-efficient. Hence, for 1996, SOO was selected as the benchmark for the low-cost benchmarking exercise, and BNSF was selected as the benchmark for the cost-efficient benchmarking exercise. From 1997 through 2000, BNSF was both low-cost and cost-efficient. Hence, only one benchmarking exercise was conducted for each of these years, with BNSF selected as the low-cost and cost-efficient benchmark.

Thus, except in 1996, all low-cost railroads turned out to be cost-efficient in every year. Hence, only one benchmark was selected for the cost-efficient benchmarking exercise conducted for every year except 1996. The results of the low-cost benchmarking exercise for 1996 are reported in Table 5.3.

The material price effect had zero means and standard deviations in all years because the material price index used for each year was the same across all railroads. Hence, the price effect consists of only two components – the labor price component and the energy price component.

The cost difference was about $1.4 billion, but less than 5 percent of this gap can be attributed to the variable input price effect. This tells us that the benchmark railroad (SOO) was low-cost not only because it faced relatively low variable input prices. In fact, its labor price accounted for most of the price effect. The activity effect accounted for approximately 60 percent of the cost gap, suggesting that SOO was relatively small among the Class I railroads. The technical efficiency and allocative efficiency effects accounted for 10 percent of the cost gap. Since these two effects are under management’s control, this means that the benchmarking railroads can learn from the benchmark railroad when it comes to cost savings.

In 1996, SOO incurred a cost of $0.007 per revenue ton mile, less than the sample mean of $0.012 per revenue ton mile.

BNSF instead of UP, was chosen to be the benchmark for the cost-efficient benchmarking exercise for 1996 because BNSF had lower average total cost compared to UP.
Table 5.3: Short-run Cost Gap Decomposition Using the Low-cost Benchmark

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<td></td>
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<td>Price Effect</td>
<td>Mean</td>
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<td>Activity Effect</td>
<td>Mean</td>
</tr>
<tr>
<td></td>
<td>SD</td>
</tr>
<tr>
<td>Technical Efficiency</td>
<td>Mean</td>
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<tr>
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<td>SD</td>
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<tr>
<td>Allocative Efficiency</td>
<td>Mean</td>
</tr>
<tr>
<td></td>
<td>SD</td>
</tr>
<tr>
<td>Individual Price Effect</td>
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<tr>
<td></td>
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</tbody>
</table>

* Low-cost benchmark: SOO Line
Approximately 25 percent of the cost gap can be attributed to the capital effect. This implies that, on average, the benchmark railroad had lower capital expenditures compared to other firms in the industry.

Table 5.4 on the following page displays the results of the cost-efficient benchmarking exercise. The large and negative mean cost gaps were mostly due to the fact that the benchmark railroads were large and so they produced more output. In fact, 80 percent of the cost gap in 2000 can be attributed to the activity effect. The large negative activity effect tells us that the benchmark railroads had relatively low short-run average total costs and were cost-efficient because they were larger than the benchmarking railroads and so they produced more output. This is also true from 1996 through 1999, during which time the activity effect accounted for more than 90 percent of the cost gap. This is no surprise at all given that BNSF is one of the two largest railroads in the U.S.

The price effect varied over time. The price variations across firms were large given that the standard deviations of the price effect were larger than the means. The negative price effect from 1997 through 1999 tells us that the cost-efficient benchmark railroad faced higher variable input prices; e.g. labor and energy prices. For example, from 1997 through 2000 the benchmark firm (BNSF) faced relatively high labor input prices. In 2000, although BNSF faced relatively low energy prices, less than 0.5 percent of the cost gap can be explained by the price effect. In general, the impact of the variable input price difference on the cost gap is rather minimal compared to the capital and quantity effects.

The negative capital effect implies that the benchmark railroads had higher capital expenditure. This is consistent with the large, negative activity effect and the fact that the benchmark railroad was indeed larger in terms of size and volume and production.

From 1995 through 2000, the technical efficiency and allocative efficiency effects are positive and larger than the price effect, implying that the benchmarking railroads were less efficient and therefore incurred higher costs.
Table 5.4: Short-run Cost Gap Decomposition Using the Low-cost and Cost-efficient Benchmark

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<td></td>
<td>$ mil</td>
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</tr>
<tr>
<td>SD</td>
<td>871.279</td>
<td>1028.185</td>
<td>1541.674</td>
<td>1534.111</td>
<td>1686.070</td>
<td>1973.784</td>
</tr>
<tr>
<td>SD</td>
<td>161.936</td>
<td>217.650</td>
<td>317.871</td>
<td>323.773</td>
<td>361.750</td>
<td>382.585</td>
</tr>
<tr>
<td>SD</td>
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<td>137.391</td>
<td>108.656</td>
<td>193.652</td>
<td>155.533</td>
<td>162.356</td>
</tr>
<tr>
<td>SD</td>
<td>733.750</td>
<td>846.671</td>
<td>1218.258</td>
<td>1215.289</td>
<td>1432.112</td>
<td>1649.610</td>
</tr>
<tr>
<td># of Railroads</td>
<td>11</td>
<td>10</td>
<td>9</td>
<td>9</td>
<td>8</td>
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Quantity Effect

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<tbody>
<tr>
<td>Activity Mean</td>
<td>-1213.543</td>
<td>-2213.063</td>
<td>-2165.282</td>
<td>-2351.977</td>
<td>-2230.628</td>
<td>-2404.348</td>
</tr>
<tr>
<td>SD</td>
<td>644.461</td>
<td>759.190</td>
<td>1084.854</td>
<td>938.609</td>
<td>1072.122</td>
<td>1223.344</td>
</tr>
<tr>
<td>TE Mean</td>
<td>74.425</td>
<td>75.063</td>
<td>82.887</td>
<td>108.034</td>
<td>129.164</td>
<td>133.016</td>
</tr>
<tr>
<td>SD</td>
<td>93.239</td>
<td>95.056</td>
<td>90.761</td>
<td>121.660</td>
<td>160.007</td>
<td>181.267</td>
</tr>
<tr>
<td>AE Mean</td>
<td>168.700</td>
<td>140.132</td>
<td>162.638</td>
<td>221.703</td>
<td>232.684</td>
<td>278.786</td>
</tr>
<tr>
<td>SD</td>
<td>211.207</td>
<td>169.474</td>
<td>173.071</td>
<td>217.183</td>
<td>288.226</td>
<td>369.366</td>
</tr>
</tbody>
</table>

Ind. Price Effect

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<tbody>
<tr>
<td>SD</td>
<td>99.455</td>
<td>128.370</td>
<td>104.640</td>
<td>178.086</td>
<td>147.928</td>
<td>190.721</td>
</tr>
<tr>
<td>SD</td>
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<td>30.178</td>
<td>31.685</td>
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<tr>
<td>Material Mean</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<td>0</td>
</tr>
</tbody>
</table>

\( ^a \) Low-cost and cost-efficient benchmark: Burlington Northern
\( ^b \) Cost-efficient benchmark: Burlington Northern Santa Fe
\( ^c \) Low-cost and cost efficient benchmark:Burlington Northern Santa Fe
We see that in the low-cost benchmarking exercise, the benchmark railroad was low-cost because it was small and also had lower capital expenditure. Only a small proportion of the cost gap can be attributed to differences in variable input prices. In the cost-efficient benchmarking exercise, the benchmarks were cost-efficient because they were large, produced more output, and had higher capital expenditure. Variable input prices did not play a significant role in explaining the cost gaps across railroads. In both exercises, the benchmarking railroads can learn from the low-cost and cost-efficient benchmarks when it comes to cost savings.

5.7 Conclusions

The intertemporal and cross-sectional short-run cost decompositions help us identify the sources of cost changes in the presence of fixed capital. Unlike the conventional economic approach to index number decomposition, this essay examines the relationship between cost changes and productivity changes by means of differences instead of ratios.

The results of the intertemporal decomposition indicate that variable input prices play an important role in short-run cost changes. A large proportion of the price effect can be attributed to changes in the price of labor. Energy prices did not contribute much to cost increases, except for the periods 1988–1989, 1989–1990 and 1999–2000. The railroad industry experienced significant technical progress over the time period of the analysis. The capital effect was a crucial factor in determining changes in cost, especially when the price and quantity effects offset each other. In any given period, the capital effect and the short-run cost changes moved in the same direction. This implies that an increase in capital expenditure would cause short-run costs to rise. Railroads with aging fixed rail capital are especially likely to incur higher costs in the short-run.

The cross-sectional decomposition shows the low-cost benchmark railroad faced relatively low variable input prices, but the benchmark was low-cost mostly because it used fewer inputs and produced less output. On the other hand, the cost-efficient benchmarks were
large and produced more output. This, however, does not necessarily mean that the cost-efficient benchmarks faced lower variable input prices. In both benchmarking exercises, the positive technical and allocative efficiency effects imply that the benchmarking firms were less efficient. Thus, the benchmarking railroads could learn from the benchmarks when it comes to cost savings.

We have, so far, examined the linkage between cost changes and productivity changes in the short run. In the intertemporal analysis, we observed the crucial role of capital in affecting the direction of cost changes, especially when the price and quantity effects offset each other. In the next chapter, we will explore the linkage between short-run profit change and changes in productivity, and re-examine the role of capital in that regard.
6.1 Introduction

*For years prior to railroad deregulation in 1980, the term “railroad profits” was an oxymoron. While rail profitability has improved since deregulation, railroad earnings are still not sufficient to cover all costs of rail operations - and railroads lag most other U.S. businesses with which they must compete for capital. — The Association of American Railroads [8]*

We have, so far, observed the linkage between productivity change and total cost change in the short run, and the role of the capital effect in determining the direction of total cost change. In this chapter, we will examine the linkage between productivity change and profit change in the short run. Thus, the objective of this chapter is to examine how short-run profit changes can be attributed to changes in productivity in the railroad industry, given that improvements in productivity do not necessarily imply increases in short-run profit. Although numerous studies have examined railroad productivity in recent decades, the existing economics literature has paid very little attention to the linkage between profit and productivity.

As we have seen in Chapters 2 and 3, railroad productivity studies are limited in numbers when it comes to connecting productivity to financial performance, and most of these studies were conducted on international railroads. Using an unbalanced panel of U.S. Class I railroads for the period 1986 - 2000, a short-run profit-change decomposition model is used in this chapter to attribute intertemporal short-run profit changes to its causal factors. The data
were obtained from the Analysis of Class I Railroads, and the details and variable definitions were described in Chapter 4.

The model is adapted from the original work of Grifell-Tatjé and Lovell [50], and is performed using sequential DEA. We modify the Grifell-Lovell model [50] by replacing long-run profit frontiers with short-run profit frontiers. By doing so, we are able to introduce a fixed input or capital effect into the three-stage decomposition model. The profit frontier is piecewise linear and nonparametric. Additionally, we use Bennet (1920) price and quantity indicators as opposed to the Fisher and Törnqvist indexes. Details of the construction of Bennet indicators are provided in Chapter 5 and Appendix B. Figure 6.1 displays the three-stage decomposition of short-run profit change.

In the first stage, short-run profit change is decomposed into two components. The first component contains a capital or fixed input effect, which identifies the impact on profit change of changes in capital expenditures. The second component consists of a price effect and a quantity effect. The price effect identifies the impact on profit change of changes in the output and variable input price in the short run. The quantity effect identifies the profit change of an expansion or contraction of railroad operations in the short run.

In the second stage, we decompose the quantity effect into a productivity effect and an activity effect. The productivity effect identifies the profit changes attributable to changes in railroad productivity. The activity effect identifies the profit changes attributable to changes in the sizes of production.

In the third stage, the productivity effect is decomposed into a technical change effect and an operating efficiency effect. The technical change effect reflects the increase in output quantity brought about by the improvement in technology. The operating efficiency effect measures the change in productive inefficiency between two time periods. Both the technical change and the operating efficiency effects directly affect the revenue side of profit change. All these effects are evaluated at Bennet price or quantity indicators.
We learn from this analysis that falling rail rates and rising input prices are the central ingredients of observed profit declines. The survival of railroads depends on their ability to overcome these two problems. The evidence suggests that improvements in productivity and increases in production have helped mitigate, if not eliminate, the downward pressure on profit. In other words, the success and sustainability of railroads rely upon their (internal) productivity and output growth instead of (external) changes in output and input prices.

This chapter consists of five sections. The next section provides the analytical framework of the model. In section 6.3 the three-stage decomposition model is discussed in details. The empirical results are presented in section 6.4. Section 6.5 provides a brief summary and conclusion.

6.2 The Analytical Framework

Suppose a firm uses N inputs to produce M outputs. Let $X = (X_1, X_2, \ldots, X_N) \geq 0$ represent the input quantity vector and $Y = (Y_1, Y_2, \ldots, Y_M) \geq 0$ represent the output quantity vector.
Let \( W = (W_1, W_2, \ldots, W_N) > 0 \) be the input price vector and \( P = (P_1, P_2, \ldots, P_M) > 0 \) be the output price vector.

In a long-run analysis, the production set is the set of output quantity vectors and input quantity vectors that is feasible, and is defined as

\[
S_L = \{(Y, X) : Y \text{ is producible with } X\}. \tag{6.1}
\]

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

\[
Q(X) = \{Y : (Y, X) \in S\}. \tag{6.2}
\]

An output set is assumed to be closed and convex, and to satisfy strong disposability of outputs.

The outer boundary of an output set is known as an output isoquant, defined by

\[
O(X) = \{Y : Y \in Q(X), \lambda Y \notin Q(X), \lambda > 1\}. \tag{6.3}
\]

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

The output distance function is defined as

\[
D_o(Y, X) = \min\{\delta : Y/\delta \in Q(X)\}. \tag{6.4}
\]

If \( Y \) belongs to production set \( Q(X) \), \( Y \in Q(X) \), then \( D_o(Y, X) \leq 1 \). If \( Y \) belongs to the output isoquant, then \( D_o(Y, X) = 1 \).

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

\[
L(Y) = \{X : (X \text{ can produce } Y)\}, \tag{6.5}
\]

which is assumed to be closed and convex, and to satisfy strong disposability of inputs.
The lower bound of the input set is the input isoquant given by

\[ I(Y) = \{ X : X \in L(Y), \lambda X \notin L(Y), \lambda < 1 \}. \]  

(6.6)

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

The input distance function is defined as

\[ D_i(Y, X) = \max \{ \theta : X/\theta \in L(Y) \}. \]  

(6.7)

If \( X \) belongs to the input set \( L(Y) \), then \( D_i(Y, X) \geq 1 \). If \( X \) belongs to the input isoquant \( I(Y) \), then \( D_i(Y, X) = 1 \).

In a short-run analysis, let input \( X = (X_v, X_f) \), where \( X_v \) represents a subvector of variable inputs and \( X_f \) is a subvector of fixed inputs. Let output be represented by \( Y \). \( W_v \) and \( W_f \) are the associated input prices for variable and fixed inputs, respectively, and are strictly positive. The output price vector \( P \) is strictly positive.

The production set is the set of output quantity vectors and variable input quantity vectors that is feasible given the fixed input quantity vector, and is defined as

\[ S_R = \{ (Y, X_v|X_f) : Y \text{ is producible with } X_v|X_f \}. \]  

(6.8)

The short-run output set is given by

\[ Q(X_v|X_f) = \{ Y : (Y, X_v|X_f) \in S_R \}. \]  

(6.9)

A short-run output set is assumed to be closed and convex, and to satisfy strong disposability of outputs.

The outer boundary of the producer's short-run output set is the short-run output isoquant defined as

\[ O(X_v|X_f) = \{ Y : Y \in Q(X_v|X_f), \lambda Y \notin Q(X_v|X_f), \lambda > 1 \}. \]  

(6.10)

An output quantity vector \( Y \) must be within its output set \( Q(X_v|X_f) \) but need not be located on its output isoquant \( O(X_v|X_f) \).
The short-run output distance function is defined as

$$D_o(Y, X_v|X_f) = \min \{\delta : Y/\delta \in Q(X_v|X_f)\}.$$  \hfill (6.11)

If $Y$ belongs to production set $Q(X_v|X_f)$, $Y \in Q(X_v|X_f)$, then $D_o(Y, X_v|X_f) \leq 1$. If $Y$ belongs to the output isoquant, then $D_o(Y, X_v|X_f) = 1$.

The short-run input set is defined as

$$L(Y|X_f) = \{X_v : (X_v \text{ can produce } Y|X_f)\},$$ \hfill (6.12)

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

The lower bound of the short-run input set is the short-run input isoquant given by

$$I(Y|X_f) = \{X_v : X_v \in L(Y|X_f), \lambda X_v \notin L(Y|X_f), \lambda < 1\}.$$ \hfill (6.13)

A variable input quantity vector $X_v$ must be within its input set $L(Y|X_f)$. However, it does not need to belong to its input isoquant $I(Y|X_f)$.

The short-run input distance function is

$$D_i(Y, X_v|X_f) = \max \{\theta : X_v/\theta \in L(Y|X_f)\}.$$ \hfill (6.14)

If $X_v$ belongs to the short-run input set $L(Y|X_f)$, then $D_i(Y, X_v|X_f) \geq 1$. If $X_v$ belongs to the short-run input isoquant $I(Y|X_f)$, then $D_i(Y, X_v|X_f) = 1$.

Finally, the short-run profit frontier is given by

$$\pi^t = P^t Y^t - W^t X^t$$

$$= P^t Y^t - W^t_v X_v^t(W, Y, X_f) - W^t_f X^t_f.$$ \hfill (6.15)

The profit frontier is increasing in $P$, decreasing in $W_v$ and convex in $(P, W_v)$. 
6.3 Three-Stage Profit-Change Decomposition

In the first stage of the profit-change decomposition, we totally differentiate (6.15) and rearrange terms to get

$$d\pi^t = Y^t dP^t + P^t dY^t - X^t_v dW^t_v - W^t_v dX^t_v - X^t_f dW^t_f - W^t_f dX^t_f$$

$$= -X^t_f dW^t_f - W^t_f dX^t_f \quad \text{Capital Effect}$$

$$+ Y^t dP^t - X^t_v dW^t_v \quad \text{Price Effect}$$

$$+ P^t dY^t - W^t_v dX^t_v \quad \text{Quantity Effect}$$

(6.16)

where the three major components of profit change at this stage are the capital effect, the price effect, and the quantity effect.

Using Bennet’s method [16], we can rewrite (6.16) in discrete time terms:

$$\pi^{t+1} - \pi^t = -\frac{1}{2} (X^t_f + X^{t+1}_f) (W^{t+1}_f - W^t_f) - \frac{1}{2} (W^t_f + W^{t+1}_f) (X^{t+1}_f - X^t_f)$$

$$\quad \text{Capital Effect}$$

$$+ \frac{1}{2} (Y^t + Y^{t+1}) (P^{t+1} - P^t) - \frac{1}{2} (X^t_v + X^{t+1}_v) (W^{t+1}_v - W^t_v)$$

$$\quad \text{Price Effect}$$

$$+ \frac{1}{2} (P^t + P^{t+1}) (Y^{t+1} - Y^t) - \frac{1}{2} (W^t_v + W^{t+1}_v) (X^{t+1}_v - X^t_v).$$

$$\quad \text{Quantity Effect}$$

(6.17)

The capital or fixed input effect consists of two parts – the fixed input price change evaluated at a Bennet fixed input quantity indicator and the fixed input quantity change evaluated at a Bennet fixed input price indicator. The capital effect identifies the impact on profit change of changes in the fixed input quantity, and of changes in fixed input prices. The capital component is important. We saw in Chapter 2 that, even years after passage of the Staggers Act in 1980, overcapitalization persisted in the railroad industry despite the legislative goal to free railroads from being tied to unprofitable routes and services. Thus,
by isolating the capital effect from the price and quantity effects, we can observe the role of capital in determining short-run profit change.

The price effect is the output price change evaluated at a Bennet output quantity indicator minus the variable input price change evaluated at a Bennet variable input quantity indicator. The price effect identifies the impact on profit change of changes in the output and variable input prices in the short run. If the change in variable input prices is greater (smaller) than the change in output prices, the price effect contributes negatively (positively) to profit change.

The quantity effect is the output quantity change evaluated at a Bennet output price indicator minus the variable input quantity change evaluated at a Bennet variable input price indicator. The quantity effect identifies the profit change of an expansion or contraction of railroad operations in the short run. If railroads expand their output proportionately more (less) than their input usage, then the quantity effect contributes positively (negatively) to profit change.

In the second stage, the quantity effect is decomposed into a productivity effect and an activity effect:

\[
QE = \frac{1}{2}(P^t + P^{t+1})^T(Y^B - Y^t) - \frac{1}{2}(P^t + P^{t+1})^T(Y^C - Y^{t+1}) + \frac{1}{2}(P^t + P^{t+1})^T(Y^C - Y^B) - \frac{1}{2}(W^t_v + W^{t+1}_v)(X^{t+1}_v - X^t_v).
\]

**Productivity Effect**

\[
+ \frac{1}{2}(P^t + P^{t+1})^T(Y^C - Y^B) - \frac{1}{2}(W^t_v + W^{t+1}_v)(X^{t+1}_v - X^t_v).
\]

**Activity Effect**

Figure 6.2 provides an illustration of the decomposition of the quantity effect in (6.18). The period \( t \) production set \( S^t_R \) is lower than the period \( t + 1 \) production set \( S^{t+1}_R \). The implicit assumption here is that technical progress has taken place between periods \( t \) and \( t + 1 \). This assumption, however, is not necessary for the analysis. The path from \((X^t_v, Y^t)\) to \((X^{t+1}_v, Y^{t+1})\) goes through \(Y^A\), \(Y^B\) and \(Y^C\).
The productivity effect compares the path from $Y^B$ to $Y^t$ in period $t$ with the path from $Y^C$ to $Y^{t+1}$ in period $t + 1$. In Figure 6.2, the productivity effect consists of three parts. The first part is the path from $Y^B$ to $Y^A$ in period $t$, which represents an expansion of the production set from $S^t_R$ to $S^{t+1}_R$, and the additional output that can be produced with no increase in variable input as a result of an improvement in technology. Technical progress (regress) contributes positively (negatively) to profit change. The second part of the productivity effect measures the path from $Y^A$ to $Y^t$ in period $t$. This path indicates a failure to produce maximum output in period $t$, and hence results in a profit reduction. The third part of the productivity effect is the path measured from $Y^C$ to $Y^{t+1}$ in period $t + 1$. This path indicates a failure to produce maximum output in period $t + 1$. If \((Y^A - Y^t) > (Y^C - Y^{t+1})\), then operating efficiency improves and results in a positive impact on profit change. If \((Y^A - Y^t) < (Y^C - Y^{t+1})\), then operating efficiency declines and results in a negative impact on profit change.

The activity effect is measured along the path from $Y^B$ to $Y^C$, and indicates the change in output from $Y^B$ to $Y^C$ as a result of the change in variable input use from $X^t_v$ to $X^{t+1}_v$, reflecting the impact on profit change of changes in the size of production. If output rises proportionately more than does the use of variable inputs, then the activity effect contributes positively to profit change in the short run. As mentioned in Chapter 5, the activity effect is not equal to a returns-to-scale measure even though it appears to be.

In the third stage, the productivity effect (PE) decomposes as

$$PE = \frac{1}{2}(P^t + P^{t+1})^T(Y^B - Y^A) \quad \text{Technical Change Effect}$$

$$- \left[\frac{1}{2}(P^t + P^{t+1})^T(Y^C - Y^{t+1}) - \frac{1}{2}(P^t + P^{t+1})^T(Y^A - Y^t)\right]. \quad \text{Operating Efficiency Effect}$$

(6.19)

The decomposition of the productivity effect is also illustrated in Figure 6.2. The productivity effect consists of two parts – a technical change effect and an operating efficiency effect. The technical change effect represents an increase in output quantity from $Y^A$ to $Y^B$ brought
Figure 6.2: The Decomposition of the Quantity Effect

The decomposition of profit change in the first stage uses observed data such as \((X^t, Y^t)\) and \((X^{t+1}, Y^{t+1})\). Hence, the capital effect, the price effect, and the quantity effect can be computed directly from the input and output data.

The implementation of the decompositions of the quantity effect and the productivity effect involves not just the observed quantity vectors, but the unobserved quantity vectors, \(Y^A, Y^B\) and \(Y^C\). Fortunately, since each of the unobserved quantity vectors is either a radial expansion or a radial contraction of an observed quantity vector, the unobserved quantity...
vectors can be recovered from the observed quantity vectors by means of distance functions. Using distance functions, the unobserved quantity vectors, $Y^A$, $Y^B$ and $Y^C$, can be obtained as follows:

$$Y^A = Y^t / D_o^t(X^t_v, Y^t | X^t_f), \quad (6.20)$$

$$Y^B = Y^t / D_{o+1}^t(X^t_v, Y^t | X^t_f), \quad (6.21)$$

$$Y^C = Y^{t+1} / D_{o+1}^{t+1}(X_v^{t+1}, Y^{t+1} | X_f^{t+1}). \quad (6.22)$$

The distance functions in (6.20), (6.21) and (6.22) can be computed using Data Envelopment Analysis (DEA). Sequential DEA, as opposed to conventional DEA, is used to improve the robustness of the results since the number of railroads is small and declining over the sample period.

Suppose we have $t$ time periods and that in time period $s$ we have $I_s$ railroads, $s = 1, \ldots, t$. Grifell-Tatjé and Lovell consider a multiple output case. In this analysis, we assume that railroads produce only one output, hence $M = 1$.

Let $Y^\zeta_t$ and $X^\zeta_t$ be the $M \times 1$ output quantity vector and the $N \times 1$ input quantity vector of railroad $\zeta$ in period $t$ respectively. Also, let $Y^\zeta_s$ be the sequential $M \times s$ matrix of $M$ outputs produced and $X^\zeta_s$ be the $N \times s$ matrix of $N$ inputs used by railroads in each of periods $s = 1, \ldots, t$.

Let $Y^s = \{Y^{1s}, \ldots, Y^{\zeta s}, \ldots, Y^{Is}\}$ be an $M \times \sum_{s=1}^t I_s$ matrix of $M$ outputs produced by all $I_s$ railroads in each of periods $s = 1, \ldots, t$. Let $X^s = \{X^{1s}, \ldots, X^{\zeta s}, \ldots, X^{Is}\}$ be an $N \times \sum_{s=1}^t I_s$ matrix of $N$ inputs used by $I_s$ railroads in each of periods $s = 1, \ldots, t$. The matrices $Y^s$ and $X^s$ include output and input quantity data for all railroads represented in periods 1 through $t$. Hence, the matrices are sequential.

1Details of sequential DEA are available in Chapter 5.
2Because of their multiple output setting, Grifell-Tatjé and Lovell further decomposed the activity effect into a scale effect, a resource mix effect and a product mix effect. But since we are only dealing with a single rail output, no similar decomposition is possible for the activity effect.
Now we are ready to recover the unobserved quantity vectors \((Y^A, Y^B, Y^C)\) for each railroad by solving each of the following sequential DEA linear programming problems. Note that each linear programming problem is solved \(I_t\) times, once for each railroad in the sample in period \(t\). A value \(\theta\) is then obtained for each railroad in period \(t\).

The unobserved quantity vector \(Y^\zeta A\) can be recovered by solving the following linear programming problem:

\[
[D_o^t(Y^\zeta t, X_v^\zeta t|X_f^\zeta t)]^{-1} = \max \theta^A
\]

subject to

\[
\theta^A Y^\zeta t \leq Y^s \lambda^s,
\]

\[
X_v^s \lambda^s \leq X_v^\zeta t,
\]

\[
\lambda^s \geq 0,
\]

\[
\sum_i \lambda^{is} = 1, \quad i = 1, \ldots, \sum_{s=1}^t I_s,
\]

(6.23)

where \(\lambda^s\) is a \(\sum_{s=1}^t I_s \times 1\) activity vector. From (6.20), we know \(Y^\zeta A = \theta^A Y^\zeta t\). Thus, \(Y^\zeta A\) is recovered.

The unobserved quantity vector \(Y^\zeta B\) can be recovered by solving the following linear programming problem:

\[
[D_o^{t+1}(Y^\zeta t, X_v^\zeta t|X_f^\zeta t)]^{-1} = \max \theta^B
\]

subject to

\[
\theta^B Y^\zeta t \leq Y^{s+1} \lambda^{s+1},
\]

\[
X_v^{s+1} \lambda^{s+1} \leq X_v^\zeta t,
\]

\[
\lambda^{s+1} \geq 0,
\]

\[
\sum_i \lambda^{is+1} = 1, \quad i = 1, \ldots, \sum_{s=1}^t I_{s+1},
\]

(6.24)

where \(\lambda^{s+1}\) is a \(\sum_{s=1}^t I_{s+1} \times 1\) activity vector. From (6.21), we know \(Y^\zeta B = \theta^B Y^\zeta t\). Thus, \(Y^\zeta B\) is recovered.
The unobserved quantity vector $Y^{\zeta C}$ can be recovered by solving the following linear programming problem:

\[
[D_{t+1}^{t+1}(Y^{\zeta t+1}, X_{s}^{t+1}, X_{f}^{t+1})]^{-1} = \max \theta^{C}
\]

subject to \( \theta^{C} Y^{\zeta t+1} \leq Y^{t+1} \lambda^{s+1} \),

\( X_{s}^{t+1} \lambda^{s+1} \leq X_{s}^{\zeta t+1} \),

\( \lambda^{s+1} \geq 0 \),

\( \sum_{i} \lambda^{is+1} = 1 \), \( i = 1, \ldots, \sum_{s=1}^{t} I_{s+1} \), \( (6.25) \)

where \( \lambda^{s+1} \) is a \( \sum_{s=1}^{t} I_{s+1} \times 1 \) activity vector. From (6.22), we know \( Y^{\zeta C} = \theta^{C} Y^{\zeta t+1} \). Thus, \( Y^{\zeta C} \) is recovered.

After recovering the unobserved quantity vectors for each railroad in each time period, we substitute these vectors into (6.18) and (6.19) for the implementation of the three-stage profit change decomposition.

### 6.4 Results

The three linear programming problems in equations (6.23) through (6.25) are solved in order to obtain the three unobserved quantity vectors $Y^A, Y^B$ and $Y^C$. The values of these vectors are inserted into the intertemporal short-run profit decompositions (6.18) and (6.19). By doing so, we are able to implement the decompositions for each railroad. The results are displayed in Table 6.1.

We observe that railroad profit changes from year to year. Railroads managed to achieve positive annual profit gains (on average) before 1991. Profit changes became volatile after 1996, when railroads making profit in one year often experienced negative profit in the next. There are huge variations in profit change across railroads. For example, in the 1995-1996 period, the mean profit change was -$9 million but the standard deviation was over $200 million. Similarly, in the 1999-2000 period, the mean profit change was -$1.6 million but the standard deviation was nearly $240 million.
Table 6.1: The Short-run Profit Change Decomposition

<table>
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<tr>
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<td>Quantity Effect</td>
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Quantity Effect

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Productivity Effect

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</tr>
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<tr>
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</tr>
<tr>
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<td>-27.353</td>
<td>86.232</td>
<td>77.444</td>
</tr>
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<td></td>
<td>SD</td>
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<td>177.723</td>
<td>197.960</td>
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<td>Technical</td>
<td>Mean</td>
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<td>52.158</td>
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<td>Change Effect</td>
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<td>54.772</td>
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<td>Operating</td>
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<td>-79.510</td>
<td>-14.482</td>
<td>32.986</td>
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<td>Efficiency Effect</td>
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<td>159.717</td>
<td>111.234</td>
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The influence of the capital effect on profit change exhibits no systematic pattern. In the 1994-1995 period, the capital effect contributed negatively to profit change. But since both the price and quantity effects were positive and relatively larger than the capital effect, the negative impact of capital on profit change appeared to be less obvious. In the 1995-1996 period, the capital effect contributed positively to profit change. However, since the magnitude of the negative price effect was larger than that of both the capital and quantity
effects combined, a decline in profit occurred. From the 1996-1997 period to the 1999-2000 period, the capital effect contributed negatively to railroad profit. This may be due to high capital depreciation during these periods of time. Because the capital effect was small relative to the price and quantity effects most of the time, the impact of the capital effect appeared to be minimal.

The price effect was negative in almost every time period except 1994-1995 and 1996-1997. This tells us that the price effect contributed negatively to profit change most of the time. The impact of the negative price effect was large. In the 1990-1991 period, the $67 million negative price effect was the main source of negative profit change. In the 1997-1998 period, the negative profit change was a result of the large negative price effect (-$105 million) that outweighed the positive quantity effect ($60 million). This should not be a surprise since rail rates had been declining and rail labor wages had been on the rise in both real and nominal terms. The price effect can be decomposed into an output price effect and a variable input price effect in order to identify the source of downward pressure on the price effect. The decomposition of the price effect is shown in Figure 6.3.

Clearly, Figure 6.3 shows that the output price effect was negative in almost every time period. This implies that rail rates had hardly increased. Similarly, the variable input price effect was negative in almost every time period, indicating that rising input prices were also the primary factor behind the negative price effect.

When the magnitude of the negative price effect was greater than the positive quantity effect, profit change was negative because the capital effect was relatively small. Fortunately, in most cases, the negative price effect was outweighed by the large positive quantity effect, resulting in positive profit change to the railroads. Since output and variable input prices were beyond firms’ control, the quantity effect became very critical. While the price effect was putting downward pressure on profit, the quantity effect was pushing profit up.

What were the key factors determining the strong positive quantity effect? Recall that the quantity effect is decomposed into an activity effect and a productivity effect. The activity
effect contributed positively to the profit change in all time periods except 1997-1998 and 1998-1999, implying that railroads had increased their production over time. The large standard deviations of the activity effect means that the scale of production varied greatly across railroads. As shown in Chapter 4, the amount of output produced and inputs used varied greatly across railroads. This is consistent with the fact that the size of railroads in the sample varied tremendously despite the fact that they were all classified as Class I.

The productivity effect contributed positively to profit change in all time periods except the late 1980s and early 1990s. The large standard deviations in the productivity effect reflect the large variations of productivity across railroads. The productivity effect is decomposed into a technical change effect and an operating efficiency effect.

Technical change was large and positive in almost all time periods, implying that the U.S. railroad industry had experienced significant technical progress. The improvement in tech-
technology contributes positively to profit change. In the 1993–1994 period, the technical change effect ($101 million) accounted for 67 percent of the positive profit change ($150 million). Even though the operating efficiency effect was negative (-$14 million), it is negligible when compared with the technical change effect. Hence, the productivity effect remained positive because the positive technical change effect outweighed overwhelmingly the negative operating efficiency effect for that period of time.

The operating efficiency effect was smaller (in terms of magnitude) than the technical change effect in most time periods, and was negative in some cases. The negative operating efficiency effect represents a failure of the railroads to improve their performance over time. In the 1992–1993 period, operating inefficiency caused the productivity effect to be negative because the positive technical change effect was not large enough to offset the negative operating efficiency effect (-$80 million). However, in the 1996–1997 period, railroads experienced technical regress, but the positive operating efficiency effect was larger and therefore able to overcome this problem.

Although railroad profit had been on the rise from 1986 through 2000, year-to-year profit changes show that railroad profits were volatile. The primary source of the year-to-year negative profit change was the negative price effect. Rail rates did not increase (fast) enough to offset rising input costs such as the price of labor. Because of the large scale of production and improvements in technology, which in turn caused the quantity effect to be large and positive, railroads were able to experience positive profit gains amid rising input prices.

6.5 Conclusions

The U.S. railroad industry has experienced a shrinking market share, rising production cost and falling rail rates in recent decades. After years of financial distress, changes in the regulatory environment, and industrial restructuring, the future survival of railroads relies heavily upon their prospects for continued productivity growth.
A three-stage profit-change decomposition model is used to analyze the sources of year-to-year profit change in the U.S. railroad industry. We modify the original Grifell-Tatjé and Lovell model [50] by adding a capital effect and by using Bennet price and quantity indicators. Our findings suggest that the railroad industry as a whole can strengthen its financial health primary by increasing productivity and reducing operating inefficiency.

We find that year-to-year profit changes became volatile after 1996. Railroads making a profit in one period experienced a loss in the next. Variations in profit and output were also large across railroads because of the variation in railroad size, despite the fact that the railroads in our sample were all classified as Class I. Operating inefficiency contributed negatively to profit change, but its impact was reduced by substantial technological progress. Interestingly, the capital effect appeared to play a minimal role in determining profit change in the short run. This suggests that, in the short run, fixed inputs have a smaller impact on railroad financial performance if we consider the profit (which includes total revenue) side of production instead of just the cost side.

We learn from this analysis that falling rail rates and rising input prices are the driving forces behind the negative profit change we observed. Railroads need to overcome these forces in order to survive. The evidence suggests that improvements in productivity and increases in production mitigate, but do not eliminate, the downward pressure on profit. In other words, the success and sustainability of railroads rely upon increases in (internal) productivity and output instead of (external) changes in demand and input prices.
Since passage of the Staggers Act, railroads have increased their level of production and experienced significant productivity and financial improvements. In spite of that, railroad profit increased at a much slower rate compared to productivity change. Productivity studies of railroads in the past are limited when it comes to explaining the linkage between productivity growth and changes in financial performance.

In this study, such a linkage is examined thoroughly using a short-run total cost change decomposition model and a short-run profit change decomposition model. Short-run analyses are both important and relevant for the railroad industry, because previous research had shown that overcapitalization was a key factor that led to non-optimal railroad operations. I modified the Grifell-Lovell three-stage decomposition models ([50] & [51]) by replacing long-run profit and total cost frontiers with short-run profit and total cost frontiers. By doing so, I was able to capture the impacts of physical capital, as well as the impacts of variable prices and quantities, on firms’ profit and total cost changes in the short run.

The short-run total cost change decomposition model consists of an intertemporal analysis and a cross-sectional analysis. The intertemporal analysis enables us to observe year-to-year total cost changes, while the cross-sectional analysis allows us to conduct a benchmarking exercise across railroads. These decompositions involve the use of Bennet price and quantity indicators as opposed to other price and quantity indexes in the literature, because the Bennet indicators satisfy nineteen tests, whereas the Laspeyres and Paasche indexes do not satisfy the circularity test and also fail the country or time reversal test. The Fisher Index is
also intransitive, and the Törnqvist index fails both the circularity test and the monotonicity test.

Additionally, a sequential Data Envelopment Analysis (DEA) technique was used to improve the robustness of the results since the number of railroads over the sample period is small and declining. The advantage of using sequential DEA is that it allows the current period technology to be constructed from input and output quantity data for all railroads represented in all periods prior to and including the current period. Thus, technologies once used are not forgotten, and remain available for adoption [50].

In the intertemporal total cost change decomposition analysis, short-run total cost change varied across railroads. In any given year, if the variable price and quantity effects offset each other, then the capital effect became the sole determinant of cost changes. As a result, if the capital effect was positive (negative), total cost change would be positive (negative). This means that railroads with high depreciation or capital expenditure would incur higher costs in the short run. We also observed that the price effect raised costs. Labor price accounted for most of the price effect, and energy price was volatile. The railroad industry had experienced significant technical progress over this time frame. The negative productivity effect suggests that improved railroad productivity helped to reduce costs. The quantity effect also reduced cost, except for some periods during which the (positive) activity effect outweighed the (negative) productivity effect. The positive activity effect tells us that railroads incurred higher costs as a result of increased output.

In the cross-sectional analysis, Soo Line was selected as the low-cost railroad for the low-cost benchmarking exercise because it had the lowest average total costs among all firms. On the other hand, BNSF (or BN before 1996) was chosen as the cost-efficient railroad for the cost-efficient benchmarking exercise. The cross-sectional decomposition shows that the low-cost benchmark railroad faced relatively low variable input prices, but the benchmark railroad was low-cost mostly because of its relatively small size of production. The benchmarks BN and BNSF were cost-efficient because they were large and therefore produced more output.
This does not necessarily mean that the cost-efficient benchmarks faced lower variable input prices. In both low-cost and cost-efficient benchmarking exercises, the positive technical and allocative efficiency effects imply that the benchmarking firms were less efficient. Since these effects were also larger than the price effect in both exercises, the benchmarking railroads could learn from the benchmarks when it comes to cost savings.

The results from the short-run profit change decomposition analysis show that railroads managed to achieve positive profit gains (on average) before 1991. However, annual profit changes became volatile after 1996, when railroads making a positive profit in one time period often experienced negative profit in the next. There are huge variations in profit change across railroads. The primary source of year-to-year negative profit change was the negative price effect – rail rates had been falling, and input prices continued to increase. Because of the increasingly large size of production and improvements in technology, which in turn caused the quantity effect to be large and positive, railroads were able to experience positive profit gains amid rising input prices. The capital effect appeared to have much lower impact on profit change. Thus, the price and quantity effects accounted for most of the changes in profit in the short run.

Railroads typically do not have control over variable input prices (e.g. labor and energy) and output prices (rail rates). Hence, railroads act as price takers in both input and output markets. Unfortunately, falling rail rates and rising input prices are the driving forces behind negative profit changes. Railroads need to overcome these forces in order to survive. The evidence suggests that improvements in productivity and increases in production help mitigate, if not eliminate, the downward pressure on profits. In other words, the past successes and future sustainability of railroads rely upon their (internal) productivity and production growth instead of (external) changes in demand and input prices.

The decomposition models in this study were capable of attributing firms’ financial performance to different factors, but I did not directly examine the possible role of market competition. Specifically, how were railroads’ performance affected by intermodal and intramodal
competition. Thus, further empirical work is needed to identify the sources of competition and their subsequent impacts on the industry. Additionally, capital-prices measurements in this study can be improved if more financial data becomes available. In spite of that, the overall results from these analyses remain valid since the second and third stages of the decompositions involve only the price and quantity measures for the variable inputs.


[60] Laspeyres, E., 1871, “Die Berechnung einer mittleren Waarenpreissteigerung,” 
*Jahrbucher fur Nationalokonomie und Statistik* 16, 296–314.


Appendix A

Supplemental Data Information

In 1986, consolidations of the Class I railroads (on the right of the following table) led to joint financial reporting under three corporate names:

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<tr>
<th>Name</th>
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<td>CSX Transportation:</td>
<td>Baltimore &amp; Ohio Railroad (BO),</td>
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<tr>
<td></td>
<td>Chesapeake &amp; Ohio Railway (CO), and</td>
</tr>
<tr>
<td></td>
<td>Seaboard System Railroad, Inc. (SBD)</td>
</tr>
<tr>
<td>Norfolk Southern Corp.:</td>
<td>Southern System (SRS), and</td>
</tr>
<tr>
<td></td>
<td>Norfolk Western Railroad (NW)</td>
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<tr>
<td>Union Pacific Railroad:</td>
<td>Union Pacific Railroad (UP),</td>
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<tr>
<td></td>
<td>Western Pacific Railroad (WP), and</td>
</tr>
<tr>
<td></td>
<td>Missouri Pacific Railroad (MP)</td>
</tr>
</tbody>
</table>

In 1987, some data for Boston and Maine Corporation (BM) and the Delaware and Hudson Railway Company (DH) were not available. In 1988, the financial and statistical data for BM were excluded from the Analysis because of its failure to meet the Class I annual revenue threshold for three consecutive years. Beginning January 1, 1989, BM was re-classified to Class II status by the ICC. Hence, both BM and DH were completely excluded from our analysis.

The 1988 data for Missouri-Kansas-Texas Railroad (MKT) are only for its operation from January to July, because MKT was purchased by the Missouri Pacific Railroad (MP) in August 1988, which was part of Union Pacific (UP). Thus MP’s financial and statistical data
for 1988, which included MKT’s operating and financial data since August, were included in the combined 1988 UP financial data.

Due to merger, Southern Pacific Transportation Company (SP) and St. Louis Southwestern Railroad (SLSW) filed their financial reports to the ICC on a combined basis for 1990. In 1994, SP and Denver & Rio Grande Western Railroad Company (DRGW) merged and were identified as SP.

In 1995, as a result of the late-April UP purchase of the Chicago and North Western Railroad Company (CNW), there was no CNW Annual R-1 Report filed with the ICC. Hence, the 1995 UP data also contain financial data for CNW from May 1, 1995.

The Atchison, Topeka, and Santa Fe Railway Company (ATSF) and Burlington Northern Railroad Company (BN) merged during 1995 into the Burlington Northern Santa Fe Railroad (BNSF). The two railroads reported separately for 1995.

On September 11, 1996, Southern Pacific Transportation Company (SP) merged with Union Pacific (UP). For 1996, the two railroads filed their financial reports to the STB separately. For 1997, their annual financial and accounting data were combined.

During 1998, Canadian National Railways (CN) sought authority to acquire control of Illinois Central (IC). The transaction was approved in May 1999. IC continued to report to the STB as a separate corporate entity for the full year 1999.

In the same year, CSX Corporation (CSX) and Norfolk Southern Corporation (NS) received approval to operate the routes and assets of Consolidated Rail Corporation (Conrail). However, Conrail continued to operate separately throughout 1998 and for the first 5 months of 1999. CSX and NS began operating their respective portions of Conrail on June 1, 1999. Conrail filed a complete annual report for the period of January 1, 1999 through May 31, 1999. Thus, Conrail was excluded from the 1999 data in our analysis. Reports for the final seven months of 1999 for the portion of Conrail operated by CSX and NS were included in the CSX and NS data.
A nice feature of the Bennet indicators of price and volume change is their additive over commodities property which gives them a big advantage over the superlative indicators of price and volume change, which are inherently nonadditive over commodities.” — W.E. Diewert, [36]

The Bennet price and quantity indicators are based on the celebrated work of T. L. Bennet [16] published in the Journal of Royal Statistical Society in 1920. Bennet observed that a change in expenditure can be induced by two factors: changes in the cost of living and changes in the standard of living.

In a short period, the rate of increase of household expenditure can be divided into parts $x$ and $l$, where $x$ measures the increase caused by price changes and $l$ measures the increase caused by increases in consumption. Thus, part $x$ is the sum of all quantities of goods consumed multiplied by their respective price increases, and part $l$ is the sum of prices of all goods multiplied by the respective increases in consumption.

Suppose that the change in expenditure in a finite period is divided into two corresponding parts $X$ and $L$, where $X$ is derived by taking each infinitesimal increase of price of each good, multiplying by the consumption, and adding up for all goods for the entire period. Part $L$ is obtained from multiplying infinitesimal changes of consumption and adding up for all goods for the entire period. Thus $X$ is the aggregate of all the increases in cost of living, and $L$ is the aggregate of all the increases in satisfaction from consumption. Figure B.1 displays changes in consumption and price for some goods. Prices ($P$) and consumption ($Q$) are inversely related.
Let $A$ represent the consumption bundle at time 0 and $B$ the consumption bundle at time 1. Thus, the movement from $A$ to $B$ represents variations in both price and consumption. The increase in the cost of living or part $X$ is represented by the area $ABFE$, while the change in the cost of an increase in the standard of living or part $L$ is represented by the area $ABDC$.

An increase in expenditure is measured by

$$\sum \varepsilon_1 - \sum \varepsilon_0 = \sum P_1 Q_1 - \sum P_0 Q_0.$$  \hspace{1cm} (B.1)

Based on (B.1), the aggregate of the increases in the cost of living can be computed as

$$X = \sum \frac{1}{2} (Q_1 + Q_0)(P_1 - P_0)$$
$$= \frac{1}{2} \sum (\varepsilon_1 - \varepsilon_0) + \frac{1}{2} \sum (P_1 Q_0 - P_0 Q_1).$$  \hspace{1cm} (B.2)
and the aggregate of cost of increases in standard of living can be defined as

\[
L = \sum \frac{1}{2} (Q_1 - Q_0)(P_1 + P_0) \\
= \frac{1}{2} \sum (\varepsilon_1 - \varepsilon_0) - \frac{1}{2} \sum (P_1 Q_0 - P_0 Q_1).
\]

As shown in figure B.1, the price indicator is a linear approximation to the area ABFE under the inverse demand curve, and the quantity indicator is a linear approximation to the area ABDC under the demand curve. Part X is known as the Bennet price indicator \((P_{\text{Bennet}})\), and part \(L\) is the Bennet quantity indicator \((Q_{\text{Bennet}})\).

Diewert [36] derives the Bennet price and quantity indicators in terms of the arithmetic average of the Paasche [73] and Laspeyres [60] indicators. Recall that the Paasche quantity indicator is defined as

\[
Q_{\text{Paasche}} = \sum P_1 (Q_1 - Q_0),
\]

and the Paasche price indicator is defined as

\[
P_{\text{Paasche}} = \sum Q_1 (P_1 - P_0).
\]

The Laspeyres quantity indicator, on the other hand is defined as

\[
Q_{\text{Laspeyres}} = \sum P_0 (Q_1 - Q_0),
\]

and the Laspeyres price indicator is defined as

\[
P_{\text{Laspeyres}} = \sum Q_0 (P_1 - P_0).
\]

Diewert showed that the Bennet price indicator can be redefined as

\[
P_{\text{Bennet}} = \frac{1}{2} \sum P_{\text{Laspeyres}} + \frac{1}{2} \sum P_{\text{Paasche}},
\]

and the Bennet quantity indicator can also be derived as

\[
Q_{\text{Bennet}} = \frac{1}{2} \sum Q_{\text{Laspeyres}} + \frac{1}{2} \sum Q_{\text{Paasche}}.
\]

He also showed that the Bennet quantity and price indicators satisfy a series of nineteen tests:
• Continuity Test
• Identity Test for Prices
• Identity Test for Quantity
• Bounding Test
• Monotonicity in Period 1 Prices
• Monotonicity in Period 0 Prices
• Monotonicity in Period 1 Quantities
• Monotonicity in Period 0 Quantities
• Positivity of Price Change if the Period 1 Price Exceeds the Period 0 Price
• Negativity of Price Change if the Period 0 Price Exceeds the Period 1 Price
• Positivity of Quantity Change if the Period 1 Quantity Exceeds the Period 0 Quantity
• Negativity of Quantity Change if the Period 0 Quantity Exceeds the Period 1 Quantity
• Invariance to Changes in the Units of Measurement
• Linear Homogeneity in Prices
• Linear Homogeneity in Quantities
• Symmetry Test: Time Reversal
• Quantity Weights Symmetry
• Price Weights Symmetry
• Factor Reversal Test

These properties are the difference analogues of the properties that a Fisher Ideal Index satisfies. Hence, Bennet indicators are preferred to other indexes.