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RAILROAD COMMON COSTS AND FACILITY ABANDONMENTS

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Theodore Robert Bolema

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Ph.D. degree in Economics

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Major professor

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RAILROAD COMMON COSTS AND FACILITY ABANDONMENTS

By

Theodore Robert Bolema

A DISSERTATION

Submitted to
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in partial fulfillment of the requirements
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ABSTRACT

RAILROAD COMMON COSTS AND FACILITY ABANDONMENTS

By

Theodore Robert Bolema

Allocating railroad common costs to specific traffic flows is an old problem in the economics literature. Recently, economists and the Interstate Commerce Commission have given high priority to avoiding cross-subsidization of one set of shippers by another set of shippers when allocating these common costs. Under the current regulatory institutions, the problem of avoiding cross-subsidization can better be understood as a problem of finding a cost allocation which leads to the shipment of the most efficient traffic quantities over the most efficient transportation network configuration.

The existing economic literature on this problem generally assumes no abandonment of transportation facilities. This assumption may have been appropriate earlier in this century, when rail links were abandoned far less frequently. Under this assumption, the problem of recovering the common costs of maintaining and operating the rail network with no abandonment of track (except in the case of failing railroads) is basically the familiar natural monopoly cost recovery problem. However, assuming no facility abandonments is inappropriate today because of the large number of track miles which have been abandoned during the 1970s and 1980s.

When a cost allocation is found which encourages carriers and shippers to transport the most efficient shipments quantities over the most efficient network, then that cost allocation is non-subsidizing. A procedure for finding such a cost allocation is found and applied to a sample from the 1984 Michigan rail shipments. It was found to be Pareto efficient to abandon some Michigan facilities and reroute some shipments over the remaining rail links.

This dissertation is dedicated to my parents, for all of their love and support while I was completing it.

ACKNOWLEDGEMENTS

I owe a great deal to the members of my dissertation committee and want to acknowledge all of the contributions they made. They are Dr. John Wolfe, Dr. Harry Trebing, and Dr. Bruce Allen of the Michigan State University Department of Economics. I especially want to give credit to the chair of my committee, Dr. Kenneth Boyer of Michigan State University for all of his ideas, support, and patience. I also received substantial support and assistance from Dr. John Williams, Dr. Daniel Christiansen, Dr. James McCarley, and Dr. Larry Steinhauer of Albion College. Of course, any errors or omissions are not attributable to any of them.

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TABLE OF SYMBOLS

In Chapter 1

C_i ......the marginal transportation cost per unit for shipper i.
e_i ......elasticity of demand for shipper i.
P_i ......the transportation price for shipper i.
λ ......a constant for all shippers which is determined by the revenue requirement. If more (less) revenue is required, λ is simply increased.

In Chapters 3 and 4

A^f_{ijkm} ...the allocation to the shippers of X_{ijkm} for the fixed costs of the facilities in L_{ijkm}
$C(L^S,S)$ ..the total variable transportation costs of serving coalition S over network L^S.
c_{ih} ......the variable cost of shipping a unit of product i over link h.
c^*_{ijkm} ...the variable cost of shipping X_{ijkm} over route m.
CS_{ijkm} ...the carriers' gross benefits (before fixed costs are allocated) from carrying shipment X_{ijkm}.
$E(L^*,S)$ ..the upper bound on fixed costs of operating network L^* which can be allocated to coalition $S(L^*)$, so that $E(L^*,S) = \min(F^r(L^S), GB(L^*,S))$.
$F^r(L)$ ....the total fixed costs of operating all rail links in network L.
f_h ....the fixed cost associated with rail link h, where $h = 1,2,\ldots,H^r$.
G_{ijk} .....the increase in social surplus (before fixed costs of the shared facilities are allocated) from the shipping product i between j and k over the most efficient route (which may or may not include rail links) instead of over the most efficient route which includes no rail links.
$GB(L,S)$ ..the gross benefits (gross rail surplus gain) to all shippers in coalition S(L) from the shipment of X^S over the rail facilities in L.
H ....the number of links between cities in the network.
H^r ....the number of rail links.
H^t ....the number of truck routes, with $H^r + H^t = H$.

h ....the index for links, with $h = 1,\ldots,H^r$ for rail links, and $h = H^r+1,\ldots,H$ for truck links. h will generally refer to a member of set L_{ijkm}.

I ....the number of products shipped over the network.

i ....the product index, $i = 1,2,\ldots,I$.

J ....the number of cities (or nodes) served by the network.

J_i ....the set of all nodes where shipments enter the network.

j ....a member of set J_i.

K_i ....the set of all nodes where shipments enter the network.

k ....a member of set K_i.

L ....the set of all links available for shipments.

L_{ijkm} ....the set of all links used when commodity i is shipped from j to k over route m.

L^S ....a subset of L.

L^* ....the most efficient network configuration.

M_{ijk} .....the number of routes over which product i can be carried from j to k.

m ....the index for the routes, with $m = 1,2,\ldots,M_{ijk}$.

$N(L)$ .....the set of all shippers and carriers in network L

$N^*(L)$ ....the most subset of players in N(L) who are served over the most efficient network L^S.

$NB(L,S)$ ..the net benefits (surplus gain) to group S, where $NB(L,S) = GB(L,S) - R(L,S) \geq 0$.

n ....is a member of set N(L).

P_{ijk} .....the price per unit paid for transportation service from j to k by the shippers of product i.

$R(L,S)$ ...the allocation of the fixed costs to group S.

$S(L)$ .....a subset of N(L).

$SAC(X^S)$ ..the stand-alone cost of providing transportation services to coalition S.

$SAFC(X^S)$ .the stand-alone fixed cost of service X_{ijkm}.

T ....a subset of N(L) or of $S(L^S)$.

TS_{ijk} ....the surplus from shipping product i between j and k over the most efficient non-rail mode of transportation.

$TS^S{}_{ijk}$ ...the surplus which would be received if all shipments are carried by the intermodal competitor.

$v(L,S)$ ...the characteristic function which defines the maximum benefits (or gross rail surplus gain) to all members of S(L) from the operation of the facilities in L.

X_{ijkm} ....the quantity of product i shipped from j to k over route m.

X ....the set of all X_{ijkm}.

X^S ....a subset of X.

$X^S{}_{ijkm}$ ...a service in X^S which can be shipped by the players in S(L).

y^s ....the number of members in $S(L^*)$.

y^n ....the number of members in $N^*(L^*)$.

CHAPTER 1: PROBLEM STATEMENT AND BACKGROUND

The recent regulatory reform legislation in the railroad industry has led to increased emphasis by regulators on the profitability of railroads and on the economic efficiency of rail rates. In particular, the Railroad Revitalization and Regulatory Reform Act of 1976 and the Staggers Rail Act of 1980 have directed the Interstate Commerce Commission to allow railroads to abandon unprofitable services, to take the profitability of railroads into account when making regulatory decisions, and to determine reasonable rates for services which do not face competition (Railroads are allowed to determine their own rates on competitive traffic under the Staggers Act). In its recent statement on guidelines for determining rates on coal shipments not facing competition, or market dominant traffic, the ICC has decided that rates should not exceed the stand-alone cost (SAC) of providing the service and should be apportioned according to the individual demands of the shippers.[1]

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[1]Coal shippers and electrical utilities have complained that as captive shippers, they are charged very high monopoly rates. In response, the ICC on September 3, 1985 issued the following clarification of their guidelines for coal shipment rates:

> --Captive shippers should not be required to pay more than necessary for the rail carrier(s) involved to earn adequate revenues.
> --Captive shippers should not bear the cost of any facilities or services from which no benefits are derived.
> --A captive shipper's responsibility for payment for facilities of services that are beneficially shared by other shippers should be apportioned according to the individual demands of the various shippers. Thus, railroads will have an incentive to insure that competitive traffic contributes as much as possible toward facility or service costs.
> --Changes in coal rates should not be so precipitous that they cause severe economic distortions.

These regulatory changes in the railroad industry are the regulators' attempts to better allocate the fixed and common costs in a railroad network. As such, the problems with which the rail industry regulators are concerned are the same sorts of problems discussed in the long literature of common cost allocations. Although the focus here is on the allocation of rail network shared costs, many of the conclusions below are also applicable to other industries with similar network structures, such as pipelines, power transmission, and telephone networks.

In the rail industry, the problem arises because there are substantial costs of operating and maintaining facilities used in common by several services. In Figure 1 below, the rail link between city 1 and city 3 would be used for shipments from city 1 to city 3 and also for shipments from city 1 to city 4. The rail link between cities 3 and 4 would be used for shipment from city 1 to city 4 and also for shipments between cities 2 and 4. If the common costs of

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from "ICC News: Decisions and Orders," Traffic World, September 9, 1985.

It should be noted that the ICC has not extended these guidelines to shipments of commodities other than coal. The ICC had earlier issued the following statement on SAC theory:

> The 'stand-alone cost to any given shipper (or shipper group) is the cost of serving that shipper alone, as if it were isolated from the railroad's other customers. It represents that level at which the shipper could provide the service itself. No shipper would reasonably agree to pay more to a railroad for transportation than it would cost to produce in isolation itself, or more than it would cost a competitor of the railroad to produce the service to it. Thus, the stand-alone cost serves as a surrogate for competition; it enforces a competitive standard on rail rates in the absence of any real competitive alternative.

from Interstate Commerce Commission (1983).

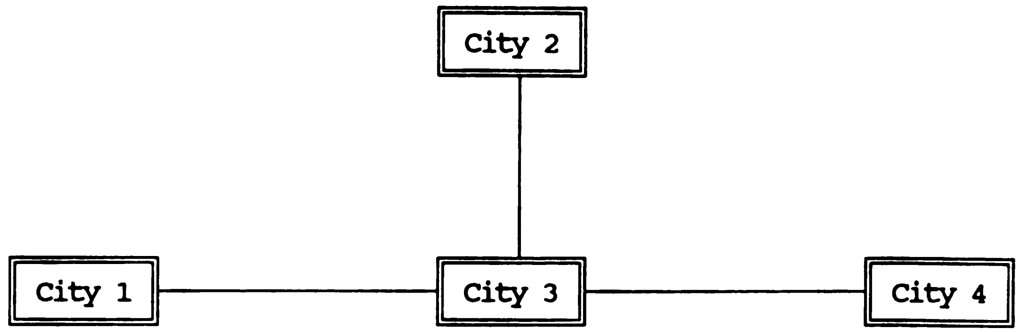

Figure 1

operating these shared rail facilities do not vary substantially with the levelof service (an assuming that marginal cost pricing is not feasible), there will be no clear cost-based way to allocate these costs.

Earlier contributions to the theory of efficient pricing with shared costs have advocated recovering the unallocatable shared costs with charges that vary with the demands for the service or with the stand-alone cost of providing the service.[2] However, previous work was based upon the assumption that all facilities will be used. This may have been a reasonable assumption before the Staggers Act was implemented, because the ICC allowed few service abandonments. But the Staggers Act liberalized the abandonment procedures, so now rail carriers have more freedom to eliminate services and facilities which cannot be provided profitably. By abandoning all services using a certain facility, a carrier can avoid the fixed costs of operating that facility.

Therefore, cost allocation proposals for rail transportation must

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[2]These allocations will be discussed in detail in chapter 2.

consider the possibility that the allocation of costs might lead the carrier(s) to operate an inefficient network (to operate facilities which should not be used and to abandon facilities that could be operated profitably).

PURPOSE

The purpose here is to show:

1) that in previous contributions to the theory of efficient pricing with shared fixed costs, the importance of facility abandonments in allocating shared fixed costs has not been recognized;

2) when efficient operation (or efficient abandonment) of facilities is considered, a first-best allocation of common costs can be found which is less arbitrary than was previously thought possible; and

3) this proposed allocation can be applied to a specific shared facility cost allocation problem based upon the Michigan rail transportation, and therefore, the proposed allocation has practical applications.

Many of these economic principles behind the deregulatory changes have been described as satisfying efficiency and equity criteria.[3] In this dissertation, however, these principles are interpreted as efficiency considerations, and the cost allocation proposal developed

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[3]See for example:

Fanara and Grimm (1985) p. 298.

The Moriarity Rule satisfies the following axioms of fairness:

1. No project pays more than its stand-alone cost
2. Every project pays some common cost
3. Every project shares some of the joint saving
4. The sum of the allocations equals the total cost of providing the joint project. Therefore, no excess over the total cost is charged, and no outside subsidy is required
5. The allocation is homogeneous of degree 1 in costs...

here will be based upon efficiency grounds only. In other words, questions involving the fairness of rates and the distribution of income will not be considered when evaluating this and other cost allocation proposals.

PROPOSED PROPERTIES OF AN EFFICIENT COST ALLOCATION

It will be argued that the first-best allocation should have the following properties:

1) The provider(s) of the service should be allowed to recover all costs (fixed and variable).

2) It should induce the provider(s) of the transportation services to provide the traffic flows over the network which maximize social surplus.

3) It should induce the provider(s) of the transportation services to operate the facilities so that social surplus is maximized. In other words, if the total surplus for all who benefit from the rail facilities can be increased by abandoning a service, the provider(s) should have the incentive to do so. It is this property that has been ignored in previous work.

It will also be shown that a cost allocation which has the three properties above also has the following desirable properties:

4) It will lead to a non-subsidizing cost allocation (by proof in chapter 3 and through an application in chapter 4).

5) It will allocate the fixed costs with less arbitrariness or equity-based elements than allocations which ignore possible efficient facility abandonments (by proof in chapter 3 and by an application in chapter 4).

An additional desirable property is:

6) It should be at least as practical to implement as previous cost allocation proposals (as demonstrated by an application to the Michigan transportation network).

DEFINING EFFICIENCY

In order to compare the cost allocation proposals surveyed and developed in the next two chapters, some measure of the efficiency of the proposal is needed. Pareto efficiency will be used as the standard here. The most Pareto efficient cost allocation is the one that leads to traffic flows which cannot be changed without making at least one party worse off without being compensated by the gainers. In other words, the most Pareto efficient cost allocation and traffic flows are those which lead to the greatest total surplus.

The Pareto efficiency standard can be extended to permit policy changes which lead to potential Pareto improvements, or policy changes improving total surplus for which those who benefit from the change could hypothetically compensate those who are made worse off. This avoids the problem of determining whether such compensation is given and how the compensation will be made, and reduces the problem to finding the flows which maximize total surplus for all who benefit from the rail facilities.

Besides ignoring the problem of compensating those made worse off, defining the most efficient flows as those which maximize total surplus (as a measure of social welfare) also requires the assumption that the only interpersonal comparisons are those based upon their market behavior (and not on their income or preferences). Therefore, the most efficient traffic flows are those which best take advantage of gains from trade, and not necessarily those which lead to utility maximization. It is assumed here that total surplus is the best available approximation of social welfare, despite the problems outlined above.[4]

CROSS-SUBSIDIZATION AND EFFICIENCY

Recently, economists have developed theories of cross-subsidization that depend upon whether or not individual or groups of consumers have an incentive to break away from the supplier and be served by another firm, provide the service for themselves, or not receive the service.[5] If a consumer or group of consumers has such an incentive, that consumer or group is said to be cross-subsidizing other users.

This definition of cross-subsidization was first proposed by Faulhaber (1974), who defined cross-subsidization as when at least one consumers (or group of consumers) pays more than their "stand alone cost", or more than they would pay if they alone were served. It may be the case that when the most Pareto efficient rates are calculated for traffic on a given network, some consumers or groups of consumers may pay more than their stand-alone cost. If these consumers are prevented by regulators from switching to another supplier, then the regulators will have the luxury of maximizing efficiency with some consumers subsidizing other consumers. It may be the case that the subsidized consumers and the subsidizing consumers purchase different

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[4]See Zajac (1979), chapters 2 and 5, Brown and Sibley (1986), pp. 8-18, and Varian (1984), pp. 198-209 and 268-276 for a more detailed discussion of the use and implications of Pareto efficiency.

[5]See Faulbaber (1980), Sharkey (1982), Zajac (1979), and Brown and Sibley (1986).

services from the supplier.

If, however, the consumers are able to switch to other suppliers, then rates set by the supplier or regulators to maximize efficiency which do not consider cross-subsidization may lead to consumers dropping their service. In this case, the rates which lead to cross-subsidization cannot be considered to be optimal because they are not sustainable and will not recover all of the fixed costs if the cross-subsidizing consumers choose not to be served by this supplier.

If the objective is to prevent cross-subsidization, then an upper bound equal to the stand-alone cost of providing a service (or group of services) can be considered to be a constraint on the cost allocation. Such an upper bound can be calculated for every service and every possible group of services.

The stand-alone cost upper bounds are based upon the game theory concept of the core. If a cost allocation is in the core, then no users of the network will be able to increase their benefits by breaking away from the grand coalition. If no service or group of services is allocated more than its stand-alone cost, then by Faulhaber's definition of cross-subsidization, this is a subsidy-free allocation, since no service pays more than it would outside of the network. The Faulhaber definition is based upon the cost of providing the service.

Sharkey (1982) extended the definition to include cases in which these consumers pay more than the benefits they receive from the service. His definition of cross-subsidization looks at both stand-alone costs and at the demands of the users of the services. Sharkey's extension is based upon the net benefits of the users or group of users. The net benefits of the service are the incremental benefits received from the service minus the additional variable production and transportation costs of adding the service minus the costs allocated to the service. If, when the total surplus is maximized and the fixed costs are allocated, the net benefits for all services and groups are positive (and no service pays more than its stand-alone cost), the allocation is in the core and therefore subsidy-free.[6] In other words, the most efficient flows and cost allocation must be in the core.

JUSTIFICATION OF THE PROPERTIES OF AN EFFICIENT ALLOCATION

Property 1: The provider(s) of the service should be allowed to recover all costs.

In the familiar case of provision of a service by a natural monopoly, a marginal cost pricing structure will be the most efficient, (will maximize social surplus) but will not allow the producer to recover its fixed costs. For much of the analysis in chapter 3, it will be assumed that the providers of transportation service have a constant marginal cost function. With a constant marginal cost and marginal cost pricing, there is no producers' surplus for the carriers, so the carriers will be unable to cover any fixed costs.

If the carriers in the rail industry were government owned, marginal cost pricing in the cases described in the previous paragraph might be practical, because any operating losses could be recovered through the general revenues of the government. But the carriers in the rail industry are private carriers, so they will have no incentive

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[6]Sharkey (1982) pp. 61-64.

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to operate under marginal cost pricing, because they will not be operating profitably.[7] Given this institutional arrangement, carriers must be allowed to recover all of their costs, or else the service will not be provided--even when providing the service(s) maximizes social surplus.

Property 2: The cost allocation should induce the provider(s) of the service to provide the traffic flows over the network which maximize social surplus.

Since Pareto efficiency is the standard used here to evaluate cost allocation proposals, the most efficient cost allocation must give the provider(s) of the service the incentive to provide the most efficient traffic flows over a given network.

Property 3: The cost allocation should induce the provider(s) of the service to operate the facilities which lead to social surplus maximization.

Most of the approaches to allocating the rail transportation costs surveyed in chapter 2 are attempts to find the price structure which leads to the most efficient traffic flows (or minimum distortion away from the most efficient traffic flows) over a given network.[8] The purpose here is to consider a more general case where the network structure can be changed. If total surplus can be increased by changing the network structure, the cost allocation proposal should

[7]Unless they can cross-subsidize unprofitable services with profits from other operations. Cross-subsidization will be discussed further in subsequent chapters.

[8]See for example, Baumol and Bradford (1970), Brautigam (1979), the discussion of the various Ramsey pricing proposals in Tye (1985), Damus (1984) and Roberts (1983), and the Fanara and Grimm proposal 1985).

give shippers and carriers the incentive to make efficient configuration changes. Therefore, the problem is to simultaneously find the most efficient network structure and the most efficient traffic flows over that network structure. Of course, the efficiency of any network structure is defined by the most efficient traffic flows over the network, so the two problems are interdependent.

It will be shown in chapter 3 that a cost allocation which satisfies the three properties above will also satisfy the following two properties:

Property 4: The cost allocation will lead to a non-subsidizing cost allocation.

Cross-subsidization is a concern in many of the discussions of efficient cost allocations in the economics literature[9] and in the ICC rulings.[10] It will be shown that the issues involving cross-subsidization (as defined by Sharkey (1982) only arise when the problem is defined too narrowly. When the problem is defined as finding a cost allocation which gives carriers the incentive to operate the most efficient network, then the efficient cost allocation will also be a subsidy-free cost allocation.

Property 5: It will allocate the fixed costs with less arbitrariness or equity-based elements than allocations which ignore possible efficient facility abandonments.

Multi-part tariffs with one part of the cost allocation consisting of fixed charges will be more arbitrary or else more

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[9]See Tye (1984) and Fanara and Grimm (1985), for example.

[10]See Ex Parte 347 (1983) and the coal rate guidelines in footnote 1 to this chapter.

dependent upon equity considerations rather than efficiency than a per-unit cost allocation, since the allocation is likely not to be the same for all users and is not directly determined by the economic decisions of the users. However, a multipart tariff solution to the rail cost allocation problem which satisfies properties 3 and 4 above will be less arbitrary than a multi-part cost allocation which does not consider facility abandonments. To have the properties described above, a cost allocation must include the constraints that no service or group of services be allocated a share of the fixed costs which lead to inefficient operation or abandonment of services, and these constraints narrow the range of efficient cost allocations.

Property 6: It should be no more difficult to implement than the cost allocation proposals surveyed in chapter 2.

In chapter 4, the proposal developed here will be applied to a simplified model of the Michigan rail transportation system to show that the proposal is indeed one which has practical applications. The Ramsey-pricing proposals described below require excessive data collection and rapidly become more complex to calculate as the size of the problem increases. As a cost allocation becomes more difficult to calculate, it becomes more difficult to implement. Therefore, the cost allocation should economize on data collection and calculations in order to be practical to apply.

MODELING RAILROAD NETWORKS

The techniques described in this thesis are meant to be applied to abstractions from actual rail networks. In these networks, a typical railroad network consists of a number of links between a set of nodes over which a variety of commodities are carried. The links may have different lengths, costs of construction and operation, and traffic densities. Commodities may follow routes over one or several links and may often be classified as long hauls or short hauls. Each commodities is produced at one set of nodes and sold (demanded) at another set of nodes, and different commodities may be produced at different nodes and have different demand and cost functions.

The transportation costs consist of variable costs of carrying commodities and fixed costs of operating links. It is assumed that the costs of operating links do not vary with the amount of traffic carried on the link, but these fixed costs can be avoided by abandoning the link. Variable transportation costs may include the congestion costs (such as delays) imposed upon other users of the network. There may also be economies of network operations, because as the amount of traffic increases, the fixed costs can be spread over more users.

RELEVANT RAILROAD REGULATIONS AND INSTITUTIONS

Until recently, railroads were heavily regulated by the Interstate Commerce Commission, which exercised considerable control over railroad rates, entry into new routes, and abandonment of old routes. However, the industry has been partially deregulated in the last decade.[11]

The first major piece of deregulation legislation was the Railroad Revitalization and Regulatory Reform Act of 1976 (the 4R Act). The 4R Act contained provisions for the elimination of rate regulation where railroads did not possess market dominance (monopoly

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[11]This discussion of the American railroad industry's structure and recent regulatory reform is based primarily upon Keeler (1983).

power), and for the ICC to consider the financial health of railroads when making rate decisions. Before the 4R Act, few abandonments of existing services were allowed for railroads if there were any significant protest from the affected users, but the 4Rs Act gave railroads more freedom to abandon unprofitable services. An important consideration behind the passage of the 4Rs Act was the poor financial health of many railroads. However, even after the 4Rs Act was implemented, the financial condition of railroads continued to deteriorate, partly because just about everywhere the railroads had discretionary power to raise rates in accordance with the act, the ICC found the existence of market dominance.[12]

The deregulation process was continued with the Staggers Rail Act of 1980. The Staggers Act is based on the premises that the rail carriers no longer have the market power they once had, that most traffic is now competitive, and market forces will be more efficient than regulation.[13] Some of the major goals in section 3 of the Act are to improve the financial conditions of railroads, to reform regulation to reduce inefficiency, and to balance the goals of carriers, shippers, and the communities served by railroads.

The Staggers Act preserves rate regulation only to prevent rates from rising to monopoly rates on routes found to be market dominant, and also to prevent ruinous competition from breaking out by requiring rates to remain above the variable costs for each service. So long as the extreme cases of market dominance on one hand and rate wars on the

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[12]Keeler (1983) p. 97.

[13]See Section 2 of The Staggers Rail Act of 1980, Public Law 96-449 (1980).

other do not occur, the Act allows railroads to determine their own rates. However, market dominance is no longer determined by the ICC: it is based upon the ratio of a railroad's revenues to variable costs. If this ratio does not exceed 1.8 (if rates are less than 80% higher than variable costs) the railroad is not considered to have market dominance. The Act also allows the ICC to exempt certain commodity groups entirely from regulation. This provision was meant for products such as fresh fruits and vegetables for which intermodal (truck) competition is strong enough to provide a competitive standard without rate regulation, making rate regulation unnecessary.

Abandonment procedures had already been simplified and liberalized under the 4Rs Act, but the Staggers Act further reduced the railroads' obligation to provide money-losing services (to cross-subsidize these unprofitable services). The abandonment process was limited to 255 days from application by the railroad to prevent delaying tactics, and the ICC was required to take the financial condition of the railroad into consideration when making the decision.

In his study of recent rail track abandonment, Due (1987) found that there have been many of these facility abandonments. Between 1976 and 1986, 35,000 miles of track were abandoned (about 20% of the 1976 total miles), and as of 1986, the railroads were considering abandoning another 7,000 miles of track. Much of this abandonment can be attributed to railroad failures, and many of the facilities were taken over by smaller competitors, but there have nonetheless been considerable facility abandonments since the abandonment procedures were liberalized.

One final provision of the Staggers Act is relevant to this project. The Staggers Act encouraged contract rates between shippers and carriers, and the parties have considerably more flexibility over how they set up their contracts. Now these contracts can contain fixed charges which do not depend upon the amount carried. Thus, railroad costs can be recovered with fixed charges on shippers which will have less distortionary effect than per-unit charges which vary with the level of service.

Keeler summarized the Staggers Act as follows:[14]

> Overall, then, the Staggers Act gives belated recognition to the fact that the railroad industry is no longer the monopoly it was in the nineteenth century and no longer able to cross-subsidize common carrier obligations of all sorts from profits on captive shippers. In fact, in recognizing that cross-subsidies come at the expense of captive shippers and in placing limits on prices they can be charged, the act actually discourages cross-subsidization and explicitly encourages raising rates or terminating money-losing services.

COMMON COSTS AND ECONOMIC THEORY

This problem of allocating railroad costs can be traced back to the Taussig and Pigou exchange (and earlier)[15]. Taussig (1891) argued that rail rates could be explained by the jointness of the costs of providing services over the network. Pigou argued that the costs were not truly joint--except in a few cases such as backhauls--and argued that the explanation for rate discrimination could be found in the standard case of monopoly supplier discrimination.[16] "Their

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[14]Keeler (1983) p. 102.

[15]The origins of the problems discussed here can be traced back to the famous Taussig-Pigou debate (and earlier). Some of the articles surveyed in the first two chapters trace their origins back to the Taussig-Pigou debate. See for example, Fanara and Grimm (1985).

[16]Taussig (1891), Pigou (1912), and the Taussig and Pigou exchange in the 1913 Quarterly Journal of Economics.

underlying difference of opinion was whether the costs of serving different railroad customers may properly be regarded as joint... or common"[17], where the distinction between joint and common costs depends upon whether the products (different transportation services in this case) are produced in fixed proportions (joint) or in variable proportions (common).

Economists have also used the value of service to explain rates. In general, if the price of the commodity shipped is high, then the transportation charge will be a small percentage of the total price, and the shipper will pay a high transportation charge. These shippers are likely to be less sensitive to additional transportation charges than those shippers for whom the same transportation charge would be a higher percentage of the total price, so the quantity distortion is likely to be lower. The value of the service is an upper bound on how high the rate can be (the value of the service is not the same concept as the value (price) of the commodity). A similar concept is "charging what the market will bear," which is the rate structure which raises the maximum amount of revenue (and is lower than the value of the service upper bound).

In recent years, these concepts have been extended and formalized in the public utility pricing and transportation economics literature. Efficiency is usually the standard used to evaluate rates in this literature (and here as well). The brief discussion which follows is meant to show the relationship between the proposed solutions to the railroad ratemaking problem (discussed in chapter 2 and proposed in chapter 3) and the traditional issues discussed of public utility

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[17]Kahn (1970) footnote 11, pp. 93-94.

pricing problems.

MARGINAL COST PRICING

Pricing at marginal cost is usually considered to be the most efficient because then buyers pay a price equal to the cost of supplying an incremental unit of output, so that the most efficient output is supplied. Producers supply that output because it is profitable for them to produce up to that output level, but beyond the output at which the price equals the marginal cost, the costs exceed the incremental revenue for the producer, so no additional output is supplied. This is the most efficient output level because the sum of producer surplus and consumer surplus is maximized.

Although the above analysis provides a starting point for determining rail rates, Kahn (1970) discusses several sets of issues which must be addressed before the implications of marginal cost pricing may be determined.

The first set of issues involve the proper measurement of marginal cost. Kahn cites two economic principles for determining what should and should not be included in the marginal cost for pricing purposes.[18] The first is that everyone should bear the causal responsibility for all costs imposed by the provision of an additional unit of output, and the second is that pricing should be at the short run marginal cost, because the properly defined short run marginal cost (SRMC) is the social opportunity cost at the time the decision is made. The SRMC can include costs incurred after the decision is made, such as depreciation, maintenance, and repair costs, so long as these costs vary with the output level and can be anticipated when the

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[18]Kahn (1970) vol. 1, p. 71.

decision is made.[19] The SRMC should be based on the smallest possible incremental unit of output. As the incremental unit gets larger, more costs become variable and the common or shared costs become smaller. For rail transportation, some possible increments are space allocated to a commodity on a train, one trip by an entire train, and the operation of a route which many trains will use. These incremental units reflect different decisions; whether to ship a commodity by train, whether to alter the frequency of the train service, or whether to operate a train route. It will be assumed in the model developed in chapter 3 that the incremental units are units of space on a train, which is the smallest possible unit.

The second set of issues are concerned with whether even properly defined marginal cost pricing is desirable by criteria other than (Pareto) efficiency. An example of this type of issue is whether consumers are capable of determining the value (what they are willing to pay) of an increment of output. Such calculations may be too complicated, or consumers may simply make the wrong choices because they do not know what is in their best interest or do not agree with the economists' definition of their best interest. Another example is whether or not the income distribution for a society is optimal. If income is distributed differently, consumers may make different aggregate choices and may provide the producer with a different demand curve, so the price will equal marginal cost at a different output level. Economists generally do not address these issues, at least not

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[19]There is a further set of issues which involves the choice of depreciation measurements and other problems of defining the costs associated with the fixed investment but still included in the SRMC. See Tye (1985) for a discussion of these problems.

when evaluating whether marginal cost pricing is desirable. Since the efficiency criteria for evaluating cost allocations is being considered here, the desirability of pricing at marginal cost will henceforth be evaluated by efficiency standards alone, but it is acknowledged that there are other considerations than efficiency.

Another set of issues is concerned with what to do when marginal cost pricing is not a viable option.[20] It may be possible but prohibitively expensive to calculate all relevant marginal costs, or else the marginal cost may be varying and the seller may not want to alter the price frequently as the marginal cost changes. Another question in this grouping is very important to the analysis in the next two chapters: Marginal cost pricing may not allow the rail carrier to recover its total costs, yet at the same time it may be Pareto efficient for the firm to operate and charge more than its SRMC, either by raising its price above the SRMC or by recovering the remaining costs through other charges.

RAMSEY PRICING

Baumol and Bradford (1970) applied the Ramsey pricing concept from public finance literature to the problem which arises when marginal cost pricing does not allow the public utility (rail carrier in this case) to operate profitably. They proposed using Ramsey pricing to find the most efficient rates above the marginal cost which allow the utility to recover its fixed costs.

Ramsey pricing originates with Ramsey's (1926) classical

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[20]Kahn (1970) Vol. 1, pp. 83-86.

discussion of optimal excise taxes.[21] He argued that in order for a government to raise a given amount of revenue from commodity taxes, the tax on each commodity should be inversely proportional to the elasticity of demand for the commodity. In practice, Ramsey pricing maximized total surplus subject to a break-even constraint for the supplier.

When Ramsey pricing is applied to railroad rates, each service is charged the marginal cost of the service plus an additional charge per unit shipped to cover the fixed costs of the entire network. To minimize the quantity distortions (and maximize total surplus), these Ramsey charges are inversely proportional to each shipper's elasticity of demand for transportation services. For each shipper (or shipper group) i, the percentage markup over cost is:

$$\frac{P_i - C_i}{P_i} = \frac{\lambda}{e_i} \qquad (1)$$

In equation 1, P_i, C_i, and e_i are the transportation price, marginal cost, and elasticity of demand for shipper i, and λ is a constant for all shippers which is determined by the revenue requirement. If more (less) revenue is required, is simply increased (decreased) as much as is needed to cover exactly the revenue requirement.

Ramsey pricing in this form is dependent upon the assumption of independent demands. Rohlfs (1979) developed a superelasticy which replaces the elasticity in equation 1.1 to account for non-zero cross-elasticities of demand. However, as more complicated flows and

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[21]See Baumol and Bradford (1970) and Brown and Sibley (1986), pp. 39-44 for discussions of the origins of Ramsey pricing.

interdependent demands are introduced, Ramsey prices rapidly become difficult to calculate.[22]

Braeutigam (1979) extended the Ramsey pricing theory to rail transportation facing intermodal competition (and no intramodal competition). After applying Ramsey pricing to a totally regulated transportation system (the totally regulated second best, or TRSB, problem), Braeutigam developed a theory of partially regulated second best (PRSB) regulation for when the competing modes are not regulated. Routes with more intermodal competition would have less ability to raise rates above marginal cost (will face larger quantity distortions), because the unregulated intermodal competitors can take away some of the traffic by pricing at their marginal costs. Intermodal competition will also be considered in the proposal in chapter 3, but since two-part tariffs will be used to recover the fixed costs, TRSB and PRSB allocations will not be necessary to recover the fixed costs.

OTHER COST ALLOCATION APPROACHES

The basic idea behind Ramsey pricing is to recover the unallocatable fixed costs by raising the rates above the marginal cost as efficiently as possible--which is to say, according to the elasticities of demand of the users. In practice (and in the public utilities literature), similar looking procedures have been used, except with rates being raised above the marginal cost by other criteria.[23]

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[22]This discussion is based upon Brown and Sibleys' (1986) account of Rohlf's article (1979), pp. 42-43 and 197-199.

[23]See Brown and Sibley (1986) pp. 44-49, 51-54, and 59-60, and Braeutigam (1980).

One such procedure is based upon Fully Distributed Costs, under which common costs are distributed among services in proportion to the service's share of total ton-miles, revenue, or other measurement without much economic meaning[24]. Under another approach which comes out of the theory of cooperative games, (see the discussion of the Fanara and Grimm proposal in chapter 2), the common costs are allocated in a manner which avoids cross-subsidization (as defined by Faulhaber).

These approaches are less concerned with economic efficiency per se and are largely arbitrary in the manner in which costs are allocated. But they are generally easier to calculate than Ramsey pricing allocations and can be designed to avoid any inefficient cross-subsidization which might arise from Ramsey pricing.

NONUNIFORM PRICES

When per-unit rates are raised above the marginal cost, a quantity distortion and dead-weight loss are created. The Ramsey pricing solution creates the minimum distortion while still allowing the utility to recover all costs through per-unit charges, since maximizing total surplus subject to breakeven constraints also minimizes the dead-weight loss created by the per-unit charges to recover the fixed costs.

Coase (1946) suggested that even the minimum dead-weight loss from Ramsey-pricing rates could be reduced or eliminated with a two-part tariff. It may be possible to recover all of the fixed costs of operating a rail network using a Coase-type two-part tariff. One

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[24]See Brown and Sibley (1985) for an extensive discussion of the shortcomings of Fully Distributed Costing.

part of the tariff would be equal to the marginal cost of providing the service and the other part would be an access fee charged to the shippers or producers (and paid out of their surplus) to recover any remaining deficit.

A two-part tariff such as this would be more Pareto efficient than any uniform price which recovers the fixed costs because the two-part tariff (if implemented correctly) would not create any quantity distortions because the marginal rate per unit could still be equal to the marginal cost per unit. The cost allocation in chapter 3 will be developed assuming that the fixed costs of operating facilities can be recovered with access charges[25] and the marginal costs can be recovered with variable charges.

OVERVIEW OF THE REMAINING CHAPTERS

In the next chapter, several cost allocations from the rail transportation literature will be surveyed, including allocations based upon fully distributed costs, Ramsey-pricing, stand-alone costs, and Ramsey pricing constrained by stand-alone costs. It will be shown that in each of these proposals, either the possibility of service abandonments is ignored, or else inefficient service abandonments are not defined correctly.

The model of rail facilities and an efficient cost allocation will be developed in chapter 3. This multi-part tariff will be shown to be less arbitrary than was previously thought possible. It will also be proven that an allocation with the first three properties defined in this chapter will also avoid the problem of cross-

[25]These fixed costs will be chosen so that they do not lead to cross-subsidization or inefficient abandonment of services.

subsidization that is discussed so extensively in the previous literature.

The fourth chapter will consist of a simulation based upon the 1984 Michigan rail transportation network. The optimal Michigan railway network and the optimal cost allocation will be found for the traffic flows. Although this chapter is not necessary to justify the conclusions from chapter 3, it will show that the application rules are in fact practical to apply.

CHAPTER 2: OTHER RAIL TRANSPORTATION COST ALLOCATION PROPOSALS

Problems in implementing the regulatory reform described in chapter 1 were encountered when coal rates were contested. Much of the coal transportation is by rail over market-dominant routes to cities where it is used by utilities to generate electrical power. These utilities and their coal suppliers argued that they were being charged unreasonably high rates because they are captive shippers. In the economics literature, several cost allocations have been proposed since the passage of the Staggers Rail Act and the subsequent debate over coal rates which are claimed to allocate these common costs efficiently and fairly. Three of these proposals will be considered in this chapter.

THE RAMSEY PRICING PROPOSAL

When their coal rates were contested, the railroads' representatives argued that railroads should be allowed to charge what the market will bear, up to the point at which they earned an adequate return on their investment. In other words, they argued for second best, or Ramsey pricing[1]. However, the utilities and coal shippers' representatives argued that pure Ramsey pricing would often result in coal shippers paying more than the stand-alone cost of the service. The ICC also agreed that pure Ramsey pricing rules for determining rates might lead to some rates exceeding the stand-alone

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[1]A brief descriptions of Ramsey pricing and how it relates to marginal cost pricing principles was provided in chapter 1.

cost of the service[2] (cross-subsidization by Faulhaber's definition[3]).

The railroad representatives have modified their proposal to advocate Ramsey pricing rates in market dominated traffic with the stand-alone costs imposed as upper bounds on rates. Under their proposal, rates will be allocated initially according to the Ramsey pricing rule, but if any services are allocated more than their stand-alone cost, the cost allocation will be recalculated with these services paying their stand-alone cost and other services will pay a larger share of the fixed costs.
Therefore, this modified Ramsey pricing proposal would have some of the coal shippers paying all of the fixed costs of the routes they use, even though these links are shared facilities.[4]

However the Ramsey price allocation is determined, this type of allocation assumes that the capital stock of the entire network is homogeneous, so users pay according to their demands and not according to what links they use. It is not clear what is the relationship between the stand-alone cost for individual services (or groups of services) and a Ramsey pricing break-even constraint for an entire network. The former assumes that some capital (but not all) is

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[2]Interstate Commerce Commission (1983). See also Fanara and Grimm (1985), p. 297, and footnote 1 to chapter 1 for more on the ICC statements on stand-alone costs.

[3]See Tye (1985) for a discussion of the problems of measuring stand-alone costs which are not clarified in the ICC statements. Note also that the ICC has not stated that it is using Faulhaber's definition of cross-subsidization, especially in regards to groups of shipper's paying more that the stand-alone cost of serving the entire group alone.

[4]Roberts (1983), p. 28.

shared, but not necessarily by all users, while a break-even constraint implies that all capital is homogeneous and shared by all users.

This assumption of a homogeneous capital stock may be appropriate for electrical utilities and some other public utilities, where an increase in the output level may benefit any of the users of the utility. But the existence of stand-alone costs for different services over a network by definition denies that the capital stock is homogeneous. Unlike the case of power generation, if some rail facilities are abandoned, not all users of the network will be affected the same by the reduction of service levels over the network. Damus made this point when he argued that "Ramsey pricing is essentially a public finance tool or a pricing technique for a nationalized industry. As such, it is not a suitable response to deregulation."[5]

The Ramsey pricing allocations are one-part tariff cost allocations which are meant to be the most efficient (least distortionary) allocation of common costs using one-part tariffs[6]. However, the distortion created by the recovery of common costs using per-unit charges can be reduced even further (or eliminated altogether) with a two part tariff. The per-unit charge under such a two-part tariff would be the costs which can be allocated to individual units of the services, and the fixed part of the tariff would be the share of common costs allocated to the service. A

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[5]Damus (1984), p. 60.

[6]The Ramsey prices may be the most efficient allocation of common costs only under the assumption of a homogeneous capital stock.

two-part tariff based on the Fanara and Grimm proposal below will be more efficient than any one-part tariff[7].

THE UNIFORM RATIO RULE

Merrill Roberts advocated using the uniform ratio rule[8] to allocate the shared facility costs. "The 'Uniform Ratio Rule'... treats as a class all shippers who are discriminated against as identified by P/MC ratios above the systemwide average" (emphasis Roberts's).[9] Under such a cost allocation, a uniform price-to-marginal-cost ratio is calculated as a ceiling on the per-unit charges which is to be applied to all traffic.[10]

This proposal would divide the users into two classes; those discriminated for (with demand elasticities for transportation services greater than the system average) and those discriminated against (whose demand elasticities are below the system average).

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[7]Other criticisms of the Ramsey pricing allocations are raised by Tye (1985), pp. 9-12, Damus (1984), pp. 59-60, and Roberts (1983), pp. 27-29. Tye points out that the railroads' representatives use a more "permissive" definition of stand-alone costs (p. 9). Rather than using the historical cost of the incumbent railroads, the railroads' representatives propose using the replacement costs of a hypothetical entrant. Tye argues that the costs of a hypothetical entrant would be inflated because they would include the costs of overcoming barriers to entry under conditions of market dominance.

Damus argues further that the railroads' representatives propose applying the stand-alone upper bound on rates only to groups, and then turn around and advocate fully-allocated costs (but not Ramsey pricing) within the groups.

Roberts argues that the Ramsey pricing allocations ignores intermodal competition (unless Braeutigams' extension of Ramsey pricing is adopted), will require any service which is allocated more than its SAC under unconstrained Ramsey pricing to pay all of the shared costs under this constrained Ramsey pricing allocation, and will be impossible to calculate if the traffic flows are too complex.

[8]first proposed by Alfred Kahn (1970), pp. 137-139.

[9]Robert's (1983), p. 28.

[10]Roberts (1987), p. 98.

Kahn proposed charging the long run average cost to shippers with less elastic demands to recover the fixed costs and charging the long run marginal cost to shippers with more elastic demands. Then all in the class discriminated against pay a uniform markup over their marginal transportation cost.

Note that by advocating applying this procedure to rail cost allocation problems, Roberts makes the same assumption of homogeneous capital as the Ramsey pricing advocates, although he does exclude "highly specialized facilities."[11] Therefore, the uniform ratio rule is very much like the constrained Ramsey pricing proposal in that it also makes the assumption that capital is homogeneous. According to Roberts, "(t)he key premise that all shippers have a stake in the system as a whole (but not in facilities specialized to particular users) realistically solves the allocation problem."[12]

But shippers do not have a stake in facilities they do not use and requiring them to pay for these facilities could lead to inefficient cross-subsidization and service abandonments. Also, if demand curves for smaller groups of services can be estimated, the uniform ratio rule will be less efficient than an allocation based upon more than two groups (but easier to calculate).

THE FANARA AND GRIMM PROPOSAL

Fanara and Grimm (1985) made another proposal for allocating the fixed costs without causing some services to subsidize others (by Faulhaber's definition). They point out that there is a history of using accounting rules based upon stand-alone costs to allocate shared

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[11]Roberts (1983), p. 28.

[12]Roberts (1983), p. 29.

overhead costs. They propose first calculating the stand-alone cost for each service (or group of services, depending upon the allocation rule chosen) and then using an arbitrary allocation rule to allocate the costs in a manner which does not lead to cross-subsidization and has all users paying some share of the costs[13]. In other words, they propose first allocating all traceable costs to the appropriate services, and then allocating the fixed costs of the network in proportion to the stand-alone costs of the services. The share of fixed costs allocated to any service (or groups of services which are considered in the allocation rule) will be less than the stand-alone fixed cost of the service. Their procedure can be used when alternative sources of transportation services are available, such as motor carriers.

In this form, the Fanara and Grimm allocation is recovered through two-part tariffs (rather than as uniform prices). Under the recent regulatory changes, contracts between shippers and carriers are encouraged, and these contracts might include fixed charges. The two-part tariff, would have the variable costs recovered from a charge which varies with the quantity shipped and the fixed costs recovered from lump-sum charges to the shippers. Assuming that these charges do not divert any traffic because they are lump-sum charges (and therefore lead to no inefficient service abandonments), this allocation will lead to no quantity distortions, and therefore this allocation procedure will be more efficient than the Ramsey pricing or Uniform Ratio allocations.

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[13]The characteristics of four such arbitrary allocation rules were compared by Hamlen, et.al. (1977).

These charges could also be passed on to the final consumers as markups over the variable cost (as per-unit charges). Either way the costs are recovered, under an allocation based upon Fanara and Grimm's proposal, all shippers are paying less than the stand-alone cost of their service (are not cross-subsidizing each other by Faulhaber's definition[14]), and the total costs of the network are recovered from the shippers. It is argued here that these upper bounds on allocations to flows are efficient because cross-subsidization (and therefore loss of traffic to other carriers) is avoided so long as none of these upper bounds is exceeded.

Of the three cost allocation proposals discussed in this chapter, the Fanara and Grimm proposal has the advantage of being the easiest to apply, because it requires only information about the costs of the transportation service (while the others require information about demand elasticities). The Fanara and Grimm proposal is calculated in a manner which prevents cross-subsidization by Faulhaber's definition, while both the Roberts and the Ramsey pricing proposals must be modified to prevent this cross-subsidization.

Later it will be argued that this range of efficient (in the core) allocations is too broad. Even if no service pays more than its stand-alone cost, the allocation may still be outside of the core, leading to inefficient loss of traffic. The Fanara and Grimm proposal is based solely upon the costs of providing the service, and therefore may lead to cross-subsidization by Sharkey's definition, because the

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[14]It should be noted that by using a Moriarity rule allocation, Fanara and Grimm are only considering whether individual shippers (and not any shipper groups) are pay more than their stand-alone costs, so their final allocation proposal really may not avoid cross-subsidization by Faulhaber's definition.

benefits (demands) of each service group are not considered when the rates are determined.

CONCLUSION

There have been several proposals made advocating the replacement of the current methods of allocating rail costs with less arbitrary costing rules. The Ramsey pricing proposals are the most efficient (by definition) of the per-unit allocations which assume a fixed network configuration, but it is not clear how the most efficient rates for the entire network are related to individual rates when there are complex interwoven traffic flows. Roberts advocates the uniform ratio rule first proposed by Kahn because it would lead to more efficient rates than the Rail-Form-A rates[15] which are currently used, but this proposal retains much of the arbitrariness of the current rates by using the Rail-Form-A rates as the starting point. Both the Ramsey pricing and the Roberts' proposal depend upon knowing the demands of the users in order to calculate the demand elasticities of each service. The Fanara and Grimm proposal would be much easier to apply, because it requires only information about the costs of the transportation service. The Fanara and Grimm proposal by definition leads to no service group paying more than its stand-alone cost (one of the ICC guidelines), while both the Roberts and the Ramsey pricing proposals must be modified to prevent cross-subsidization. However, the Fanara and Grimm proposal may lead to cross-subsidization by Sharkey's definition, because the benefits of each service group are not considered when the rates are determined.

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[15]Rail-Form-A rates are a form of fully distributed costing which allocates costs in proportions which have little economic meaning.

As will be seen in the next chapter, all of these proposals as designed for fixed networks. However, it may not be optimal to provide all services, and under the Staggers Act, carriers are given the freedom to abandon unprofitable services in most cases. In the next chapter, it will be shown that a more efficient cost allocation procedure can be found when the problem of avoiding cross-subsidization is properly defined as a problem of finding a cost allocation which leads to both the most efficient network structure and the most traffic flows over this network structure.

CHAPTER 3: EFFICIENT COST ALLOCATION AND ABANDONMENTS

In the literature of efficient pricing with shared fixed costs[1], facility abandonments have not been properly considered when allocating shared fixed costs. The purpose of this chapter is to show that when the possibility of abandonments is considered, a first-best allocation of common costs can be found which is more efficient and less arbitrary than was previously thought possible. Since the railroad industry following the Staggers Rail Act of 1980 is an industry in which such facility abandonments are important, much of the discussion of this allocation problem will be related to railroad institutions.

THE PROBLEM DESCRIPTION

In chapter 2, it was shown that previous attempts to solve this rail cost allocation problem have assumed a fixed network structure, and therefore have failed to consider the possibility of facility abandonments. In this chapter, such abandonments will be allowed, so that the incentive to operate a facility must be considered in any attempt to allocate untraceable common costs. Therefore, the problem is to start from a given set of shippers, carriers, and set of facilities, find the most efficient network structure and set of players that is in the core, and finally, to find a cost allocation that allows all of the fixed transportation costs to be recovered (with non-distortionary fixed charges) while encouraging the carriers to operate the most efficient network and provide the most efficient services levels.

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[1]This literature was discussed in chapter 2.

THE NETWORK

There are I products produced and shipped over the network. There may be different transportation demands and costs for different product shipments. Let i be the product index, $i = 1,2,\ldots,I$. The network over which the commodities will be shipped consists of J cities and H links between cities. All traffic between cities is carried over one or more links, and there may not be a link between every pair of cities. Out of the H links, H^r are rail links and H^t are truck routes between nodes, with $H^r + H^t = H$. Let h be the index for links, with $h = 1,\ldots,H^r$ for rail links, and $h = H^r+1,\ldots,H$ for truck links. It is assumed that no new rail or truck links will be added to the network. Let L = the set of all links available for shipments, and let a superscript on L (such as L^S) indicate a subset of the facilities.

THE PARTICIPANTS IN THE NETWORK

Following the literature applying game theory concepts to public utility pricing problems[2], the shippers and the carriers of products over the network will be modeled as participants in a transferable utility game. The shippers will be the consumers who demand transportation services, and the carriers will be the producers who supply transportation services over the given set of facilities. Let N(L) denote the set of all shippers and carriers in network L, with $n \in N(L)$; and let S(L) be a subset of N(L). Note that the set of players is a function which depends upon the facilities available. Therefore, for a subset L^S of L, the set $N(L^S)$ may be smaller then the set N(L), because any members of N(L) which are not in $N(L^S)$ will be

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[2]Faulhaber (1975), Zajac (1978) and Sharkey (1982)

excluded when the facilities in L^S are not sufficient to provide transportation services to these members of N(L).

There are shippers of product i in several cities. Let j = the index for one of the nodes where commodity i either enters or exits the network, and let J_i = the set of all index numbers of these nodes represented by the j index, so that $j \in J_i$. Perhaps J_i could be the set of all nodes where the commodity is produced or enters the network, or, as in the case in chapter 4, either the origin or destination node of the shipment, depending upon which has the lower index number. Also let k = the other index for nodes where commodities either enter or exit the network and let K_i = the set of all nodes represented by k, where $k \in K_i$. This K_i could be the set of all nodes where the commodity exits the network, or, as Chapter 4, the node for the shipment which has the greater index number. In order for this problem to be of interest as a transportation problem, there should be at least several overlapping shipments which share transportation facilities.

There may be several possible routes for product i to be shipped from j to k. These routes can be over rail links, truck links, or both. Let M_{ijk} = the number of routes over which product i can be carried from j to k, and let m be the index for the routes, with m = $1,2,\ldots,M_{ijk}$. It may be the case that product i can be shipped over route m from j to k, but another product cannot be carried over the same route.[3] Let L_{ijkm} = the set of all links used when commodity i

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[3]Perhaps it takes several days for a product to be carried from j to k over a route, so a product like coal could be carried over the route, but another product like fresh fruit would spoil if carried over this route.

is shipped from j to k over route m. The shippers of commodity i from j to k will be modeled as one player in this game.

Let X_{ijkm} = the quantity of product i shipped from j to k over route m, with $X_{ijkm} \geq 0$. If any of the links in L_{ijkm} are abandoned, then route m for this service will not be available, and $X_{ijkm} = 0$. It is important to note that these services are available over the given network, but there may not be a solution in the core in which one or more X_{ijkm} is shipped, in which case, some of the flows will be set equal to zero. For larger networks, X_{ijkm} will typically be zero for many of the flows. To simplify the notation, let a dot subscript indicate a sum of shipments, so that $X_{ijk.}$ = the sum of all commodity flows from j to k over any route[4]. Also let X denote the set of all X_{ijkm}, and let X^S denote a subset of X.

SHIPPERS' BENEFITS BEFORE ALLOCATING UNTRACEABLE COSTS

Both shippers and carriers in the game are interested in maximizing their surplus from their activity in the game. As in previous game theory applications to public utility pricing problems, shipper and carrier surplus is measured in monetary terms and assumed to be transferable. Therefore, every collection of players is interested in maximizing the total surplus the entire collection receives, although side payments may be needed to maximize their total surplus.

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[4]Under the assumption of constant variable transportation costs, there will almost always be a unique most efficient (least expensive) route m between two cities, so $X_{ijk.} = X_{ijkm}$ for m = the unique most efficient route between j and k.

The gross rail surplus gain[5] to shippers will be the additional consumer surplus they receive from their shipments of the product by rail instead of by truck or some other competitive non-rail mode of transportation. The shippers' demands for transportation services are derived demands from the demands of buyers and the costs of producers, since this difference is the maximum the buyers and sellers would be willing to pay for the service. The producers or final buyers may themselves be the shippers, but their demands for transportation services are kept distinct from their final demands for the product or costs of producing the product.

The demand for service $X_{ijk.}$ is assumed to be independent of the demand for any other transportation service. That is to say, shipments between two different pairs of cities are not substitute or complement transportation services (although shipments of a commodity between the same two cities but over different routes are perfect substitutes for each other). This is a rather strong assumption, because there clearly are substitutes and complements for transportation services. However, this assumption may be relaxed in a more complex model by replacing shipper demands with the product demands and production costs from which they are derived. It is also

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[5]"Gross rail surplus gain" here means the area under the transportation demand curves minus the allocable (variable) transportation costs and minus the benefits which would have been realized from shipping the product by truck or some other non-rail competitor. The net rail surplus gain will be this gross rail surplus gain minus the allocation of fixed costs to this shipper or group of shippers. Later in this chapter, the gross rail surplus gain will be one of the upper bounds on the allocation of fixed costs to a shipper group, since if the shipper group is allocated more than its surplus gain from using a rail carrier instead of another mode of transportation, the group will be better off either by using the other transportation mode or by not shipping the product.

assumed that there are no income effects. When the variable transportation costs per unit are assumed to be constant, it will be most efficient to have service $X_{ijk.}$ carried between cities j and k over the shortest route over the available facilities.

Let $P_{ijk}(X_{ijk.})$ = the inverse demand function for transportation services for product i between cities j and k, and let P_{ijk} = the price per unit paid by the shippers of this service. Then they pay $P_{ijk}X_{ijk.}$ plus the fixed costs allocated to them for their shipments of product i between cities j and k. The demand function is assumed to be downward-sloping. Let TS_{ijk} = the surplus from shipping product i between j and k over the most efficient non-rail mode of transportation. This alternative mode of transportation is modeled in the next chapter as a perfectly competitive set of truck transportation services over the shortest routes between every pair of cities. Then the willingness to pay of the shippers of a service is the area under their demand curve for the services, or $\int_0^{X_{ijk.}} P_{ijk}(x_{ijk.})dx_{ijk.}$, and their rail surplus gain (before they are allocated a share of the fixed costs of the shared facilities) is $G_{ijk} = \int_0^{X_{ijk.}} P_{ijk}(x_{ijk.})dx_{ijk.} - P_{ijk}X_{ijk.} - TS_{ijk}$.

Let GB(L,S) = the gross benefits (gross rail surplus gain) to all shippers in coalition S(L) from the shipment of X^S over the rail facilities in L, let $X^S{}_{ijkm} \epsilon X^S$ be a service which can be shipped by the players in S(L), and let $TS^S{}_{ijk}$ be the surplus which would be received if all shipments are carried by the intermodal competitor. When X_{ijkm} is a service carried by members of S(L), then $X^S{}_{ijkm} = X_{ijkm}$. When X_{ijkm} is not a service carried by members of set S(L), then $X^S{}_{ijkm} = 0$. Then

$$(2)\ GS(L,S) = \sum_{i=1}^{I} \sum_{j\epsilon J_i} \sum_{k\epsilon K_i} \int_{o}^{X^S_{ijk.}} P_{ijk}(x_{ijk.})dx_{ijk.}$$

$$- \sum_{i=1}^{I} \sum_{j\epsilon J_i} \sum_{k\epsilon K_i} P_{ijk}X^S_{ijk.} - \sum_{i=1}^{I} \sum_{j\epsilon J_i} \sum_{k\epsilon K_i} TS^S_{ijk}$$

For the grand coalition N(L),

$$(3)\ GS(L,N) = \sum_{i=1}^{I} \sum_{j\epsilon J_i} \sum_{k\epsilon K_i} \int_{o}^{X_{ijk.}} P_{ijk}(x_{ijk.})dx_{ijk.}$$

$$- \sum_{i=1}^{I} \sum_{j\epsilon J_i} \sum_{k\epsilon K_i} P_{ijk}X_{ijk.} - \sum_{i=1}^{I} \sum_{j\epsilon J_i} \sum_{k\epsilon K_i} TS_{ijk}$$

Since the product demand functions are assumed to be downward sloping, G_{ijk} for any i and k will be a concave function, and therefore, GS(L,S) and GS(L,N) will also be concave functions.

CARRIERS' COSTS AND BENEFITS

It is assumed that there are two types of costs associated with transportation services. There is a fixed cost f_h associated with all rail links ($h = 1,2,\ldots,H^r$). This fixed cost is an avoidable fixed cost, such as maintenance costs, and not the sunk cost from building the rail link. Therefore, if a link is not used, these fixed costs will not be incurred. It is assumed that there is no fixed cost of operating a truck route between two links. Of course, the problem in Ramsey-pricing and other previous literature has been to find the most efficient cost allocation which allows the carriers to recover these fixed costs. Let $F^r(L)$ = the total fixed costs of operating all rail links in network L, where,

(4) $F^{r}(L) = \sum_{h=1}^{H} f_h$

There is also a variable transportation cost of shipping each product over each link. Let c_{ih} = the variable cost of shipping a unit of product i over link h. It has been assumed that the variable transportation costs are constant. This assumption insures that marginal cost pricing (at the variable cost) will lead to economic losses for carriers with positive fixed costs, and therefore, marginal cost pricing will not allow shippers to recover their fixed costs. To simplify the notation, let $c^{*}_{ijkm} = \sum_{h \epsilon L_{ijkm}} c_{ih}$ = the variable cost of shipping a unit of product i from j to k over route m. Of course, the rail cost allocation problem will only be interesting if the transportation costs over at least some rail links are less than the costs over truck routes. It is further assumed that any differences in the quality of transportation services over different routes will be reflected in the transportation costs. These differences in service quality might include reliability, damage from movement, and speed of delivery.[6]

Let C(L,N) = the total variable transportation costs of shipping all products over the network. Since the variable transportation costs are assumed in this chapter to be constant, then,

(5) $C(L,N) = \sum_{i=1}^{I} \sum_{j \epsilon J_i} \sum_{k \epsilon K_i} \sum_{m=1}^{M_{ijk}} c^{*}_{ijkm} X_{ijkm}$

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[6]For example, if rail transportation does more damage between two nodes to fresh fruits and vegetables than truck transportation between the same two nodes (Perhaps more of the shipment will spoiled because of time delays if rail transportation is used than if trucks carrier the shipment), then the additional damage from rail transportation would be considered by the shippers to be part of the cost of using a rail carrier.

The stand-alone cost of providing a transportation service or group of services is defined as the sum of the stand-alone costs of operating the rail links over which the service is carried plus the total variable (allocatable) transportation cost of the services. For a single service, the stand-alone cost is

$$(6)\quad SAC(X_{ijkm}) = c^*_{ijkm}X_{ijkm} + \sum_{h\epsilon L_{ijkm}} f_h$$

Of more interest in this cost allocation problem is the stand-alone cost for a set of shipments X^S. Let L^S be the facilities needed to ship X^S. The general form of the stand-alone costs for a group of services will be

$$(7)\quad SAC(X^S) = \sum_{i=1}^{I} \sum_{j\epsilon J_i} \sum_{k\epsilon K_i} \sum_{m=1}^{M_{ijk}} c^*_{ijkm}X^S_{ijkm} + F^r(L^S)$$

A distinction will be made between the stand-alone cost of a service (including the variable cost) and the stand-alone fixed costs (not including the variable costs, which can be traced to individual services). Let $SAFC(X_{ijkm})$ be the stand-alone fixed cost of service X_{ijkm}, so that

$$(8)\quad SAFC(X_{ijkm}) = \sum_{h\epsilon L_{ijkm}} f_h$$

Similarly, the stand-alone fixed costs for a set of services X^S is

$$(9)\quad SAFC(X^S) = F^r(L^S)$$

The carrier(s) who operate the rail links over which any service X_{ijkm} is carried will be considered to be players in this game. Each of the carriers will want to maximize their surplus from providing transportation services. Before allocating the fixed transportation costs, the carriers' surplus, or gross rail surplus gain from service X_{ijkm} will be $CS_{ijkm} = P_{ijk}X_{ijkm} - c^*_{ijkm}X_{ijkm} - \sum_{h\epsilon L_{ijkm}} f_h$.

Under marginal cost pricing, $c^*_{ijkm} = P_{ijk}$, so the carriers' gross benefits (CS_{ijkm}) will be equal to $- \sum_{h \epsilon L_{ijkm}} f_h$ (a negative quantity). Carriers will not be willing to provide transportation services if their carrier surplus is negative, so in order to maximize efficiency with marginal cost pricing, the fixed costs must be allocated to the shippers. The carriers' gross rail surplus will be exactly zero after the fixed costs are allocated. Let A^f_{ijkm} = the allocation to the shippers of X_{ijkm} for the fixed costs of the facilities in L_{ijkm} (this allocation will be discussed below). If this is the only service carried over the network, the shippers' contribution for the fixed costs will be all of the fixed costs ($A^f_{ijkm} = SAFC(X_{ijkm})$). For a set of services X^S, the allocation will be $\sum_{X^S} A^f_{ijkm} \leq SAFC(X^S)$.

THE CHARACTERISTIC FUNCTION

A game is defined by a network L (or subnetwork L^S), a set of shippers and carriers N(L) or subset S(L) of N(L), and a characteristic function v(L,S) which defines the maximum benefits (or gross rail surplus gain) to all members of S(L) from the operation of the facilities in L. Before defining the general characteristic function, a few specific characteristic functions will be considered.

If S(L) consists of only shippers, then they will have only non-rail transportation services available to them, so their v(L,S) = 0 for rail transportation services. Similarly, if S(L) consists of only carriers, then they will receive no revenue from rail transportation services, and v(L,S) = 0. If there is one shipper and one carrier of the same product in S(L), but the shipper does not demand the same service which the carrier is providing, then v(L,S) = 0. Therefore, a necessary condition for $v(L,S) > 0$ is for the membership in S(L) to consist of at least a shipper and a carrier of the service which the shipper demands. If there is one shipper and one carrier which provides a single service over a given route which the shipper wishes to use, then the characteristic function will be

$$(10) \quad v(L,S) = \max_{X^S}\Big(\int_0^{X^S_{ijk.}} P_{ijk}(x_{ijk.})dx_{ijk.} - c^*_{ijkm}X^S_{ijkm} - TS_{ijk} - A^f_{ijkm}\Big)$$

In equation 10, A^f_{ijkm} is the share of the fixed costs allocated to the shippers of X_{ijkm}. The allocation of these costs has not yet been determined, so they will be considered to be given at this point.

Consider next a larger S(L) for which there are at least one combination of shippers and carriers of the same service. Again let X^S_{ijkm} be a shipment by the players in coalition S(L), and let L^S = the subnetwork of links that will be used by the shippers in coalition S(L). The general form of the characteristic function for any S(L) will be

$$(11) \quad v(L,S) = \max_{X^S} \Big(\sum_{i=1}^{I} \sum_{j\epsilon J_i} \sum_{k\epsilon K_i} \int_0^{X^S_{ijk.}} P_{ijk}(x_{ijkm})dx_{ijk.} - \sum_{i=1}^{I} \sum_{j\epsilon J_i} \sum_{k\epsilon K_i} \sum_{m=1}^{M_{ijk}} c^*_{ijkm}X^S_{ijkm} - \sum_{i=1}^{I} \sum_{j\epsilon J_i} \sum_{k\epsilon K_i} TS^S_{ijk} - \sum_{X^S} A^f_{ijkm}\Big)$$

Equation 11 defines the maximum benefits that the members of coalition S(L) receive from the facilities in L, given some allocation of fixed costs which has not yet been defined. Note that attaining this maximum net benefit may require that only the members of players' subset T of S(L) participate and the members of S(L) not in T voluntarily not participate in the game. Since this is a transferable utility game, the players in T will be able to compensate non-participating players and all players will be better off than if all players participate. Since GS(L,S) is concave and C(L,S) has a constant slope, the v(L,S) is a concave function. If the allocation is the stand-alone fixed transportation charges for the services the shippers are able to provide, then $\sum_{X^S} A^f{}_{ijkm} = SAFC(X^S)$. By Faulhaber's (1975) definition of cross-subsidization in public utility pricing, cross-subsidization occurs (a cost allocation is not in the core) when any shipper or group of shippers pays more than the stand-alone cost of serving only that shipper or group of shippers. If cross-subsidization is to be avoided, then it is necessary to have $\sum_{X^S} A^f{}_{ijkm} \leq SAFC(X^S)$.

Finally, the maximum benefits to all members of the grand coalition N(L) are

$$(12)\quad v(L,N) = \max_{X} \{ \sum_{i=1}^{I} \sum_{j\epsilon J_i} \sum_{k\epsilon K_i} \int_0^{X_{ijk.}} P_{ijk}(x_{ijkm}) dx_{ijk.} - \sum_{i=1}^{I} \sum_{j\epsilon J_i} \sum_{k\epsilon K_i} \sum_{m=1}^{M_{ijk}} C^*{}_{ijkm} X_{ijkm} - \sum_{i=1}^{I} \sum_{j\epsilon J_i} \sum_{k\epsilon K_i} TS_{ijk} - F^r(L) \}$$

This v(L,N) will also be a concave function. Note that all of the fixed costs of the links that are used (which may be a smaller set than L if not all links are needed to efficiently serve all players in N(L)) must be recovered from the members in N who participate in this game.

THE CORE OF THE GAME

The core of the game is defined by network L, players N(L), and characteristic vector v. Each shipper and carrier is interested in maximizing its gross rail surplus gain. To simplify the notation below, no distinction will be made between carrier and shipper surplus. Let GB(L,n) = the gross rail benefits gain to shipper or carrier n in N(L) from the facilities in L[7]. Then GB(L,S) = the gross benefits to all members of coalition S(L) when all members in N(L) participate in the coalition (or voluntarily do not participate). For a shipper in N(L), that shipper's gross benefits are denoted by $GB(L,n) = G_{ijk}$.

Under Sharkey's (1982) definition of cross-subsidization, a non-cross-subsidizing cost allocation is one in which no shipper or group of shippers pays more than either its stand-alone cost or its gross benefits. Under this definition of cross-subsidization, a core allocation is one in which no shipper or group of shippers is allocated a share of fixed costs greater than the minimum of its SAFC and GB(L,S).

The core of the game is based upon Sharkey's definition of cross-subsidization. Let R(L,S) = the allocation of the fixed costs to group S. Then for the grand coalition, $R(L,N) = F^r(L)$; and for a group S consisting of one producer, one buyer, and one shipper between the producer and the buyer, $R(L,S) = A^f{}_{ijkm}$. The net benefits (surplus gain) to group S are then defined as

(13) $NB(L,S) = \max \{GB(L,S) - R(L,S), 0\}$

or (14) $NB(L,S) = v(L,N) - v(L,N-S)$

Note that v(L,N) and v(L,N-S) both include allocated shares of the fixed costs. Thus, either definition of the net benefits is the anticipated gains to members of coalition S from participating in the grand coalition N(L). So long as the cost allocation is in the core,

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[7]Player n may voluntarily choose not to participate in the game

the members of coalition S will be willing to pay $R(L,S) \geq 0$, so for a cost allocation in the core, equation 13 may be rewritten as

(15) $NB(L,S) = GB(L,S) - R(L,S) \geq 0$

The core of a game can be defined by a set of net benefits vectors NB(L,S) for which

(16) $NB(L,S) \geq v(L,S)$ for all subsets S(L) of N(L)

(17) $NB(L,N) = v(L,N)$

Equation 17 simply states that the benefits to all participants in N(L) are divided up among the members of N(L). Equation 16 states that no subset of players S(L) would be better of after dropping out of the grand coalition. Equations 16 and 17 can be rearranged as:

(18) $v(L,N) \geq v(L,N-S)$, for all subsets S(L) of N(L)

Proposition 1: A cost allocation R(L,S) which satisfies equations 16 and 17 is not a cross-subsidizing cost allocation (is in the core).

Proof: If equation 16 is satisfied, then no coalition pays more than its gross benefits, so every possible coalition receives positive net benefits from membership in the coalition and therefore, the net benefits definition of non-cross-subsidization will not be violated. Also, if equations 15 and 16 are satisfied, then

$GB(L,S) - R(L,S) = NB(L,S) \geq v(L,S) = GB(L,S) - F^r(L^S)$

Therefore, $R(L,S) \leq F^r(L^S) = SAFC(X^S)$, and GB(L,S) includes variable transportation costs, so no coalition is required to pay more than its stand-alone cost. Since $R(L,S) \leq SAFC(X^S)$, then the net benefits constraint in 16 is a more restrictive requirement than a SAC constraint on cost allocations as proposed in previous rail cost allocation proposals.

In such a core, all fixed transportation costs would have to be allocated in such a way as to insure that equation 16 is satisfied for all possible coalitions. Even if a cost allocation exists so that all members of N(L) have an incentive to participate in the game, a different allocation of the same costs may cause some members of N(L) to drop out of the game and lead to less benefits for all members than v(L,N). However, the question of the existence of a core involving all members of N(L) will be considered first.

SHOULD ALL PLAYERS AND FACILITIES BE INCLUDED IN THE GAME?

Proposition 2: The necessary and sufficient condition for all facilities to be used is

(19) $v(L,N) \geq v(L^S,S)$ for all possible subsets L^S of L and all possible subsets S of N.

That is, the benefits after subtracting all costs to all members of the grand coalition N (some of whom may choose not to participate in the game) must be at least as great as the benefits to any subset of N from the facilities in a subset of L, or else efficiency could be increased by abandoning facilities.

Proof: Equation 19 is a necessary condition to serve all players because if it is not satisfied, then $v(L^S,S) > v(L,N)$ for some subset S(L) of N(L), which will then have the incentive to withdraw from coalition N. Then by equations 16 and 17, $NB(L^S,S) \geq v(L^S,S) > v(L,N) = NB(L,N)$. Therefore, no allocation in the core exists, because the members of S(L) will be able to increase their net benefits by withdrawing from the network and operating only network L^S.

Equation 19 is a sufficient condition because if it is satisfied, then $GB(L,N) - F^r(L) \geq GB(L^S,S) - F^r(L^S)$, and $GB(L,N) - GB(L^S,S) \geq F^r(L) - F^r(L^S)$. Let T = N(L) - S(L). Then

$GB(L,N) = GB(L,S) + GB(L,T)$, and

$GB(L,S) + GB(L,T) - GB(L^S,S) \geq F^r(L) - F^r(L^S)$. Rearranging slightly,

(20) $[GB(L,S) - GB(L^S,S)] + GB(L,T) \geq F^r(L) - F^r(L^S)$

The right side of Equation 20 is the cost savings if the facilities in L but not in L^S are abandoned, perhaps because coalition S(L) breaks away from the grand coalition. The term $GB(L,S) - GB(L^S,S)$ is the benefits to members of S(L) from staying in the network and using the facilities in L but not in L^S. It is also the maximum that the members of S(L) will be willing to pay for any additional facilities not in L^S. The term GB(L,T) is the benefits to the members of T from participating in the coalition (or from coalition S(L) not defecting from the coalition). The maximum that the members of T will be willing to pay for any additional facilities not in L^S is the minimum of GB(L,T) and $F^r(L^T)$. If $GB(L,T) \leq F^r(L^T)$, then by Equation 20, the sum of what the members of S(L) are willing to pay toward the facilities in L but not in L^S plus what members of T are willing to pay for those facilities is at least as great as the cost of providing those facilities, so both members of S(L) and T will have the incentive to contribute enough to pay for those facilites. If $GB(L,T) > F^r(L^T)$, then the members of T will be willing to pay at most $F^r(L^T)$. Note that $F^r(L^T) \geq F^r(L) - F^r(L^S)$. Therefore, the members of T are willing to pay at least as much as the cost of providing the facilities in L but not in L^S, even if the members of S(L) do not contribute anything toward the cost of those facilities. Either way, Equation 20 shows that those facilities will be provided, so Equation 19 is a sufficient condition for all facilities in L to used.

The proposals surveyed in the previous chapter all assume that no facilities or services will be abandoned. If equation 19 can be satisfied for all possible coalitions of players, then some or all of these allocation proposals may lead to efficient provision of services. However, if equation 19 cannot be satisfied for all possible coalitions of players, then by definition, any of the proposals in the previous chapter will lead to inefficient provision of some services. Many facilities and services have been abandoned since the passage of the Staggers Rail Act, so it is argued in the next section that the problem of allocating fixed costs cannot be separated from the problem of determining the most efficient network structure.

THE MOST EFFICIENT NETWORK

If equation 19 is satisfied for the existing set of facilities L and players N(L), allowing for voluntary nonparticipation, then Proposition 1 shows that a two-part tariff in the core exists, so the problem is simply to find such a cost allocation. Several approaches to the problem of finding a cost allocation in the core will be proposed in the final section of this chapter.

Suppose, however, that equation 19 is not satisfied for L and N(L). There will always be some network for which a core solution exists, because equation 19 will certainly be satisfied for $L^S = \emptyset$. If $L^S = \emptyset$, then $F^r(L^S) = 0$, so equation 19 will be satisfied for an empty set of players. Of course, this will not be a rail transportation problem. But there will always be a set of players and facilities for which a core allocation exists, since this condition is always satisfied by an empty set of rail facilities.

Another case, where condition 19 is not satisfied for L and all members of N(L), but may be satisfied for L and a subset S(L) of N(L), has already been considered, since the analysis above allows for nonparticipation of members of N(L). The previous analysis also considers (in equation 13) which subset of N(L) for which a core solution exists is most efficient. In this case, let $N^*(L)$ be the subset of players in N(L) who participate in the game over the set of links L. Of course, the solution will be the same for N(L) and $N^*(L)$, since participation is always voluntary in this game.

But the more interesting cases are where equation 19 cannot be satisfied for L and any S(L), or else where a more efficient solution can be found when links are abandoned. To solve such a problem, the characteristic function can be rewritten as:

$$(21)\quad v(L^*,N^*) = \max_X \{ \sum_{i=1}^{I} \sum_{j\epsilon J_i} \sum_{k\epsilon K_i} \int_0^{X^*_{ijk.}} P_{ijk}(x_{ijkm})dx_{ijk.}$$

$$- \sum_{i=1}^{I} \sum_{j\epsilon J_i} \sum_{k\epsilon K_i} \sum_{m=1}^{M_{ijk}} c^*_{ijkm}X_{ijkm} - \sum_{i=1}^{I} \sum_{j\epsilon J_i} \sum_{k\epsilon K_i} TS_{ijk} - F^r(L^*) \}$$

This is still the same characteristic function that was defined in equation 13, but in equation 21, L^*, $N^*(L^*)$, and $X^*_{ijk.}$ are included for emphasis on the services and facilities that are included in the game. However, this distinction between L and subset L^* of L will be used in the next section when finding ranges of cost allocations in the core.

It should be noted that with constant variable transportation costs, then there may not be a unique most efficient network. If alternative routes have the same variable transportation cost (if $c^*_{ijka} = c^*_{ijkb}$ for $a \neq b$ regardless of X^*_{ijka} and X^*_{ijkb}), then there may be more than one set of most efficient facilities and traffic flows. However, there will be only one $X^*_{ijk.}$[8]. There will be no inefficient exclusion of shippers, because all shippers that are able to able to use a route at least as inexpensive as the best alternative shipper (using either transportation mode) will add to the total consumer surplus (and contribute to the recovery of the fixed costs), which is maximized for the most efficient network.

FINDING AN ALLOCATION IN THE CORE

A non-subsidizing cost allocation exists for L^* and $N^*(L^*)$, so the last stage of the problem is to find a cost allocation in the core for some L^* and $N^*(L^*)$[9]. It has been argued in this chapter that this discussion of non-subsidizing networks cannot be separated from the discussion of the most efficient network configuration. This close relationship between the two concepts made the discussion of the theory of the most efficient network structure rather complicated, but the benefit of that discussion is that in the process of determining the most efficient network structure, the constraints on the cost allocation are determined. A non-subsidizing cost allocation is one which gives the shippers and carriers the incentive to operate the most efficient network, so a cost allocation which satisfies equations 16 and 17 will be a non-subsidizing cost allocation. In other words, the problem of avoiding cross-subsidization is redefined as a problem of maximizing the efficiency of the network structure.

Such a non-subsidizing (or core) allocation was found to be one

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[8]See Theorem 8 in Shapley (1965) for an existence proof which is applicable to $X_{ijk.}$ and the most efficient network, but not applicable to X_{ijkm}.

[9]This L^* may be the empty set of facilities.

in which all fixed costs are allocated to shippers so that no shipper or group of shippers pays more than either its stand-alone cost or the gross rail surplus gain received from participation. Thus, a cost allocation in the core would be one for which:

(22) $R(L^*,S) \leq \min(F^r(L^S), GB(L^*,S)$ for all subsets $S(L^*)$ of $N(L^*)$

Therefore, once the constraints in equation 22 (which must be satisfied for the most efficient network) are found, these constraints can be used to find a core allocation. Since both rail benefits and stand-alone costs are used to define upper bound constraints, this cost allocation based upon avoiding inefficient abandonment of facilities allows the fixed costs of the network to be recovered in a less arbitrary manner than would be possible without considering the abandonment of facilities.

By definition, this process of finding the most efficient network will also generate a set of lower bound constraints, since the existence of a maximum allocation for one set of shippers $S(L^*)$ imposes the requirement that the remaining shippers in $N(L^*)$ pay any fixed costs that the shippers in $S(L^*)$ are unwilling to pay. Therefore,

(23) $R(L^*,T) \geq \max\{F^r(L^*) - R(L^*,S), 0\}$ for $T = N(L^*) - S(L^*)$

Any cost allocation using fixed charges which do not violate the constraints in 22 and 23 is a non-subsidizing cost allocation. A number of cost allocation rules have been proposed elsewhere to arbitrarily allocate costs subject to constraints such as the upper bounds on allocations to groups in equation 22. Hamlen, et. al. (1977) use core theory to evaluate at length four allocation rules, including the Moriarity Rule used by Fanara and Grimm. To use these allocation rules, the unallocatable costs $F^r(L^*)$ of the network are added up and allocated according to some predetermined weights. Let $E(L^*,S)$ be the upper bound on fixed costs of operating network L^* allocated to coalition $S(L^*)$, so that $E(L^*,S) = \min(F^r(L^S), GB(L^*,S))$.

Hamlen, et. al., find that three of the allocation rules produce allocations in the core (and therefore are appropriate to use in this problem), but the Moriarity Rule may not. An example of a cost allocation which is always in the core is based upon the Shapely[10] value (based upon the benefits to buyers and sellers of x_{ijkm}). This allocation rule has each shipper in $N^*(L^*)$ allocated its Shapely value so that

$$(24) \quad A^f{}_{ijkm} = \frac{(y^s-1)!(y^n-y^s)!}{y^n!}(E(L^*,S) - E(L^*,S-n))$$

where y^s = the number of members in $S(L^*)$ and y^n = the number of members in $N^*(L^*)$. This Shapely-value allocation will always be in the core, but it becomes increasingly difficult to calculate as the number of members in $N^*(L^*)$ increases.

CONCLUSION

In this chapter, it was shown that the largest L^S for which equation 19 can be satisfied will be the most efficient subset of network L, and efficiency can be increased by abandoning all facilities in L but not in L^S. Allowing for facilities abandonments also narrows the range of the fixed charges which may be charged to shippers in order to allocate the shared costs of the facilities in

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[10]Shapely (1953) proposed this value as a method for potential players to decide whether to enter a game by finding a priori their expected benefits from playing the game.

L^S, because allocating more than the upper bound to a facility or set of facilities will lead to inefficient facility abandonments.

This cost allocation based upon avoiding inefficient abandonment of facilities allows the fixed costs of the network to be recovered in a less arbitrary manner than would be possible without considering the abandonment of facilities. Under this allocation, the problem of avoiding cross-subsidization is redefined as a problem of maximizing efficiency. Such an approach by itself leads to a non-subsidizing allocation, so it is not necessary to consider issues of cross-subsidization separately, as was the case with proposals based upon Ramsey-pricing with stand-alone cost constraints.

CHAPTER 4: AN APPLICATION TO THE MICHIGAN RAIL NETWORK

In this chapter, the first-best allocation of fixed costs developed in the previous chapter will be applied to the 1984 Michigan rail shipments. It will be shown that when the abandonment of rail facilities is promoted if such abandonments will increase efficiency, then a first-best cost allocation may be found which is more efficient and less arbitrary than was previously though possible. The primary purpose of this chapter is to show that the approach to allocating costs proposed in chapter 3 can indeed be applied to existing traffic flows.

THE MODEL AND THE DATA

Although all railroad services would have different transportation demands and costs, data limitations and the costs of analyzing a highly complex network make it desirable to aggregate shipments into a set of relatively few homogeneous product categories and origins and destinations into a smaller number of regions. Since the purpose of this application is to show primarily how such a first-best cost allocation would be found for an existing transportation system, the services to which the cost allocation are applied are aggregated into a relatively small number of services. This relatively high level of aggregation simplifies the cost allocations procedure, making the cost savings from efficient abandonment of services more apparent, while still demonstrating how such a cost allocation could be found for a more complicated (less aggregated) set of traffic flows.

The commodities shipped into and out of Michigan were aggregated into four commodity groups chosen to roughly correspond with the commodity groups defined by Friedlaender and Spady[1]. The commodity groups are defined in Table 1 below. In the notation of Chapter 3, I = 4, with i = 1 for durable manufactures, i = 2 for nondurable manufactures, i = 3 for petroleum and related products, and i = 4 for minerals, chemicals, and all other shipments.

Origins and destinations of commodities in the lower peninsula of Michigan were divided into six regions; Southwestern Michigan (including Kalamazoo), Southeastern Michigan (including Detroit), the "Thumb" region (extending to Flint and the Northern Detroit suburbs), Northern Michigan, Western Michigan (the area around Grand Rapids), and Central Michigan (including Lansing). Each of the six regions is considered to be one location, so that all shipments into and out of the regions will be regarded as if they had the same point of origin or destination. These regions are shown in Table 2.

Origins and destinations of freight shipments entering or leaving the lower peninsula of Michigan were also divided into six regions. Two of these regions include the areas which have Michigan borders and thus, relatively short shipping distances. One of these regions borders on the Southeastern Michigan region and consists of Ohio, Western Pennsylvania, West Virginia, Eastern Kentucky, and Ontario, and the other region borders on the Southwestern Michigan region and consists of Indiana, Illinois, and Western Kentucky. The states west of the Mississippi River plus Wisconsin, the Upper Peninsula of Michigan, and the Canadian Provinces west of and including Manitoba are divided into two regions. The remaining states north and east of

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[1]Friedlaender and Spady (1981), p. 57.

Virginia plus the Canadian Provinces east of Ontario are the fifth non-Michigan region, and the final region consist of the remaining southern states west of the Mississippi River. These six regions outside of Michigan are shown in Table 3, and the combinations of i, j, and k for commodities and their origins and destinations are shown in Table 4.

The rail links between these locations are hypothetical rail links. If two Michigan regions share a border, it was assumed that there is one rail link between them. The links between any two Michigan locations are considered to be abandonable links. It is assumed that there is enough traffic over all links partially or entirely outside of the Michigan lower peninsula to make abandonment of any of them inefficient. Only the fixed costs from the 9 available Michigan rail links will be recovered in this exercise. The fixed costs of the other links are ignored because the data used below are for shipments into and out of Michigan only, so the recovery of the fixed costs of the non-Michigan links will also include allocations to shipments which are not in the sample.

The principal source of data is the ICC's Annual Rail Waybill Sample Master File for 1984, which provides commodity codes, actual and short-line distances, weights, and transportation revenues on rail shipments between different origins and destinations. The shipments in this sample are a one-percent sample of the total shipments into or out of the lower peninsula of Michigan. Out of this sample of 18178 shipments which had Michigan Lower Peninsula origins or destinations, 36 were removed because they had no reported origin, destination, commodity code, or shipment weight, and another 1481 were removed

Table 1: Commodity Categories
with Two Digit Census Codes and Numbers of Shipments

Category 1: Durable Manufactures (7894 Shipments in the Sample)

Commodity Code	Commodity	Number of Shipments
33	metal alloys and fabricated products	618
34	fabricated metal products	13
35	non-electrical machinery	24
36	electrical machinery and products	91
37	transportation equipment (including autos)	7148

Category 2: Nondurable Manufactures (1361 Shipments)

Commodity Code	Commodity	Number of Shipments
19	ammunition	3
22	textiles and finished textile products	18
23	finished textile products	101
24	lumber and wood products	206
25	furniture and fixtures	29
26	paper and paper products	902
27	printed matter	1
30	rubber and plastic products	101

Category 3: Petroleum and Related (380 Shipments)

Commodity Code	Commodity
29	petroleum products

Category 4: Mineral, Chemical, and Other (5815 Shipments)

Commodity Code	Commodity	Number of Shipments
1	farm products	244
10	iron ore, aluminum, bauxite	687
11	coal	1190
14	nonmetallic minerals	319
20	food and kindred products	711
28	chemicals	399
32	stone, clay, glass, concrete	376
39	misc. products	10
40	waste and scrap	591
41	misc.	347
42	returned containers	238
43	mail	9
44	freight forwarded	1
45	shipper association	48
46	mixed shipments	629
47	small packages	16

Table 2: Michigan Transportation Regions
with Four-Digit Standard Point Location Codes (SPLC)

Region 1: Northern Michigan

Michigan County	SPLC	Michigan County	SPLC	Michigan County	SPLC
Presque Isle	3111	Cheboygan	3112	Alpena	3113
Montmorency	3114	Otsego	3116	Alcona	3117
Oscoda	3118	Crawford	3119	Emmet	3121
Charlevoix	3122	Antrim	3124	Leelanau	3125
Kalkaska	3126	Grand Traverse	3128	Benzie	3129
Iosco	3131	Ogemaw	3132	Roscommon	3133
Arenac	3134	Gladwin	3135	Clare	3136
Bay	3137	Midland	3138	Isabella	3139
Missaukee	3141	Wexford	3142	Manistee	3143
Osceola	3144	Lake	3145	Mason	3146
Mecosta	3147	Newaygo	3148	Oceana	3149

Region 2: The "Thumb" Region (including Flint)

Michigan County	SPLC	Michigan County	SPLC	Michigan County	SPLC
Huron	3151	Salinac	3152	Tuscola	3153
St. Claire	3154	Lapeer	3155	Genese	3156-3157
Macomb	3158	Oakland	3159		

Region 3: Mid-State Region (including Lansing)

Michigan County	SPLC	Michigan County	SPLC	Michigan County	SPLC
Saginaw	3161-3162	Gratiot	3163	Shiawassee	3164
Clinton	3165	Livingston	3166	Ingham	3167-3168
Eaton	3169				

Region 4: Western Michigan (including Grand Rapids)

Michigan County	SPLC	Michigan County	SPLC	Michigan County	SPLC
Montcalm	3171	Muskegon	3172	Ionia	3173
Kent	3174-3175	Ottawa	3176	Barry	3178
Allegan	3179				

Region 5: Southeastern Michigan (including Detroit)

Michigan County	SPLC	Michigan County	SPLC	Michigan County	SPLC
Wayne	3181-3183	Washtenaw	3184	Jackson	3186
Monroe	3187	Lenawee	3188	Hillsdale	3189

Region 6: Southwestern Michigan (including Kalamazoo)

Michigan County	SPLC	Michigan County	SPLC	Michigan County	SPLC
Calhoun	3191	Kalamazoo	3192-3193	Van Buren	3194
Branch	3196	St. Joseph	3197	Cass	3198
Berrien	3199				

Table 3: Transportation Regions Outside of Michigan with Two-Digit Standard Point Location Codes (SPLC)

Region 7: Ohio Border

State or Province	SPLC	State or Province	SPLC
Ontario	04	Western Pennsylvania	21
West Virginia	27	Eastern Kentucky	28
Ohio	34-35		

Region 8: Indiana Border

State or Province	SPLC	State or Province	SPLC
Western Kentucky	29	MI Upper Penninsula	30
Wisconsin	32-33	Indiana	36-37
Illinois	38-39		

Region 9: Eastern U.S. and Canada

State or Province	SPLC	State or Province	SPLC
Eastern Canada	00-03	Maine	11
New Hampshire	12	Vermont	13
Massachusetts	14	Rhode Island	15
Connecticut	16	New York	17-18
New Jersey	19	Eastern Pennsylvania	20
Delaware	22	Maryland	23
District of Columbia	24		

Region 10: Southeastern U.S.

State or Province	SPLC	State or Province	SPLC
Virginia	25-26	North Carolina	40-41
Tennessee	42-43	South Carolina	44
Georgia	45-46	Alabama	47
Mississippi	48	Florida	49

Region 11: Central U.S.

State or Province	SPLC	State or Province	SPLC
Minnesota	50	North Dakota	51
South Dakota	52	Iowa	53-54
Nebraska	55	Missouri	56-57
Kansas	58-59	Arkansas	60-61
Oklahoma	62-63		

Region 12: Western U.S. and Canada

State or Province	SPLC	State or Province	SPLC
Western Canada	05-09	Louisiana	64-65
Texas	66-69	Montana	70-71
Wyoming	72-73	Colorado	74-75
Utah	76	New Mexico	77-78
Arizona	79	Alaska	80-82
Idaho	83	Washington	84
Oregon	85	Nevada	86
California	87-88		

after the lower peninsula was divided into regions because their origins and destinations were in the same region. Finally, many of the prices and shipments weights appeared to be implausibly high, so shipments were removed until all shipments had prices (per ton-mile) and shipment weights less than 5 times the mean prices and shipment weights. This led to the removal of the 358 shipments with the highest prices and the 853 shipments with the greatest weights. The final sample consists of 15450 shipments.

Fixed transportation costs were estimated from data in the March of 1984 Transport Statistics in the United States. The ICC cost of capital was 15.8% in 1984[2], so the cost of capital was defined as 15.8% of the Net (after depreciation) Road and Equipment entry for all class 1 railroads in 1984. The total freight ways and structure expense and the total freight general and administrative expense were also defined as unallocatable overhead costs and the sum of these costs was divided by the miles of track operated by freight carriers. This fixed cost was estimated as $82,608 per mile of track for each of the nine Michigan facilities in 1984.

Variable transportation costs over rail links were estimated by adding the total freight equipment expense and the total transportation expense and dividing by the gross ton-miles of revenue freight. This variable cost was 2.03 cents per ton-mile of freight.

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[2]Government Accounting Office Documents, Railroad Revenues: Analysis of Alternetive Methods to Measure Revenue Adequacy, released October 2, 1984.

Net Road and Equipment	$42,115,494,000	
(including passenger service)	x .158	
Cost of Capital		$6,654,248,000
Freight Ways and Structures Expense		4,210,046,000
General and Administrative Expense		2,666,680,000
Total Fixed (Unallocatable) Costs		$13,530,974,000

Average Fixed Costs per Mile = Total Fixed Cost / Track Miles
= $12,772,895,000 / 163,798 = $82,608 per mile of track

Freight Equipment Expense	$6,512,674,000
Total Freight Transportation Expense	12,126,312,000
Total Variable Freight Cost	$18,638,959,000

Average Variable Costs per Ton-Mile of Rail Traffic
= Total Variable Freight Costs / Gross Ton-Miles of Freight
= $18,638,959,000 / 918,672,776 = 2.03 cents per ton-mile

Distances between any pair of Michigan cities were estimated as the average short-line miles from shipments between the two regions in the ICC sample. It was observed that the shipments which tended to travel the furthest when entering or leaving the state were those from the regions on the southern Michigan border. Thus, for all shipments to and from a particular region outside of Michigan by way of a particular border region inside of the state (over links 10 to 18), the the difference between the total short-line miles and the miles to or from the border region were calculated. The average of these differences was used as the mile length of the link between the region outside of the state (regions 7 to 12) and the Michigan borger region (regions 2, 5, or 6). The rail links and the miles assigned to them are shown in Figure 2.

It was assumed that all shipments not carried by rail could be carried by truck carriers over the shortest route (or part of a route) between the two cities. The distances by truck between two regions were assumed to be the same as the short-line rail track distance

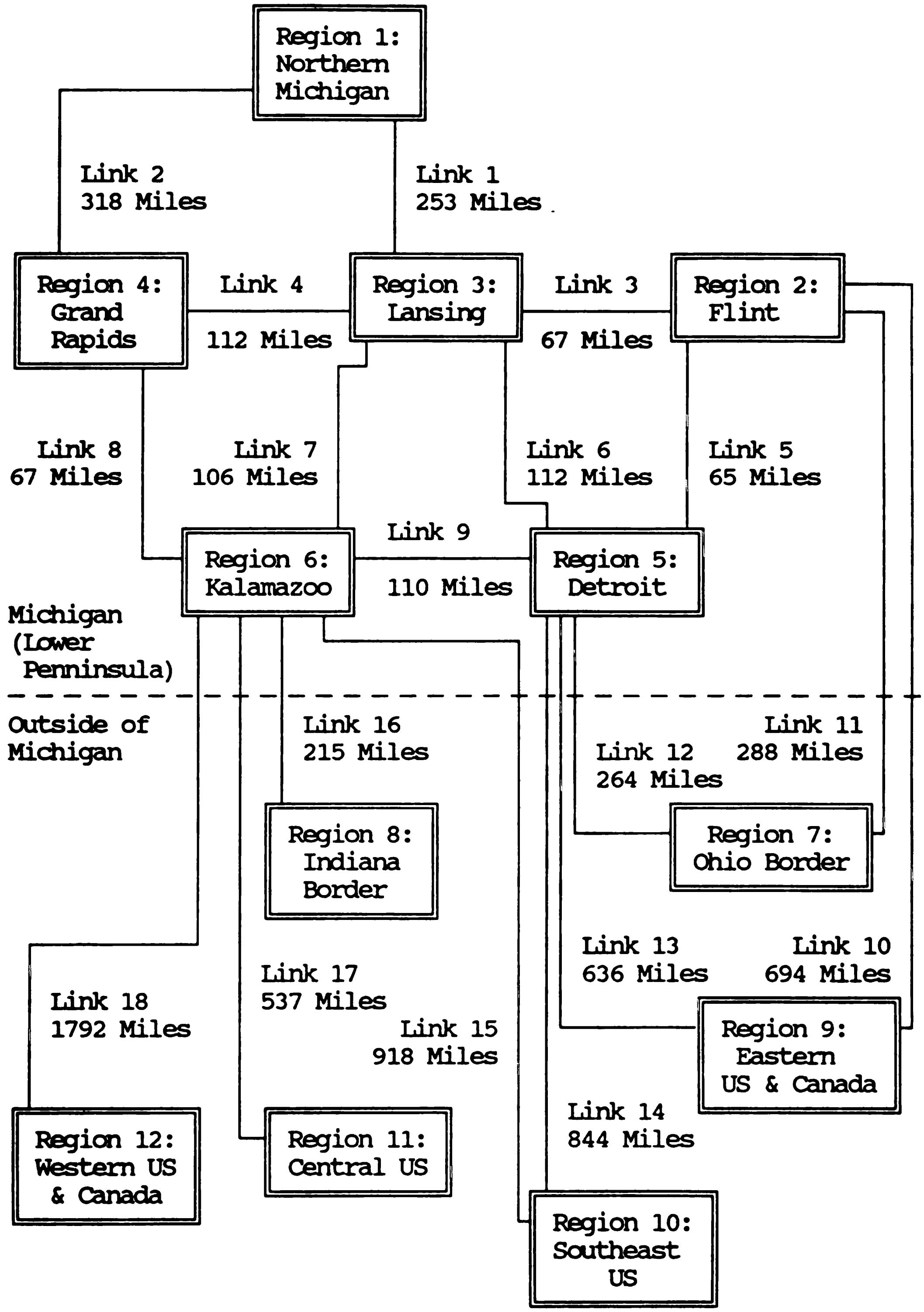

Figure 2: The Available Rail Links

between the cities. Shipments could be carried part-way by truck and part-way by rail. These truck carriers were assumed to charge a constant rate per ton-mile and no fixed charges. The estimate of average revenue per ton-mile for Class I trucks was 9.9 cents[3] for 1986. Deflating that estimate by the producer price for 1986 (relative to 1984), the 1984 average truck rate was estimated as 9.56 cents per ton-mile.

When estimating the demand curves for commodities carried over the network, no attempt was made to distinguish between origin and destination locations. All shipments in the same commodity category carried in either direction between two locations were considered to be part of the same service. The relevant quantities are the tons shipped of the commodity.

The demand curve for any given service was found from the average price charged for all shipments of the particular commodity category between the two particular locations, the total (over all shipments in the sample) tons[4] of the commodity carried between the two locations, and the elasticity of demand for the commodity category which were estimated by Friedlaender and Spady[5] for shipments in the Eastern United States. This elasticity is assumed to be the elasticity of demand for a linear demand curve at the point on the demand curve where the price and quantity are the average rate per ton-mile (including the fixed cost allocation) and the total tons of

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[3]Reported in Transportation in America (March, 1988), page 11.

[4]Because the sample is of one-percent of the shipments, the tons in the sample were multiplied by 100.

[5]Friedlaender and Spady (1981), p. 58.

the commodity shipped between the two locations. Friedlaender and Spady estimated that these elasticities were .8428 for commodity class 1, .7022 for commodity class 2, 1.1638 for commodity class 3, and .5893 for commodity class 4. Note that the elasticity of demand is the smallest for the commodity class which includes coal shipments.

THE MOST EFFICIENT NETWORK

With L defined as the set of all 9 Michigan railroad links, the gross rail surplus gain for all possible sets[6] of facilities $L^S \epsilon L$ was found by considering every possible L^S. For each L^S, the most efficient routes and shipment quantities were found and the gross rail surplus gain from each shipment quantity were added to find the gross rail benefits for the subnetwork. This was accomplished by first finding the least expensive route for all shipments over L^S, then finding the consumer surplus maximizing quantity and respective consumer surplus for each of these shipments. Finally, the fixed costs of operating L^S were subtracted from the sum of these consumer surpluses over network L^S. Since the fixed costs are recovered through fixed charges, the most efficient shipment quantities are those for which the variable rate per ton is equal to the variable cost of transporting a ton of the commodity over the least expensive available route between the two cities.[7]

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[6]With 9 abandonable facilities, there were $2^9 = 512$ possible L^S including $L = \{1,2,3,4,5,6,7,8,9\}$ and $\emptyset$. Each of these network were considered when finding the most efficient network. If the network were much larger than 9 abandonable links, a more efficient search procedure would be needed to find the most efficient network. Several such procedures are described by Bazaraa and Jarvis (1977).

[7]Using the assumption of independent demand curves, the most efficient quantities were found by setting the variable cost allocation equal to the variable transportation cost.

The most efficient subset of facilities in L was found to be $L^* = \{1,3,5,7,8,9\}$. Therefore, it is be efficient to abandon rail links 2, 4, and 6. Equations 16, 17, and 19 could also be satisfied for any subset of L^*, but according to Proposition 2, there is no L^S which includes link 2, 4, and/or 6 for which a cost allocation in the core exists.

This L^* spans all possible origin and destination links. Thus, the most efficient set of shipment quantities X^* includes only shipments carried by Michigan rail links[8] and shipments which can be carried directly from a Michigan node to an outstate node without using Michigan rail facilities. Table 5 shows the most efficient routes and shipment quantities over the existing network, the actual average prices and total shipment quantities, the most efficient variable cost allocations and shipment quantities over most efficient network, the total surplus if all Michigan rail links are closed (truck benefits), and the additional surplus (rail net benefits before fixed costs are allocated) if transportation services over the six links in L^* are available to shippers. If the net benefits from the rail links are zero for a shipment, then that shipment can be carried by rail between the two nodes without using a Michigan (abandonable) rail link. The gross rail surplus gain for all shipments over L^* is $299,073,460 and the total fixed costs over this network are $55,182,146. Therefore, willingness to pay exceeds the costs of

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[8]This result is specific to this problem. With the truck variable rate per ton-mile almost 5 times as great as the rail variable cost per ton-mile and all nodes connected to the rail network, the shortest truck route would have to be shorter than about 20% of the shortest available rail route in order to attract traffic away from the rail carriers. For no shipments over L^* is the shortest rail route as much as 5 times as long as the shortest truck route.

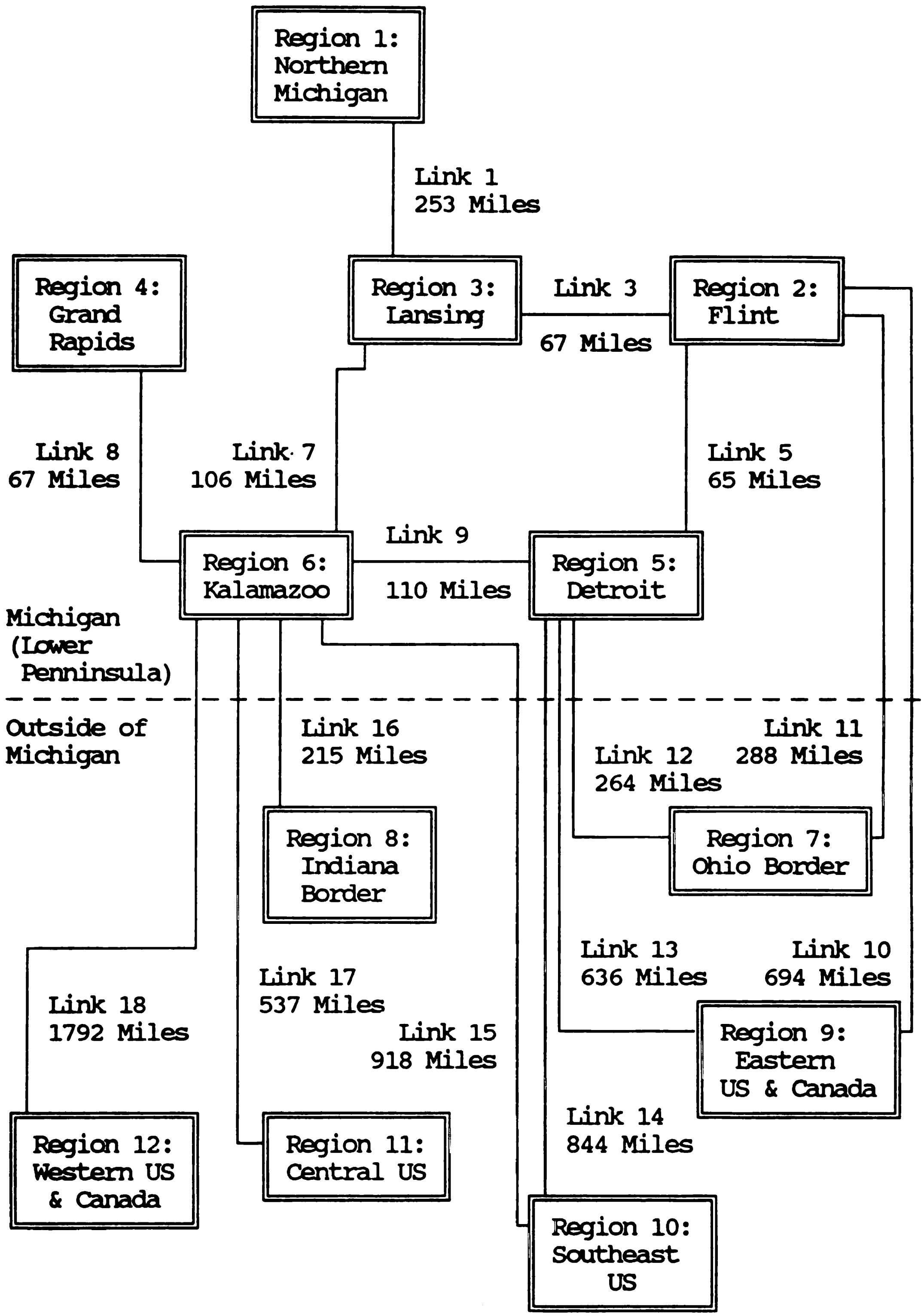

Figure 3: The Most Efficient Network

Table 4: Routes and Quantities

Between* Regions	Commodity	Observed: Total Cost Allocation Per Ton**	Observed: Tons Shipped**	Most Efficient Network: Variable Cost Allocation Per Ton♦	Most Efficient Network: Tons Shipped♦	Most Efficient Network: Truck Benefits⊙	Most Efficient Network: Rail Net Benefits§
1 and 2	2	33.80	2.50	6.50	3.92	68.46	79.33
	4	16.80	5.00	6.50	6.81	18.99	113.11
1 and 3	2	26.80	3.50	5.14	5.49	76.25	87.89
1 and 4	2	17.79	9.30	8.65	12.66	29.68	188.42
	3	6.16	8.81	8.65	4.66	0	6.51
1 and 5	2	10.90	21.98	7.82	26.34	0	244.99
	4	8.30	33.15	7.82	34.29	0	249.82
1 and 7	1	7.46	110.66	12.34	49.54	0	98.11
	2	14.57	264.40	12.34	292.82	0	3,365.40
	3	15.52	3.34	12.34	41.36	0	34.15
	4	9.65	1301.69	12.34	1,087.19	0	7,431.23
1 and 8	1	6.56	.75	11.65	.26	0	.35
	2	13.98	63.89	11.65	71.36	0	793.59
	4	8.13	346.22	11.65	257.92	0	1,325.78
1 and 9	2	20.41	238.60	20.58	237.19	94.65	3,332.53
	4	17.61	641.60	20.58	577.77	85.11	7,689.28
1 and 10	1	17.05	26.23	24.95	15.98	0	98.51
	2	24.10	187.21	24.95	182.59	111.71	2,944.77
	4	20.93	244.70	24.95	216.97	66.90	3,348.70
1 and 11	1	14.00	23.85	18.18	17.83	0	110.75
	2	23.89	173.19	18.18	202.19	409.40	3,605.60
	4	25.88	405.29	18.18	476.26	2,786.28	9,502.48
1 and 12	1	38.79	54.26	43.67	48.50	117.30	880.35
	2	75.37	19.51	43.67	25.27	1,140.05	616.77
	4	37.89	392.12	43.67	356.89	3,023.46	7,419.51
2 and 3	1	21.89	49.60	1.36	88.81	1,640.73	423.72
	4	3.40	204.32	1.36	276.51	134.45	943.80
2 and 4	1	23.19	36.11	4.87	60.14	740.13	637.82
	4	15.78	7.35	4.87	10.34	88.85	106.05
2 and 5	1	10.90	104.28	1.32	181.52	1,250.75	791.82
	2	2.77	6.18	1.32	8.45	.20	22.61
	4	6.89	270.50	1.32	399.36	1,767.83	1,677.41
2 and 6	4	5.08	5.60	3.51	6.62	0	33.70
2 and 7	1	25.00	1143.52	5.85	1,881.89	45,933.87	0
	2	30.11	140.28	5.85	219.65	7,374.90	0
	3	10.24	7.60	5.85	13.40	75.19	0
	4	14.61	1506.61	5.85	2,039.04	34,197.00	0
2 and 8	1	35.15	818.84	7.88	1,354.32	30,737.60	15,976.82
	2	25.62	64.45	7.88	95.79	1,499.67	1,097.97
	3	21.24	9.97	7.88	17.27	94.32	178.61
	4	14.36	451.71	7.88	571.85	2,941.81	5,876.13
2 and 9	1	40.14	1545.95	14.09	2,391.62	88,117.11	0
	2	32.22	123.55	14.09	172.38	5,518.22	0
	3	12.02	7.99	14.09	6.39	26.40	0
	4	37.83	289.20	14.09	396.16	17,419.40	0
2 and 10	1	44.08	1836.41	18.45	2,736.21	93,638.60	12,971.78
	2	42.04	182.88	18.45	254.92	9,425.68	1,211.13
	3	11.46	3.89	18.45	1.13	0	1.61
	4	24.72	352.09	18.45	404.65	7,872.26	1,880.02
2 and 11	1	48.96	1303.38	14.41	2,078.51	71,110.41	25,172.99
	2	38.41	144.39	14.41	207.73	5,692.70	2,482.15
	4	45.17	247.23	14.41	346.43	14,363.97	4,239.23
2 and 12	1	101.04	1478.15	39.89	2,232.13	174,027.17	28,031.57
	2	32.83	168.94	39.89	143.41	1,283.98	1,561.58
	3	30.91	30.32	39.89	20.06	11.81	164.51
	4	80.67	200.69	39.89	260.47	19,868.92	3,268.76

Table 4 (Continued)

Between Regions	Commodity	Observed: Total Cost Allocation Per Ton	Observed: Tons Shipped	Most Efficient Network: Variable Cost Allocation Per Ton	Most Efficient Network: Tons Shipped	Most Efficient Network: Truck Benefits	Most Efficient Network: Rail Net Benefits
3 and 4	1	18.28	35.20	3.51	59.17	694.81	383.71
	4	6.38	25.09	3.51	31.73	48.85	168.28
3 and 5	1	13.71	35.65	2.68	59.82	406.79	409.61
	3	3.32	6.99	2.68	8.56	0	14.94
	4	5.40	181.11	2.68	234.92	147.72	1,249.51
3 and 6	1	16.31	5.50	2.15	9.52	92.62	66.96
	4	19.50	3.30	2.15	5.03	89.90	36.97
3 and 7	1	26.81	216.59	7.21	350.06	7,319.17	1,679.45
	3	13.66	6.80	7.21	10.54	50.03	45.79
	4	13.59	2281.86	7.21	2,913.59	29,461.81	13,440.25
3 and 8	1	27.64	91.70	6.52	150.76	2,950.84	1,114.28
	3	9.15	108.73	6.52	145.15	43.70	718.05
	4	12.86	281.63	6.52	363.47	2,627.49	2,490.00
3 and 9	1	37.33	339.93	15.45	507.87	14,340.52	2,464.59
	2	40.60	13.07	15.45	18.76	686.36	91.75
	3	34.21	14.59	15.45	23.89	460.99	114.23
	4	28.25	506.33	15.45	641.55	16,383.25	3,102.29
3 and 10	1	44.07	402.33	19.81	589.00	18,069.28	4,480.43
	2	19.67	216.20	19.81	215.11	1,519.75	1,478.15
	3	11.12	133.02	19.81	11.92	0	5.10
	4	18.38	492.00	19.81	469.43	3,725.32	3,260.16
3 and 11	1	59.65	365.57	13.05	606.25	30,900.80	4,674.39
	2	26.52	32.21	13.05	43.70	797.78	321.60
	4	42.32	140.36	13.05	197.56	8,469.69	1,514.63
3 and 12	1	94.06	257.27	38.53	385.27	29,192.21	3,001.65
	2	70.67	54.45	38.53	71.83	4,213.18	556.13
	3	21.39	7.70	38.53	.52	0	.32
	4	64.20	110.30	38.53	136.28	8,116.88	1,055.53
4 and 5	1	18.93	77.36	3.59	130.18	1,031.36	1,429.15
	4	2.04	14.60	3.59	8.06	0	7.71
4 and 6	4	10.92	7.10	1.36	10.76	101.79	49.43
4 and 7	1	26.94	113.00	8.95	176.58	2,369.93	2,039.47
	2	35.42	14.83	8.95	22.61	594.22	275.25
	4	7.12	1308.73	8.95	1,110.27	0	5,690.26
4 and 8	1	10.97	235.10	5.72	329.79	1,575.52	1,433.87
	2	8.00	93.84	5.72	112.56	305.65	462.97
	3	8.77	9.76	5.72	13.70	19.80	52.63
	4	6.32	299.06	5.72	315.74	550.22	1,238.24
4 and 9	1	49.07	173.55	16.50	270.62	8,943.51	3,342.11
	2	31.49	99.64	16.50	132.94	2,403.07	1,574.47
	4	14.70	284.32	16.50	263.79	549.47	2,503.70
4 and 10	1	49.30	80.22	20.00	120.40	4,695.07	589.97
	2	18.23	293.36	20.00	273.41	2,072.09	1,235.57
	3	11.31	62.89	20.00	6.71	0	3.48
	4	17.53	292.80	20.00	268.49	2,431.75	1,229.26
4 and 11	1	55.59	170.68	12.26	282.80	14,058.17	1,393.81
	2	16.29	198.76	12.26	233.29	2,108.67	1,067.96
	4	18.42	244.57	12.26	292.74	4,098.22	1,377.33
4 and 12	1	76.58	50.48	37.74	72.05	4,316.63	356.44
	2	28.77	225.93	37.74	176.49	2,004.48	820.25
	4	32.91	326.22	37.74	298.00	6,172.05	1,429.12

Table 4 (Continued)

Between Regions	Commodity	Observed: Total Cost Allocation Per Ton	Observed: Tons Shipped	Most Efficient Network: Variable Cost Allocation Per Ton	Most Efficient Network: Tons Shipped	Most Efficient Network: Truck Benefits	Most Efficient Network: Rail Net Benefits
5 and 6	1	14.10	14.70	2.23	25.13	181.21	177.98
	4	5.66	38.80	2.23	52.64	45.33	297.29
5 and 7	1	19.12	2877.80	5.36	4,623.30	84,252.69	0
	2	22.53	53.06	5.36	81.45	2,005.55	0
	3	19.87	683.88	5.36	1,265.08	19,976.01	0
	4	8.34	4838.84	5.36	5,857.65	50,167.56	0
5 and 8	1	26.54	1255.21	6.60	2,050.15	37,115.30	15,614.22
	2	12.07	73.68	6.60	97.12	442.44	657.33
	3	12.83	112.65	6.60	176.33	411.37	1,109.99
	4	10.16	772.61	6.60	932.25	3,512.27	6,184.54
5 and 9	1	29.26	2938.20	12.91	4,321.70	110,328.53	0
	2	26.04	442.72	12.91	599.44	15,048.02	0
	3	11.66	152.79	12.91	133.68	585.80	0
	4	16.83	744.18	12.91	846.24	13,738.66	0
5 and 10	1	36.77	1802.02	17.13	2,613.00	82,641.91	0
	2	22.62	545.81	17.13	638.71	12,036.31	0
	3	21.89	620.80	17.13	777.82	9,165.79	0
	4	24.33	1013.10	17.13	1,189.73	28,843.72	0
5 and 11	1	42.89	2174.74	13.13	3,446.29	111,874.30	27,079.57
	2	24.86	277.94	13.13	369.97	5,920.90	2,795.11
	3	7.06	6.10	13.13	0	0	0
	4	17.17	998.36	13.13	1,136.71	10,617.32	8,240.12
5 and 12	1	101.89	1914.04	38.61	2,915.92	244,921.61	23,609.46
	2	29.39	349.83	38.61	272.77	2,478.56	1,972.63
	3	20.56	316.80	38.61	0	0	0
	4	38.09	1444.99	38.61	1,433.44	34,853.44	11,106.32
6 and 7	1	31.99	144.28	7.59	237.02	5,557.52	1,832.87
	2	9.99	52.35	7.59	61.18	128.19	380.54
	4	11.72	827.57	7.59	999.34	5,150.01	6,850.08
6 and 8	1	7.56	266.56	4.36	361.58	2,200.87	0
	2	10.84	58.38	4.36	82.86	907.53	0
	3	9.26	8.30	4.36	13.41	86.12	0
	4	8.23	997.40	4.36	1,273.33	11,346.16	0
6 and 9	1	38.61	95.20	15.14	143.95	3,864.65	1,121.08
	2	25.56	139.04	15.14	178.82	2,835.56	1,350.13
	4	27.95	409.90	15.14	520.57	11,662.28	4,015.41
6 and 10	1	33.82	56.45	18.64	77.81	2,151.38	0
	2	19.62	443.46	18.64	459.15	6,642.73	0
	4	24.17	778.68	18.64	883.75	20,568.50	0
6 and 11	1	59.18	98.08	10.90	165.51	9,805.64	0
	2	22.31	261.11	10.90	354.87	7,662.44	0
	3	22.64	4.00	10.90	6.41	100.03	0
	4	33.94	247.18	10.90	346.05	13,950.84	0
6 and 12	1	97.67	131.97	36.38	201.76	17,873.68	0
	2	26.61	360.01	36.38	267.17	3,756.30	0
	3	60.81	7.00	36.38	3.64	393.83	0
	4	54.92	185.70	36.38	222.64	12,438.06	0

Footnotes to Table 4

* Shipments between regions may be in either direction. The routes between the pairs of regions are reported in Table 4.3.

** The observed total cost allocation per ton (in dollars) and the observed tons shipped (in thousands of tons) are estimated from 1984 ICC Waybill Sample data. The ICC sample is a one-percent sample, so the tons shipped in the sample are multiplied by 100. The total cost allocation is estimated by dividing the total revenue from all shipments of a commodity between two regions by the observed tons shipped. These observed cost allocation and quantities (along with the elasticities for the commodity groups) are used to generate demand curves for each of the shipment categories.

♦ The variable cost allocation (variable rate) per ton (in dollars) is the estimated variable cost of a one ton shipment of the commodity between the two regions over the least expensive available route over the most efficient network. The most efficient routes are reported in Table 4.3.

π The tons of a commodity shipped between two regions over the most efficient network are the surplus maximizing shipments over the most efficient route. The tons shipped over the most efficient network are found from the demand curves and the variable costs for each shipment over its most efficient route. Surplus is maximized when the variable charge to shippers is equal to the variable cost over the least expensive available route, which can be either a rail or truck route.

☺ The truck benefits (in thousands of dollars) are the benefits from carrying the most efficient quantity of the commodity over the most efficient truck route (as if rail routes were not available). The most efficient quantity when carried over truck routes may not be the same as the most efficient quantity when carried over the available rail routes.

§ Rail net benefits (in thousands of dollars) are the gross surplus gain from using rail carriers instead of the best alternative. They are the total benefits (before the fixed costs are allocated) net of the truck benefits. No shipper will be willing to pay a fixed cost allocation that is greater than its rail net benefits.

operating these services (which must be the case anytime $L^* \neq \emptyset$, according to Proposition 2). The most efficient traffic routes over this network and the SAFC over those routes are given in Table 5.

Note that the average variable cost allocations per ton are lower and the total tons shipped are higher over this network than they were over the actual network. In this exercise, it was assumed that the fixed costs could be allocated with lump-sum charges. Recovering the costs with per-unit charges would raise the average rate per ton, so some of the difference between the observed and most efficient rates per ton can be explained by the change to a lump-sum allocation of fixed costs.

SENSITIVITY TO THE DEMAND ELASTICITIES AND COST OF CAPITAL

The results described above are not highly sensitive to the elasticities of demand. To check the sensitivity of the most efficient network structure to the demand elasticities, the most efficient network was found for the same set of shipments with different elasticities. When the four elasticities were all decreased by 25% (multiplied by 3/4), the most efficient network was again found to be $L^* = \{1,3,5,7,8,9\}$, because all regions are served by rail facilities, so even with less demand sensitivity to the cost allocation, there would be no additional rail surplus from providing additional (and evidently redundant) facilities not in L^*. The most efficient network was also not affected when the elasticities were all increased by a third (multiplied by 4/3). So when the shipment demands are more sensitive to the cost allocation, intermodal competition would not make it sufficiently more efficient to provide fewer links. If either of these changes in the demand elasticities are made, the shipment quantities and total surplus, will be affected, and the cost allocations described below will also be affected. But even the fairly large changes in the demand elasticities described above did not affect the most efficient network structure, so in that sense, the cost allocation procedure in this chapter is not very sensitive to the demand elasticities.

The Government Accounting Office suggested that the ICC cost of capital for 1984 may be too high. One alternative estimate produced by the GAO was 11.85% as the cost of capital[9]. Using this lower cost of capital of 11.85%, the most efficient network was again $L^* = \{1,3,5,7,8,9\}$. As was the case with changes in demand elasticities, this shows that the most efficient network structure is not affected by the estimate of the cost of capital being too high. A change in the cost of capital which does not affect the network structure will also have no effect on the shipment quantities. The only effect before allocating the fixed costs will be an increase in the total surplus after subtracting the lower fixed costs.

UPPER BOUNDS ON EFFICIENT COST ALLOCATIONS

In order to simplify the presentation of the cost allocation, the 155 traffic flows in Table 4 were aggregated into smaller sets of shipments in two steps. For the first aggregation, it has been assumed that different commodities carried between two regions have the same lowest cost route. Therefore, no distinction was made between commodities and benefits and costs were aggregated over all shipments carried between two regions, which reduced the number of

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[9]Government Accounting Office Documents, Railroad Revenues: Analysis of Alternetive Methods to Measure Revenue Adequacy, October 2, 1986, p. 14.

Table 5: Upper Bounds on the Cost Allocation

	Rail Links on the Most Efficient Route*		With Abandonment		Assuming No Abandonment	
Regions+	Michigan	non-Michigan	SAFC♦	Gross Rail Surplus Gain§	SAFC¶	Gross Rail Surplus Gain¶
1 and 2	1,3		26,434.6	192.4	26,434.6	192.4
1 and 3	1		20,899.8	87.9	20,899.8	87.9
1 and 4	1,7,8		35,191.0	194.9	26,269.4	237.8
1 and 5	1,3,5		31,804.1	494.8	30,151.9	519.7
1 and 7	1,3	11	26,434.6	10,928.9	26,434.6	10,928.9
1 and 8	1,7	16	29,656.3	2,119.7	29,656.3	2,119.7
1 and 9	1,3	10	26,435.6	11,021.8	30,151.9	11,237.9
1 and 10	1,3,5	14	31,804.1	6,392.0	30,151.9	6,561.8
1 and 11	1,7	17	29,656.3	13,218.8	29,656.3	13,218.8
1 and 12	1,7	18	29,656.3	8,916.6	29,656.3	8,916.6
2 and 3	3		5,534.7	1,367.5	5,534.7	1,367.5
2 and 4	3,7,8		19,825.9	743.8	14,786.8	832.4
2 and 5	5		5,369.5	2,491.8	5,369.5	2,491.8
2 and 6	3,7		14,291.2	33.7	14,291.2	33.7
2 and 7		11	0	0	0	0
2 and 8	3,7	16	14,291.2	23,129.5	14,291.9	23,129.5
2 and 9		10	0	0	0	0
2 and 10	5	14	5,369.5	16,064.5	5,369.5	16,064.5
2 and 11	3,7	17	14,291.2	31,894.4	14,291.2	31,894.4
2 and 12	3,7	18	14,291.2	33,026.4	14,291.2	33,026.4
3 and 4	7,8		14,291.2	552.0	9,252.1	667.6
3 and 5	3,5		10,904.3	1,674.1	9,252.1	1,799.2
3 and 6	7		8,756.4	103.9	8,756.4	103.9
3 and 7	3	11	5,534.7	15,165.5	5,534.7	15,165.5
3 and 8	7	16	8,756.4	4,322.3	8,756.4	4,322.3
3 and 9	3	10	5,534.7	5,772.9	9,252.1	6,088.1
3 and 10	3,5	14	10,904.3	9,223.9	9,252.1	9,749.5
3 and 11	7	17	8,756.4	6,510.6	8,756.4	6,510.6
3 and 12	7	18	8,756.4	4,613.6	8,756.4	4,613.6
4 and 5	8,9		14,621.6	1,436.9	14,621.6	1,436.9
4 and 6	8		5,534.7	49.4	5,534.7	49.4
4 and 7	8,9	11	14,621.6	8,005.0	14,621.6	8,005.0
4 and 8	8	16	5,534.7	3,187.7	5,534.7	3,187.7
4 and 9	8,9	13	14,621.6	7,420.3	14,621.6	7,420.3
4 and 10	8	15	5,534.7	3,058.3	5,534.7	3,058.3
4 and 11	8	17	5,534.7	3,839.1	5,534.7	3,839.1
4 and 12	8	18	5,534.7	2,605.8	5,534.7	2,605.8
5 and 6	9		9,086.9	475.3	9,086.9	475.3
5 and 7		11	0	0	0	0
5 and 8	9	16	9,086.9	23,566.1	9,086.9	23,566.1
5 and 9		13	0	0	0	0
5 and 10		14	0	0	0	0
5 and 11	9	17	9,086.9	38,114.8	9,086.9	38,114.8
5 and 12	9	18	9,086.9	36,688.4	9,086.9	36,688.4
6 and 7	9	12	9,086.9	9,063.5	9,086.9	9,063.5
6 and 8		16	0	0	0	0
6 and 9	9	13	9,086.9	6,486.6	9,086.9	6,486.6
6 and 10		15	0	0	0	0
6 and 11		17	0	0	0	0
6 and 12		18	0	0	0	0

Footnotes to Table 5

+ Note that the shipments between two regions in Table 5 are not divided into commodity categories as in Table 4.

* The most efficient route is the route over the most efficient network L^* which has the lowest variable transportation cost. The most efficient network was found by considering all possible subsets of Michigan rail facilities and finding the gross rail surplus gain from the most efficient shipment quantities over every possible network.

♦ The SAFC (in thousands of dollars) is the fixed cost of the incumbent carrier operating only those Michigan facilities needed to provide the particular service. The fixed costs of facilities not entirely in Michigan (links 10 to 18) are ignored, because there are shipments over these facilities which are not in the Michigan sample. The SAFC is estimated by multiplying the miles of Michigan track in the route (from Figure 2) by the average fixed cost per mile of track of $82,608 which was estimated earlier in this chapter. It is assumed that if a carrier is charging more than its stand-alone costs, then another carrier will be able to efficiently provide that same service while charging a lower rate.

§ The gross rail surplus gain from using rail carriers over Michigan links for all shipments (aggregated over commodity groups) between a pair of cities is the total benefits from these shipments minus the benefits from the next best transportation mode. No shipper would be willing to pay more than its gross rail surplus.

π The SAFC and the gross rail surplus assuming no abandonment are for all shipments over the least expensive route when it is assumed that all of the rail links (including links 2, 4, and 6) will be operated by the carriers. These columns are included to show that the range of non-subsidizing cost allocations is narrower when the cost allocation is designed not to lead to inefficient facility uses or abandonments.

shipments to 50 in Table 5. No shipper would be willing to pay a cost allocation greater than either its SAFC or its benefits from rail services (before fixed cost are allocated), so the upper constraint on the cost allocation is the lower of a service's SAFC and benefits from rail transportation. The SAFC and gross benefits for all services are shown in Table 5.

In order to compare the range of cost allocations for individual shipments to the ranges found from other cost allocations, the most efficient traffic flows were found under the assumption of no facility abandonments, so shipments over all nine Michigan rail links were allowed. The SAFC and gross rail surplus gains for these traffic flows over the entire set of facilities in L are also shown in Table 5. The SAFC upper bounds would be the upper bounds under the Fanara and Grimm proposal, and the minimum of the two upper bounds would be the upper bounds on a core allocation if no facility abandonments are allowed. In both cases, the upper bounds on the cost allocation are lower (the allocation rage is narrower) under the cost allocation procedure in chapter 3, with the exception of shipments between regions 3 and 10. The SAFC would be lower for shipments between 3 and 10 because traffic is rerouted over link 6, which is an abandoned link in the most efficient network. Therefore, the lower bound on all shipments over link (3-to-4, 3-to-5, 3-to-9, and 3-to 10) will be higher because they alone are responsible for this facility. However, any shipments over facility 6 is not a core allocation if abandonment is allowed, according to Proposition 2, since efficiency could be improved by abandoning links 2, 4, and 6. Therefore, this lower SAFC for shipment between 3 and 10 would no longer be the SAFC after facility 6 is abandoned.

ALLOCATING THE FIXED COSTS

Of course, it is the upper bounds on combinations of facilities which are more likely to constrain the cost allocation, but the upper bounds on all possible combinations[10] would be impossible to summarize in a brief table. Therefore, the shipments were aggregated a second time by collection all shipments which share the same set of Michigan rail facilities. This reduced the number of shipments to 16, of which 15 use Michigan facilities. The upper bounds were calculated for all combinations of these 15 facilities which had at least one facility in common. The upper bound on these shipments and combinations of shipments are shown in Table 6.

The existence of an upper bound on a set of shipments also implies that all remaining shipments must pay any fixed costs in excess of that upper bound for facilities which they share with the group which has the upper bound constraint. The lower bounds on combinations of facilities are also shown in Table 6.

A Moriarity allocation is the easiest to calculate of the allocations surveyed by Hamlen, et,al. (1975), but is not necessarily a core allocation. In this case, however, the Moriarity allocation was found to be in the core[11]. Under the Moriarity rule allocation, the sum of the upper bounds constraints on the cost allocation for the 15 individual shipments in Table 6 is $217,406,313 and the total costs

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[10]With 41 of these 50 shipments using Michigan rail facilities, there would be 2^{41} or 2.2×10^{12} different combinations of shipments and upper bounds.

[11]If the Moriarity allocation had not been in the core, it would have been necessary to use a more complex allocation rule, such as the Shapely rule.

Table 6: Cost Allocation Ranges

Shipments Sharing Michigan Link 1

Shipments Over Michigan Links	SAFC	Gross Surplus From Rail	Maximum Allocation	Minimum Allocation	A Core Allocation
1 *	20,899.8	87.9	87.9	0	37.6
13	26,434.6	22,143.1	22,143.1	0	9,475.3
135	31,804.1	6,886.8	6,886.8	0	2,946.9
17	29,656.3	24,255.2	24,255.2	0	10,379.1
178	35,191.0	194.9	194.9	0	83.4
1 & 13	26,434.6	22,231.0	22,231.0	0	9,512.9
1 & 135	31,804.1	6,974.7	6,974.7	0	2,984.5
1 & 17	29,656.3	24,343.1	24,343.1	0	10,416.7
1 & 178	35,191.0	282.8	282.8	0	121.0
13 & 135	31,804.1	29,029.9	29,029.9	0	12,422.2
13 & 17	35,191.0	46,398.3	35,191.0	13,730.2	19,854.4
13 & 178	40,725.7	22,338.0	22,338.0	0	9,558.7
135 & 17	40,560.5	31,142.0	31,142.0	0	13,226.0
135 & 178	46,095.3	7,081.7	7,081.7	0	3,030.3
17 & 178	35,191.0	24,450.1	24,450.1	0	10,462.5
1, 13 & 135	31,804.1	29,117.8	29,117.8	0	12,469.8
1, 13 & 17	35,191.0	46,486.2	35,191.0	13,818.1	19,892.0
1, 13 & 178	40,725.7	22,425.9	22,425.9	0	9,696.3
1, 135 & 17	40,560.5	31,336.9	31,336.9	0	13,363.6
1, 135 & 178	46,095.3	7,169.6	7,169.6	0	3,067.9
1, 17 & 178	35,191.0	24,538.0	24,538.0	0	10,500.1
13, 135 & 17	40,560.5	53,285.1	40,560.5	20,167.0	22,801.3
13, 135 & 178	46,095.3	29,224.8	29,224.8	0	12,505.6
13, 17 & 178	40,725.7	46,593.2	40,725.7	13,925.1	19,937.8
135, 17 & 178	46,095.3	31,336.9	31,336.9	0	13,409.4
1, 13, 135 & 17	40,560.5	53,373.0	40,560.5	20,704.9	22,838.9
1, 13, 135 & 178	46,095.3	29,312.7	29,312.7	0	12,543.2
1, 13, 17 & 178	40,725.7	46,681.1	40,725.7	14,013.0	19,975.4
1, 135, 17 & 178	46,095.3	31,424.8	31,424.8	0	13,447.0
13, 135, 17 & 178	46,095.3	53,480.0	46,095.3	20,811.9	22,884.7
1, 13, 135, 17 & 178	46,095.3	53,567.9	46,095.3	20,899.8	22,922.3

Shipments Sharing Michigan Link 5

Shipments Over Michigan Links	SAFC	Gross Surplus From Rail	Maximum Allocation	Minimum Allocation	A Core Allocation
135	31,804.1	6,886.8	6,886.8	0	2,946.9
35	10,904.2	10,979.1	10,904.2	0	4,663.3
5	5,369.5	18,556.4	5,369.5	0	2,297.7
135 & 35	31,804.1	17,865.9	17,865.9	0	7,610.2
135 & 5	31,804.1	25,443.2	25,443.2	0	5,244.6
35 & 5	10,904.2	29,535.5	10,904.2	0	6,961.0
135, 35 & 5	31,804.1	36,422.3	31,804.1	5,369.5	9,907.9

* Links are grouped into sets of links over which traffic is carried,
so 13 denotes all shipments carried over Michigan links 1 and 3 only, and 135 denotes all shipments carried over links 1, 3, and 5.

Table 6 (Continued)

Shipments Sharing Michigan Link 3

Shipments Over Michigan Links	SAFC	Gross Surplus From Rail	Maximum Allocation	Minimum Allocation	A Core Allocation
13	26,434.6	22,143.1	22,143.1	0	9,475.3
135	31,804.1	6,886.8	6,886.8	0	2,946.9
3	5,534.7	22,305.9	5,534.7	0	2,368.4
35	10,904.3	10,897.9	10,897.9	0	4,663.3
37	14,291.2	80,050.3	14,291.2	0	6,115.4
378	19,825.9	743.9	743.9	0	318.3
13 & 135	31,804.1	29,092.7	29,092.7	0	12,422.2
13 & 3	26,434.6	44,449.0	26,434.6	0	11,843.7
13 & 35	31,804.1	33,041.0	31,804.1	0	14,138.6
13 & 37	35,191.0	102,193.4	35,191.0	0	15,590.7
13 & 378	40,725.7	22,887.0	22,887.0	0	9,793.6
135 & 3	31,804.1	29,192.7	29,192.7	0	5,315.3
135 & 35	31,804.1	17,784.7	17,784.7	0	7,610.2
135 & 37	40,560.5	86,937.1	40,560.5	0	9,062.3
135 & 378	46,095.3	7,630.7	7,630.7	0	3,265.2
3 & 35	10,904.3	33,203.8	10,904.3	0	7,031.7
3 & 37	14,291.2	102,356.2	14,291.2	0	8,483.8
3 & 378	19,825.9	23,049.8	19,825.9	0	2,686.7
35 & 37	19,660.7	90,948.2	19,660.7	0	10,778.7
35 & 378	25,195.4	11,641.8	11,641.8	0	4,981.6
37 & 378	19,825.9	80,794.2	19,825.9	0	6,433.7
13, 135 & 3	31,804.1	51,335.8	31,804.1	0	14,790.6
13, 135 & 35	31,804.1	39,927.8	31,804.1	0	17,085.5
13, 135 & 37	40,560.5	109,080.2	40,560.5	0	18,537.6
13, 135 & 378	46,095.3	29,773.8	29,773.8	0	12,740.5
13, 3 & 35	31,804.1	55,346.9	31,804.1	0	16,507.0
13, 3 & 37	35,191.0	124,499.3	35,191.0	0	17,959.1
13, 3 & 378	40,725.7	45,192.9	40,725.7	0	12,162.0
13, 35 & 37	40,560.5	113,091.3	40,560.5	0	20,254.0
13, 35 & 378	46,095.3	33,784.9	33,784.9	0	14,456.9
13, 37 & 378	40,725.7	102,937.3	40,725.7	0	15,909.0
135, 3 & 35	31,804.1	40,090.6	31,804.1	0	9,978.6
135, 3 & 37	40,560.5	109,243.0	40,560.5	0	11,430.7
135, 3 & 378	46,095.3	29,936.6	29,936.6	0	5,633.6
135, 35 & 37	40,560.5	97,835.0	40,560.5	0	13,725.6
135, 35 & 378	46,095.3	18,528.6	18,528.6	0	7,928.5
135, 37 & 378	46,095.3	87,681.0	46,095.3	0	9,380.6
3, 35 & 37	19,660.7	113,254.1	19,660.7	0	13,147.1
3, 35 & 378	25,195.4	33,947.7	25,195.4	0	7,350.0
3, 37 & 378	19,825.9	103,100.1	19,825.9	0	8,802.1
35, 37 & 378	25,195.4	91,692.1	25,195.4	0	11,097.0
13, 135, 3 & 35	31,804.1	62,233.7	31,804.1	0	19,453.9
13, 135, 3 & 37	40,560.5	131,386.1	40,560.5	0	20,905.9
13, 135, 3 & 378	46,095.3	52,079.7	46,095.3	0	15,108.9
13, 135, 35 & 37	40,560.5	119,978.1	40,560.5	0	23,200.9
13, 135, 35 & 378	46,095.3	40,671.7	40,671.7	0	17,403.8
13, 135, 37 & 378	46,095.3	109,824.1	46,095.3	0	18,855.9
13, 3, 35 & 37	40,560.5	135,397.2	40,560.5	0	22,622.4
13, 3, 35 & 378	46,095.3	56,090.8	46,095.3	0	16,825.3
13, 3, 37 & 378	40,725.7	125,243.2	40,725.7	0	18,277.4
13, 35, 37 & 378	46,095.3	113,835.2	46,095.3	0	20,572.3
135, 3, 35 & 37	40,560.5	120,140.9	40,560.5	0	16,094.0
135, 3, 35 & 378	46,095.3	40,834.5	40,834.5	0	10,296.9
135, 3, 37 & 378	46,095.3	109,986.9	46,095.3	0	11,749.0
135, 35, 37 & 378	46,095.3	98,578.9	46,095.3	0	14,043.9
3, 35, 37 & 378	25,195.4	113,998.0	25,195.4	0	13,465.4
13, 135, 3, 35 & 37	40,560.5	142,284.0	40,560.5	4,790.8	25,569.3
13, 135, 3, 35 & 378	46,095.3	62,977.6	46,095.3	0	19,772.2
13, 135, 3, 37 & 378	46,095.3	132,130.0	46,095.3	0	21,224.3
13, 135, 35, 37 & 378	46,095.3	120,722.0	46,095.3	0	23,519.2
13, 3, 35, 37 & 378	46,095.3	136,141.1	46,095.3	0	22,940.7
135, 3, 35, 37 & 378	46,095.3	120,884.8	46,095.3	0	16,412.3
13,135,3,35,37 & 378	46,095.3	143,027.9	46,095.3	5,534.7	25,887.6

Table 6 (Continued)

Shipments Sharing Michigan Link 7

Shipments Over Michigan Links	SAFC	Gross Surplus From Rail	Maximum Allocation	Minimum Allocation	A Core Allocation
17	29,656.3	24,255.2	24,244.2	0	10,379.1
178	35,191.0	194.9	194.9	0	83.4
37	14,291.2	88,050.3	14,291.2	0	6,115.4
378	19,825.9	743.9	743.9	0	318.3
7	8,756.5	15,550.5	8,756.5	0	3,747.0
78	14,291.2	552.0	552.0	0	236.2
17 & 178	35,191.0	24,450.1	24,450.1	0	10,462.5
17 & 37	35,191.0	112,305.5	35,191.0	0	16,494.5
17 & 378	40,725.7	24,999.1	24,999.1	0	10,697.4
17 & 7	29,656.3	39,805.7	29,656.3	0	14,126.1
17 & 78	35,191.0	24,807.2	24,807.2	0	10,615.3
178 & 37	40,725.7	88,245.2	40,725.7	0	6,198.8
178 & 378	40,725.7	938.8	938.8	0	401.7
178 & 7	35,191.0	15,745.4	15,745.4	0	3,830.4
178 & 78	35,191.0	746.9	746.9	0	319.6
37 & 378	19,825.9	88,794.2	19,825.9	0	6,433.7
37 & 7	14,291.2	103,600.8	14,291.2	0	9,862.4
37 & 78	19,825.9	88,602.3	19,825.9	0	6,351.6
378 & 7	19,825.9	16,294.4	16,294.4	0	4,065.3
378 & 78	19,825.9	1,295.9	1,295.9	0	554.5
7 & 78	14,291.2	16,102.5	14,291.2	0	3,983.2
17, 178 & 37	40,725.7	112,500.4	40,725.7	0	16,577.9
17, 178 & 378	40,725.7	25,194.0	25,194.0	0	10,780.8
17, 178 & 7	35,191.0	40,000.6	35,191.0	0	14,209.5
17, 178 & 78	35,191.0	25,002.1	25,002.1	0	10,698.7
17, 37 & 378	40,725.7	113,049.4	40,725.7	0	16,812.8
17, 37 & 7	35,191.0	127,856.0	35,191.0	7265.7	20,241.5
17, 37 & 78	40,725.7	112,857.5	40,725.7	0	16,730.7
17, 378 & 7	40,725.7	40,549.6	40,549.6	0	14,444.4
17, 378 & 78	40,725.7	25,551.1	25,552.1	0	10,933.6
17, 7 & 78	35,191.0	40,357.7	35,191.0	0	14,362.3
178, 37 & 378	40,725.7	88,989.1	40,725.7	0	6,517.1
178, 37 & 7	40,725.7	103,795.7	40,725.7	0	9,945.8
178, 37 & 78	40,725.7	88,797.2	40,725.7	0	6,435.0
178, 378 & 7	40,725.7	16,489.3	16,489.3	0	4,148.7
178, 378 & 78	40,725.7	1,490.8	1,490.8	0	637.9
178, 7 & 78	35,191.0	16,297.4	16,297.4	0	4.066.6
37, 378 & 7	19,825.9	104,344.7	19,825.9	0	10,180.7
37, 378 & 78	19,825.9	89,346.2	19,825.9	0	6,669.9
37, 7 & 78	19,825.9	104,152.8	19,825.9	0	10,098.6
378, 7 & 78	19,825.9	16,846.4	16,846.4	0	4,301.5
17, 178, 37 & 378	40,725.7	113,244.3	40,725.7	0	16,896.2
17, 178, 37 & 7	40,725.7	128,050.9	40,725.7	7,460.6	20,324.9
17, 178, 37 & 78	40,725.7	113,052.4	40,725.7	0	16,814.1
17, 178, 378 & 7	40,725.7	40,744.5	40,725.7	0	14,527.8
17, 178, 378 & 78	40,725.7	25,746.0	25,746.0	0	11,017.0
17, 178, 7 & 78	35,191.0	40,552.6	35,191.0	0	14,445.7
17, 37, 378 & 7	40,725.7	128,599.9	40,725.7	8,009.6	20,559.8
17, 37, 378 & 78	40,725.7	113,601.4	40,725.7	0	17,049.0
17, 37, 7 & 78	40,725.7	128,408.0	40,725.7	7,817.7	20,477.7
17, 378, 7 & 78	40,725.7	41,101.6	40,725.7	0	14,680.6
178, 37, 378 & 7	40,725.7	104,539.6	40,725.7	0	10,264.1
178, 37, 378 & 78	40,725.7	89,541.1	40,725.7	0	6,753.3
178, 37, 7 & 78	40,725.7	104,347.7	40,725.7	0	10,182.0
178, 378, 7 & 78	40,725.7	17,041.3	17,041.3	0	4,384.9
37, 378, 7 & 78	19,825.9	104,896.7	19,825.9	0	10,416.9
17, 178, 37, 378 & 7	40,725.7	128,794.8	40,725.7	8,204.5	20,643.2
17, 178, 37, 378 & 78	40,725.7	113,796.3	40,725.7	0	17,132.4
17, 178, 37, 7 & 78	40,725.7	128,602.9	40,725.7	8,012.6	20,561.1
17, 178, 378,7 & 78	40,725.7	41,296.5	40,725.7	0	14,764.0
17, 37, 378, 7 & 78	40,725.7	129,151.9	40,725.7	8,561.6	20,796.0
178, 37, 378, 7 & 78	40,725.7	105,091.6	40,725.7	0	10,500.3
17,178,37,378,7 &78	40,725.7	129,346.8	40,725.7	8,756.5	20,879.4

Table 6 (Continued)

Shipments Sharing Michigan Link 8

Shipments Over Michigan Links	SAFC	Gross Surplus From Rail	Maximum Allocation	Minimum Allocation	A Core Allocation
178	35,191.0	194.9	194.9	0	83.4
378	19,825.9	743.9	743.9	0	318.3
78	14,291.2	552.0	552.0	0	236.2
8	5,534.7	12,740.3	5,534.7	0	2,368.4
89	14,621.6	16,862.1	14,621.6	0	6,256.8
178 & 378	40,725.7	938.8	938.8	0	401.7
178 & 78	35,191.0	746.9	746.9	0	319.6
178 & 8	35,191.0	12,935.2	12,935.2	0	2,451.8
178 & 89	44,277.9	17,057.0	17,057.0	0	6,340.2
378 & 78	19,825.9	1,295.9	1,295.9	0	554.5
378 & 8	19,825.9	13,484.2	13,484.2	0	2,686.7
378 & 89	28,912.8	17,606.0	17,606.0	0	6,575.1
78 & 8	14,291.2	13,292.3	13,292.3	0	2,604.6
78 & 89	23,378.1	17,414.1	17,414.1	0	6,493.0
8 & 89	14,621.6	29,602.4	14,621.6	4,043.9	8,625.2
178, 378 & 78	40,725.7	1,490.8	1,490.8	0	637.9
178, 378 & 8	40,725.7	13,679.1	13,679.1	0	2,770.1
178, 378 & 89	49,812.6	17,800.9	17,800.9	0	6,658.5
178, 78 & 8	35,191.0	13,487.2	13,487.2	0	2,688.0
178, 78 & 89	44,277.9	17,609.0	17,609.0	0	6,576.4
178, 8 & 89	44,277.9	29,797.3	29,797.3	4,238.8	8,708.6
378, 78 & 8	19,825.9	14,036.2	14,036.2	0	2,922.9
378, 78 & 89	28,912.8	18,158.0	18,158.0	0	6,811.3
378, 8 & 89	28,912.8	30,346.3	28,912.8	4,787.8	8,943.5
78, 8 & 89	23,378.1	30,154.4	23,378.1	4,595.9	8,861.4
178, 378, 78 & 8	40,725.7	14,231.1	14,231.1	0	3,006.3
178, 378, 78 & 89	49,812.6	18,352.9	18,352.9	0	6,894.7
178, 378, 8 & 89	49,812.6	30,541.2	30,541.2	4,982.7	9,026.9
178, 78, 8 & 89	44,277.9	30,349.0	30,349.0	4,790.8	8,944.8
378, 78, 8 & 89	49,812.6	30,898.3	30,898.3	5,339.8	9,179.7
178, 378, 78, 8 & 89	49,812.6	31,093.2	31,093.2	5,534.7	9,263.1

Shipments Sharing Michigan Link 9

Shipments Over Michigan Links	SAFC	Gross Surplus From Rail	Maximum Allocation	Minimum Allocation	A Core Allocation
89	14,621.6	16,862.1	14,621.6	0	6,256.8
9	9,086.9	114,394.7	9,086.9	0	3,883.8
89 & 9	14,621.6	131,256.8	14,621.6	9,086.9	10,140.6

to be allocated are $55,182,146, so each service was allocated fixed costs equal to 25.4% (= 55,182,146/217,406,313) of its willingness to pay. This cost allocation is given in the far right-hand column in Table 6. It can be verified in Table 6 that no set of traffic flows is allocated a share of the costs that is outside of its allocation range.

CONCLUSION

In this chapter, it was demonstrated that the cost allocation proposal in chapter 3 can be applied to an existing network. Since it was efficient to abandon links in this network, the cost allocation proposals in the literature survey (Ramsey-pricing, Fanara and Grimm) would not lead to an efficient cost allocation because they do not consider the efficiency of facility abandonments when allocating costs.

CHAPTER 5: CONCLUSION

Since the passage of the regulatory reform legislation of of 1976 and 1980, railroads have much more freedom to abandon unprofitable services and set their own rates for much of their traffic. Thus, an efficient solution to the old problem of recovering the common costs of rail carriers must now include the consideration of which facilities and services should be abandoned to maximize efficiency and the limits on cost allocations if inefficient abandonment is to be avoided.

It was shown in chapter 2 that several rail cost allocations proposed since the passage of the Staggers Act are not efficient cost allocations because they fail to consider whether efficiency can be increased by abandonment of facilities from the existing network structure. It was proven in Proposition 3.2 that if the existing network is not the most efficient network, then no non-subsidizing allocation will exist which allows all facilities to be used.

A procedure for finding an efficient cost allocation was developed in chapter 3 and applied to the 1984 Michigan rail shipments in chapter 4. Under this proposal, first the most efficient network configuration is found, and then upper bounds on the fixed charges to shipments and groups of shipments are found which encourage the carriers to operate the most efficient network while recovering all common costs. According to Proposition 3.2, these are the same upper bounds that Sharkey finds for a non-subsidizing cost allocation. Therefore, the problem of finding a non-subsidizing cost allocation using fixed charges is identical to the problem of finding a set of fixed charges which encourages the most efficient service provisions and service levels.

This cost allocation satisfies each of the properties of an efficient allocation proposed in chapter 1. This cost allocation proposal satisfies property 1 by allowing the provider(s) of the service to recover all costs. With private rail carriers, it is efficient to allow carriers to recover all of their costs, or else the carriers will not provide the service - even when providing the service would otherwise maximize social surplus.

The third property is satisfied because the most efficient set of facilities is found in the first step of the cost allocation procedure, and then the limits on a cost allocation (though fixed charges) are found which give carriers the incentive to provide the social surplus maximizing network configuration. Property 2 is also satisfied because the most efficient network is defined as the network over which the most efficient traffic flows may be carried. So long as side-payments are allowed, the potential Pareto optimality standard of efficiency insures that the winners from any movement closer to the surplus-maximizing shipments levels over the most efficient set of facilities (perhaps the captive shippers) will be able to compensate the losers (perhaps the monopolist carriers) from such a move. Even if side payments are not made, the presence of competition for most services and the ICC regulation of market dominated services insures that rates will not be greatly different from the rates which lead to the most efficient services.

It is proven in Proposition 3.2 that the cost allocation with the first three properties of an efficient cost allocation also will lead to a non-subsidizing cost allocation (property 4) and will allocate the common costs using fixed charges with less arbitrariness or equity-based elements[1] than allocations using fixed charges which ignore possible efficient facility abandonments (property 5). The principles used to allocate the fixed costs in chapters 3 and 4 were based upon efficiency considerations only, rather than both efficiency and equity criteria as in the Fanara and Grimm proposal. These equity criteria might be considered when choosing an arbitrary allocation rule[2], but the range of possible non-subsidizing allocations has been narrowed, making equity issues less important when the costs are allocated.

In chapter 4, the cost allocation proposal was applied to the Michigan transportation network to demonstrates that the cost allocation can be applied to existing transportation systems. This cost allocation requires less information than the Ramsey-pricing allocations advocated by the railroads' representatives and is also less difficult to calculate than the Ramsey-pricing proposals.

The railroad regulatory reform legislation from the late 1970s places much more emphasis upon the profitability of railroads and the economic efficiency of rail rates. To the extent that maximizing the efficiency of the provision of transportation services (while insuring

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[1]It will allocate the fixed costs with less arbitrariness than other allocations given the network structure. A case was found in chapter 4 where the upper bound constraint was less restrictive under the proposal from chapter 3 than it would have been under another proposal, but this result was because network structure in the other proposals was not the most efficient structure (so that the other cost allocation was not a core allocation).

[2]such as one from the survey of such allocation rules by Hamlen, et.al. (1975)

that railroads recover all of their costs) is the objective of regulators, then the ICC was correct in requiring that no service or service group pay more than its stand-alone cost for coal shipments[3]. It is argued here that the ICC could produce even more efficient guidelines in two ways. First, the ICC could apply these coal shipment guidelines to shipments of all products. Second, the ICC could extending its concept of cross-subsidization to situations where a shipper or shipper group pays more than either its stand-alone cost or its additional shippers surplus from using rail carriers instead of the next best alternative[4]. The ICC in its coal rate guidelines proposed that rates should be proportional to the individual demands of shippers, which is related to (but less specific than) the cross-subsidization concept based upon the shippers additional surplus from rail services[5].

The ICC's rate-making authority was limited by the Staggers Act to railroads with market dominance[6], so any non-subsidizing allocation of costs to relatively competitive services could not be imposed by the ICC. However, no shipper will pay more than its benefits from rail transportation and the definition of market dominance in the Staggers Act should protect shippers from cost allocations in excess

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[3]See footnote 1 in chapter 1. This guideline for avoiding cross-subsidization is consistent with Faulhaber's definition of cross-subsidization.

[4]This definition of cross-subsidization is based upon Sharkey's (1982) analysis of cross-subsidization in public enterprises, which was used to develop the cost allocation procedure in chapter 3.

[5]Note in footnote 1 to chapter 1 that the ICC did not extend this guideline to groups of shippers.

[6]with market dominance defined under the Staggers Act as a high revenue-to-variable cost ratio

of their stand-alone costs. Therefore, the railroads will have an incentive to avoid cross-subsidizing cost allocations and will find these guidelines for non-subsidizing allocations useful when allocating costs to any of the shippers over the network. Also under the Staggers Act, carriers and shippers are given more flexibility when making contracts. These contracts may now be written to include fixed charges such as those in chapters 3 and 4 to recover the common costs shared by many users of the network.

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