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NETWORK SEPARATION WITH AN  
APPLICATION TO US RAILROADS**

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## **ABSTRACT**

### **Subadditivity Tests for Network Separation with an Application to US Railroads**

We describe a pair of subadditivity tests that can be used to evaluate the technological feasibility of separating a vertically integrated network monopoly into a common infrastructure component and competing operating components. We implement the tests with a Generalized McFadden cost function that is globally concave in input prices and permits the assignment of zero output values without losing its flexibility properties. The tests shed light on the respective roles of regulation and competition policy. We illustrate them with an analysis of US freight railroads for the period 1978-2001 and find both vertical and horizontal economies of scope.

JEL Classification: L14, L22, L51 and L92

Keywords: networks, railroads, regulation, subadditivity and vertical integration

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There are two basic policy alternatives to state operation for dealing with vertically integrated network firms that exhibit characteristics of natural monopoly. One is regulation, which involves the monitoring of firms by either independent regulatory agencies or government administrations; the other is competition policy, a set of government activities ranging from antitrust enforcement to network separation and mandated access to establish competition on previously monopolized networks. Though there may be cases where competition policy is a *substitute* for regulation, the two forms of network oversight often appear as policy *complements* with the exact combination dictated by technological factors, potential transactions costs, public service considerations and political traditions.<sup>1</sup>

The best known empirical assessment of network natural monopoly was proposed by David S. Evans and James J. Heckman (1984), who used a translog cost function to test whether Bell System costs for the period 1947-1977 were subadditive. Their finding that the Bell System was not a natural monopoly was disputed by Lars-Hendrik Röller (1990), who analyzed the same data with a quadratic cost function, and reaffirmed by Richard T. Shin and John S. Ying (1992), who used a translog cost function and 1976-1983 data. All three papers acknowledged the limitations imposed by the functional forms they employed. Proper econometric testing for subadditivity requires a cost function which is globally concave in input prices and permits the assignment of zero output values without losing its flexibility properties. The quadratic fails the first requirement while the translog fails both.

This paper focuses on technological aspects of network oversight, particularly networks such as electricity and railroads, where service-related operations and infrastructure-related maintenance activities are the two main sources of costs. These networks pose a special challenge for competition advocates because they sometimes resist the unbundling of vertically integrated activities into a common infrastructure entity and competing operating entities. If, for example, there are vertical economies of scope *between* operations and infrastructure, there may be a loss of vertical efficiency if the two are separated.<sup>2</sup> Or, if there are economies of joint production *among* operational activities, then firms operating on network infrastructure may still exhibit characteristics of natural monopoly.<sup>3</sup>

We propose to extend the Evans and Heckman test by defining a pair of subadditivity tests that can be used to evaluate the technological feasibility of separating an integrated network monopoly into infrastructure and operating components. We show how the tests can be implemented with a multiproduct Generalized McFadden cost function which is globally concave in input prices and accommodates zero outputs. In other words, using available data on integrated firms and known concepts and techniques, we are able to provide a measure of economic stakes involved in a vertical divestiture.

Section I introduces an infrastructure separation test to establish whether the cost function is subadditive between network operations and infrastructure, and an operational separation test to establish whether there is subadditivity across types of operations. Section II shows how the tests can be implemented econometrically using the

Generalized McFadden. Section III illustrates the tests with an evaluation of recent competition proposals for U.S. freight railroads. To do this, we estimate a multiproduct GM cost function that includes both operational and infrastructure outputs. Our empirical results support and extend the work of Bitzan (1999) and Ivaldi and McCullough (2001) who find vertical economies of scope between rail infrastructure and operations and horizontal economies among on-rail operations. Section IV discusses the implications of our findings for rail policy in the U.S. and the potential relevance for rail restructuring in Europe and elsewhere.

### **I. Two Tests of Subadditivity**

Scale and scope are the standard measures to describe production economies, but these are only descriptive measures. The relevant technological measure from a policy perspective is subadditivity of the cost function. It is subadditivity (and *not* scale or scope) which finally determines whether an output vector  $y$  can be produced more cheaply by a single firm than by any group of firms.<sup>4</sup> This in turn determines whether a technology is a natural monopoly on a given territory and potentially subject to some form of government intervention.

Baumol's (1977) test of cost subadditivity for multiproduct production is as follows.

DEFINITION 1: *Cost Subadditivity Test.* Let  $C(y)$  represent the total costs associated with production of output vector  $y$ . The overall network cost function  $C(y)$  is subadditive if for any and all vectors  $y^i \neq y$  s.t.  $\Sigma y^i = y, C(y) < \Sigma C(y^i)$ , where  $i$  is an index of firms.

If  $C(y)$  is subadditive and  $y$  is significant relative to market demand, there may be a need for government oversight. Oversight can take the form of regulation and/or competition policy. One way to establish competition in this context is through government-run auctions for service over given territories and benchmarking among firms competing “for the market.” Competition can also be established through separation (“unbundling”) of the network monopoly into a regulated or publicly supported infrastructure entity and a set of operating firms with access to infrastructure who compete “on-the-market”. Underlying a policy of “on-the-market” competition, however, are two important technological assumptions which can also be evaluated using the subadditivity criterion.

DEFINITION 2: *Infrastructure Separation Test.* Let  $y^S$  and  $y^T$  represent an orthogonal partition of the output vector  $y$  into operational activities ( $y^S$ ) and infrastructure-related activities ( $y^T$ ). The cost function is subadditive between operations and infrastructure costs if  $C(y) < C(y^S, 0) + C(0, y^T)$ .

The infrastructure separation test is a subset of Baumol's test. If the test shows there are vertical economies of scope between operations and infrastructure, there should be a loss of technical efficiency if infrastructure and operations are separated. This may be offset by competition effects, in particular by lowering the degree of allocative inefficiency, but if the loss of technical efficiency is large, optimal regulation of the integrated monopoly or franchise competition for the market are the relevant policies. Partial disintegration in which the infrastructure provider is also one of the on-market competitors is another competitive solution.

DEFINITION 3: *Operational Separation Test. Assume infrastructure separation. The cost function for operations is subadditive between operations if for any and all vectors  $y^i \neq y$  s.t.  $\Sigma y^i = y^S, C(y^S, 0) < \Sigma C(y^i, 0)$ .*

This is a test of whether there are horizontal economies of joint production among operational activities. If the operational separation test shows that the cost function  $C(y^S, 0)$  is not subadditive, this is a technological indication that competition between operating companies "on the market" can be effective. If  $C(y^S, 0)$  is subadditive, then a) there may be a loss of technical efficiency if operations are forced to separate, and b) it is reasonable to expect that operations "on the market" will be concentrated. Thus, there

may be a need for optimal regulation of operating entities after operations are separated from infrastructure.

## II. Implementation with the Generalized McFadden

We test for subadditivity using a modification of the Generalized McFadden cost function that was introduced by Diewert and Wales (1987) and derived from McFadden (1978). The primary advantage of this function is that the domain of approximation is set along with the estimation of parameters. Kumbhakar (1994) proposed an extension to the multiple-output case and our function further generalizes his form. Let  $w$  be an  $n$ -dimensional vector of input prices,  $t$  a  $q$ -dimensional vector of quasi-fixed technological factors, and  $y$  an  $r$ -dimensional vector of outputs. Define  $z$  as the  $m$ -dimensional vector ( $m = q + r$ ) that includes  $y$  and  $t$ . The GM cost function is

$$(1) \quad C = \alpha'w + 0.5 \frac{w' \Delta w}{\theta' w} (\beta' y)^2 + w' \Lambda z + 0.5(\theta' w) z' \Gamma z ,$$

where  $\alpha$  is an unconstrained  $n$ -dimensional parameter vector,  $\Delta$  an  $n \times n$  symmetric parameter matrix,  $\Lambda$  an  $n \times m$  parameter matrix of nonnegative elements,  $\Gamma$  an  $m \times m$  symmetric parameter matrix, and  $\theta$  is an  $n \times 1$  vector of fixed parameters.

For  $C$  to provide a second order approximation to an arbitrary cost function  $C^*$  it must contain  $(n+m)(n+m+1)/2$  free parameters. As the cost function in (1) contains

$(n+m)(n+m+1)/2+m$  parameters, it is flexible. It is also homogeneous and monotonic in  $w$ , and it is concave in  $w$  if the estimated matrix  $\Delta$  is negative semidefinite. If not, concavity can be imposed by setting  $\Delta = -BDB'$  where  $B$  is a lower triangular matrix with the sum of its diagonal elements equal to 1 and  $D$  is a nonnegative diagonal matrix.<sup>5</sup>

To estimate  $C$  we use the vector of  $n$  factor demands derived by applying Shephard's lemma. This  $n$ -dimensional vector containing all of the cost function parameters is

$$(2) \quad X = \alpha + \left[ \frac{\Delta w}{\theta' w} - 0.5 \frac{(w' \Delta w) \theta}{(\theta' w)^2} \right] (\beta' y)^2 + \Lambda z + 0.5 \theta (z' \Gamma z).$$

To evaluate subadditivities, we begin by using the estimated parameters from (2) to identify the fixed costs that would be incurred at zero output levels. We then aggregate up from this base, comparing the projected cost levels that result as the level and composition of output are changed. Projected fixed costs are

$$(3) \quad \hat{C}^F = w' (\hat{\alpha} + \hat{\Lambda}'_t t + 0.5 \theta' \hat{\Gamma}_t t),$$

where the term in parentheses is the vector of projected factor demands in (2) but includes only the technological components (and not the output-related components) of  $\Lambda$ ,  $\Gamma$ , and  $z$ .

Projected conditional costs for the output vector  $y^*$  are

$$(4) \quad \hat{C}^C = w' \left\{ \left[ \frac{\hat{\Delta}w}{\hat{\theta}'w} - 0.5 \frac{(w'\hat{\Delta}w)\hat{\theta}}{(\hat{\theta}'w)^2} \right] (\hat{\beta}'y^*)^2 + \hat{\Lambda}_{z'}'z^* + 0.5\theta (z^*\hat{\Gamma}_{z'}z^*) \right\},$$

where the term in braces is the vector of projected factor demands but with those elements of  $y$  that do not belong to  $y^*$  set to zero and with the elements of  $t$  entering only to the extent that they interact with  $y^*$  elements. Projected stand-alone costs of producing  $y^*$  are  $\hat{C} = \hat{C}^F + \hat{C}^C$ .

The ability to project fixed costs separately from conditional cost is an important feature of this specification of the Generalized McFadden specification. As we simulate changes in cost that result from combining or separating network activities, we are able to distinguish cost effects that are purely output-related from those that might result from a duplication of fixed costs. For example, we might expect  $C(y_1, 0) + C(0, y_2)$  to have higher fixed costs than  $C(y_1, y_2)$  but we would probably not expect fixed costs to double. The above specification allows us to simulate the effect of fixed costs on total costs using

$$(5) \quad \tilde{C} = \delta \hat{C}^F + \hat{C}^C,$$

where  $\delta$  is the degree to which fixed costs are duplicated when production is separated and  $\tilde{C}$  is the estimated total cost of one of the hypothetical entity resulting from the separation.

### **III. Empirical Application to U.S. Freight Railroads**

The U.S. railroad industry consists primarily of private sector freight railroads operating under a relaxed regulatory scheme imposed by the Staggers Rail Act of 1980.<sup>6</sup> Overall output levels (ton-miles) have remained fairly constant since Staggers and overall rate levels have declined, but the number of Class I railroads has also dropped from 38 to eight.<sup>7</sup> The consolidation trend has led some legislators to call for a national system of open rail access. Regulators at the Surface Transportation Board have favored a limited access solution, requiring that tenant railroads be given the right to use host railroad tracks only in cases where shippers are shown to be “captive” to the host.

In this section we apply the subadditivity tests to U.S. freight railroads using the GM functional form. The data that we use are from regulatory reports filed by major U.S. freight railroads for the period 1978-2001. The firms are listed in Appendix Table A1.<sup>8</sup> All together the data set contains 297 observations.

The specification that we use differs from other rail cost functions in that we view the infrastructure-related activities of the firm as a variable output which imposes costs directly and which interacts with other (operational) outputs.<sup>9</sup> Our model assumes a vertical production process in which quasi-fixed land and other inputs (fuel, materials, labor,

equipment) are first transformed into infrastructure outputs and then into differentiated car-miles. This allows us to investigate the technological aspects of vertical and horizontal integration. This also avoids a potentially strong collinearity problem that could be present in the cost function for integrated network firms when the definitions of capital and infrastructure services are not precisely stated.

The cost model is

$$(6) \quad C = C (y_B, y_E, y_I, w_L, w_E, w_F, w_M; H, R, T, U, \theta),$$

where

- $C$  = fixed and conditional opportunity costs,
- $y_B$  = car-miles of bulk traffic (i.e., open hopper, closed hopper, tank),
- $y_E$  = car-miles of general traffic (i.e., intermodal, auto-carriers, gondolas and box cars),
- $y_I$  = replacement ties installed in a given year,
- $w_L$  = index of labor prices,
- $w_E$  = index of equipment prices,
- $w_F$  = index of fuel prices,
- $w_M$  = index of material prices and other input prices,
- $H$  = average length of haul,

- $R$  = miles of road operated,
- $T$  = counter for years,
- $U$  = percent of car-miles moving in unit trains,
- $\theta$  = vector of fixed effect parameters .

Here the fixed (capital) factor is land measured by the number of miles of road ( $R$ ), while variables  $H$  and  $U$  allow us to differentiate railroads in terms of their network structures. The number of ties replaced in a year provides a measure of the usage of tracks and as such, is a measure of the activity of the infrastructure department in railroads. In addition, note that there are two operational outputs and four variables inputs.

The system that we estimate includes four factor demand equations defined by (2) above, and three additional demand equations for the endogenous output variables  $y_B$ ,  $y_E$  and  $y_I$ .<sup>10</sup> The system is estimated using full information maximum likelihood with a correction for firm-level fixed effects within the factor demand equations. This is done by fixing the values of the  $\theta$  parameters at the average values of each firm's input quantities.<sup>11</sup>

The estimated cost model is globally concave in  $w$  and the full parameter set is consistent with the results of earlier rail cost models such as Wilson (1997), Bitzan (1999) and Ivaldi and McCullough (2001). The general regression results are presented in Appendix Table A2. Of particular interest are the second-order output-related parameter estimates shown in Table 1.<sup>12</sup> These show significant cost *complementarities* between

bulk operations ( $y_B$ ) and general freight ( $y_E$ ) operations, and between infrastructure outputs ( $y_I$ ) and both of the operational outputs. Our interpretation is that these complementarities result from the *capabilities* that railroads develop as traffic volumes increase and as firms become skilled in complex scheduling of trains, locomotives and crews.<sup>13</sup> The higher capabilities a railroad develops for commanding and controlling operations become available as “public inputs” for infrastructure activities, and vice versa. Interestingly, though, we find no evidence of own-cost complementarities, which suggests that U.S. railroads have exhausted the direct cost efficiencies associated with the movement of bulk and general freight traffic.

TABLE 1 (here)

We now use (3), (4), and (5) to conduct simulations of the type proposed by Evans and Heckman to evaluate single firm versus two firm subadditivity. For *infrastructure separation* we evaluate

$$(7) \quad C(y_B, y_E, y_I) \leq \delta C^U + C^C(y_B, y_E, 0) + C^C(0, 0, y_I),$$

using the sample values of  $w$ ,  $y$ ,  $t$  and  $\theta$  for each of the 297 observations. For the two-firm scenarios on the right-hand side of (7) we allow the duplication of fixed costs to be proportional to single-firm fixed costs by the factor  $\delta$  which takes values 1.0, 1.33, 1.66, and 2.0.

For *operational separation*, we evaluate

$$(8) \quad C(y_B, y_E, 0) \leq \delta C^U + C^C(\alpha y_B, \beta y_E, 0) + C^C((1-\alpha)y_B, (1-\beta)y_E, 0),$$

where the parameters  $\alpha$  and  $\beta$  take values 0, 0.33, 0.66, and 1, and where  $\delta$  varies as in the first test.

The test results are summarized in Table 2. The results for *infrastructure separation* confirm that there are complementarities between infrastructure-related activities and train operations. The degree of fixed cost duplication plays a relatively small role in determining subadditivity. The results for *operational separation* suggest that there are also complementarities between types of freight service. Operational costs are subadditive for 93.7 percent of the cases even when there is no duplication of fixed costs.<sup>14</sup>

TABLE 2 (here)

The results for vertical separation of U.S. freight railroads are restated in Table 3 where we again use (3), (4) and (5) to estimate fixed and conditional costs for the average firm in our sample of 297 observations. We project these costs for an Integrated Firm scenario (current projected costs), a Separated Firms scenario where infrastructure is unbundled from operations but operations are integrated, and a Diversified Firms scenario where infrastructure, bulk and general freight are all unbundled. For analytical

simplicity we assume that the diversifications are orthogonal and that there are no adjustments in network size ( $R$ ). We present results for limiting cases of no duplication of fixed cost ( $\delta = 1$ ) and complete duplication ( $\delta = 2$ ).

The projections suggest that the fully integrated firm would have a 20-40 percent cost advantage over a vertically separated system where the operating company provided bulk and general freight services. Even greater losses of efficiency might occur if bulk and general freight operations were unbundled. The projections indicate that a firm which combined the movement of bulk and general freight would have a 70 percent cost advantage over two separate firms, one of which moved only bulk and the other only general freight.

Table 3 (here)

There are *caveats* that apply to Tables 2 and 3. First, with our sample of integrated firms we cannot assess whether transactions costs associated with separated operations would be higher (or lower) than they are in integrated firms.<sup>15</sup> Nor can we assess whether competition effects would offset the estimated loss of technical efficiency. Finally, the results are based on firm-level observations and thus comprise a within sample test of subadditivity and not a global test of natural monopoly. Our tests use sample values for the set of technological factors  $t$ , and  $t$  includes a measure of network size ( $R$ ) for each firm and year. In fact, we might expect network sizes to change as the vertical structure of firms within the industry changed and this would affect projected

costs. Nevertheless, the results based on conditional costs are consistent with a natural monopoly hypothesis.<sup>16</sup>

#### **IV. Conclusions**

Our analysis has focused on the technological determinants of network oversight for firms such as electric utilities and railroads which exhibit the characteristic of natural monopolies and have strong operational and infrastructure maintenance components. We extend Evans' and Heckman's test for subadditivity to analyze the feasibility of separating these network technologies into an infrastructure component and operating components. We implement the tests for infrastructure separation and operational separation with a Generalized McFadden cost function. We illustrate the tests with an application to U.S. freight railroads.

Our empirical results have interesting implications for U.S. rail policy. Our simulations suggest first that there would be a 20-40 percent loss of technical efficiency if railroad freight operations were separated from infrastructure and an additional 70 percent loss of operational efficiency if on-rail operations were separated. In our view, this places a fairly heavy burden of proof on proponents of separation to establish that a) separated firms could coordinate infrastructure and operations efficiently using market mechanisms, and/or b) the efficiency gains from on-rail competition would somehow offset the loss of vertical and horizontal efficiencies.

The potential implications of our findings for rail restructuring efforts in Europe and elsewhere are less clear. European systems, which usually combine freight operations with a high level of passenger operations, have different technological characteristics than U.S. railroads. (See Footnote 6.) On the one hand, we might see stronger vertical economies between infrastructure and operations due to the complexity (and relative inflexibility) of passenger operations. On the other hand, we might not see horizontal economies between on-rail passenger and on-rail freight operations because of their qualitative differences. Careful delineation and interpretation of these effects is a subject for further research.

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## APPENDIX

TABLE A1 – U.S. CLASS I RAILROADS 1978 – 2001

<b>Railroad</b>	<b>Acronym</b>	<b>Period</b>	<b>Railroad</b>	<b>Acronym</b>	<b>Period</b>
Santa Fe	ATSF	78-95	Louisville & Nashville	LN	78-82
Baltimore & Ohio	BO	78-83	Missouri-Kansas-Texas	MKT	78-87
Burlington Northern	BN	78-01	Missouri Pacific	MP	78-85
Chesapeake & Ohio	CO	78-83	Norfolk & Western	NW	78-83
Chicago Northwestern	CNW	70-94	Norfolk Southern	NSC	86-97
Consolidated Rail	CRC	70-98	Seaboard Coastline	SCL	78-85
CSX Corp	CSX	86-01	Soo Line	SOO	78-01
Denver & Rio Grande	DRGW	78-93	Southern Pacific	SP	78-96
Grand Trunk	GTW	87-01	Southern Railway	SRS	78-85
Illinois Central Gulf	ICG	78-01	Union Pacific	UP	78-85
Kansas City Southern	KCS	78-01	Union Pacific System	UPSYS	86-01

TABLE A2 – NONLINEAR FIML SUMMARY

<b>Equation</b>	<b>SSE</b>	<b>Root MSE</b>	<b>Durbin Watson</b>	<b>R-Square</b>
$X_L$	440296	663.5	0.9528	0.9802
$X_F$	49014	221.4	1.4552	0.9921
$X_E$	1086831	1042.5	1.5354	0.9320
$X_M$	67263.1	259.4	1.1419	0.9574
$\log(y_B)$	0.0970	0.3115	0.5418	0.9347
$\log(y_E)$	0.2016	0.4490	0.2402	0.8510
$\log(y_I)$	0.1342	0.3663	1.1259	0.8783

## TABLES

TABLE 1 – MCFADDEN FIRST ORDER PRICE AND SECOND-ORDER CROSS COST PARAMETER ESTIMATES

Parameter	Estimate	T value	Parameter	Estimate	T value
$w_L$	-48.3201	-0.11	$w_E * y_E$	0.005984	4.58
$w_F$	440.0777	2.98	$w_E * y_I$	0.026104	0.03
$w_E$	461.0521	0.73	$w_M * y_B$	0.001764	3.78
$w_M$	-260.7760	-1.69	$w_M * y_E$	0.000780	2.48
$w_L * y_B$	0.003626	2.90	$w_M * y_I$	-0.103770	-0.47
$w_L * y_E$	0.004406	5.18	$y_B * y_B$	3.80E-13	6.93
$w_L * y_I$	0.812610	1.38	$y_E * y_E$	2.78E-13	8.74
$w_F * y_B$	0.000165	0.34	$y_I * y_I$	7.09E-08	3.23
$w_F * y_E$	0.000914	2.48	$y_B * y_E$	-2.98E-13	-8.35
$w_F * y_I$	-0.111160	-0.52	$y_B * y_I$	6.56E-11	-2.46
$w_E * y_B$	-0.000320	-0.17	$y_E * y_I$	-2.95E-11	-1.37

TABLE 2 – ONE FIRM VERSUS TWO FIRM SUBADDITIVITY TESTS

Cases	Subadditive Cases ( $\delta =$ Duplication Factor for Fixed Costs)				
	$\delta = 1.0$	$\delta = 1.33$	$\delta = 1.66$	$\delta = 2.00$	
	Cases	Cases	Cases	Cases	
Infrastructure Separation	297	249 (83.8 %)	260 (87.5 %)	271 (91.2 %)	279 (93.9 %)
Operational Separation	2,376	2,228 (93.7 %)	2,271 (95.6 %)	2,290 (96.3 %)	2,304 (96.9 %)

TABLE 3 – ALTERNATIVE SCENARIOS (000 \$97)

Projected Costs	Integrated Firm	Separated Firms		Diversified Firms	
		$\delta = 1$	$\delta = 2$	$\delta = 1$	$\delta = 2$
Fixed Cost		169,067	338,134	169,067	338,134
Infrastructure		217,410		217,410	
Operations					
Bulk				823,799	
General Freight				984,802	
Subtotal		1,065,292		1,808,601	
Total	1,150,860	1,451,769	1,620,836	2,195,080	2,364,147

## FOOTNOTES

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<sup>1</sup> See EC (2000) for a discussion of the relationship between optimal regulation and competition policy and for descriptions of restructuring experiments in various network industries.

<sup>2</sup> Kaserman and Mayo (1991) find vertical economies between the generation stage and transmission/distribution stages of electricity production.

<sup>3</sup> Bitzan (1999) and Ivaldi and McCullough (2001) find horizontal economies among differentiated operating outputs on U.S. freight railroads,

<sup>4</sup> Scale and scope are necessary but not sufficient conditions for subadditivity. See Panzar (1989) for an analysis of the relationship of subadditivity to economies of scale and scope.

<sup>5</sup> This parameterization is from Wiley, Schmidt and Bramble (1973).

<sup>6</sup> Intercity passenger trains operated by the National Railroad Passenger Corp. (AMTRAK) account for less than one percent of annual rail revenues.

<sup>7</sup> See Wilson (1997) and Ellig (2002) for discussions of rail performance since deregulation.

<sup>8</sup> More detailed explanation of the choice of variables and a description of their sources and construction are in Ivaldi and McCullough (2001) and the references therein.

<sup>9</sup> In most rail cost studies such as Berndt *et al* (1993) infrastructure is treated as a quasi-fixed input and represented by a monetary measure of way and structures capital. Wilson (1997) is an exception.

<sup>10</sup> There is a potential problem of output endogeneity because average freight prices are capped by the regulator and because these prices are related to costs and costs to output levels. The additional variables in the demand equations are annual system-wide population and system-wide coal consumption for each railroad. By introducing these demand equations, the estimation approach resembles an IV method.

<sup>11</sup> See Diewert and Wales, op. cit., p.49.

<sup>12</sup> The full set of estimates is available on request from the authors.

<sup>13</sup> See Ivaldi and McCullough (2001) for additional discussion of rail cost complementarities.

<sup>14</sup> We also used the Generalized McFadden to conduct Baumol's for the overall subadditivity of the rail cost function. Even without duplication of fixed costs ( $\delta = 1$ ) we find overall costs subadditive in 9,300 of 9,504 possible cases (97.8 percent). We do not report these results in Table 2 because we do not give them much credence. The overall test here assumes that operations and infrastructure can be separated without regard to output proportions. Thus, for example, it compares whether combinations like  $C(y_B, y_E, .33 y_I)$  +  $C(0, 0, .66 y_I)$  are greater than  $C(y_B, y_E, y_I)$  which does not seem relevant.

<sup>15</sup> Teece (1980) notes that transaction costs as well as technology significantly affect the "scope of enterprise".

<sup>16</sup> See the conclusion of Roller (1990) regarding Bell System natural monopoly.