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Output Aggregation and Estimates of Railroad Technology and Productivity Growth : Belgian railroads 1950-1986

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ABSTRACT

The purpose of this paper is to empirically evaluate the impact of alternative output specifications on estimates of the cost structure and the evolution of productivity growth in Belgian railroad questions. We compare the traditional homogeneous output approach with the use of hedonic output aggregates and carefully evaluate differences in estimates of input substitution possibilities, returns to scale, and productivity growth. It is found that ignoring the role of operating characteristics in cost analyses implies substantial bias in estimates of railroad technology.

Introduction

Almost all early studies and quite a few recent analyses of the cost and production structure in the transportation industries have used a single output measure for each of the two dimensions of output, viz. passengers and freight, usually taken to be passenger-miles and tonmiles, respectively. Examples of this approach include Borts (1960), Griliches (1972), Keeler (1974), Berechman (1983), Braeutigam et al (1984), and Kim and Spiegel (1987). It is clear, however, that transport firms provide a multitude of services, each of which may have a very specific impact on costs. Moreover, it is well known that operating characteristics and quality attributes significantly affect the marginal cost of an extra passenger- or tonmile. For example, the cost of a tonmile of a particular commodity critically depends on variables such as load factors, average length of haul, average shipment size, etc.

Not surprisingly, recent empirical analyses have tried to capture the explicit multidimensionality of output as well as the impact of operating characteristics on costs. A particularly convenient proposal in this respect was the introduction of hedonic output aggregators (see Spady and Friedlander (1978)). They can be introduced in a straightforward manner into flexible functional forms for the cost function in a way that is not too parameter-intensive. They provide the researcher with an empirically attractive tool that allows a fairly detailed specification of outputs in cost and production models.

The purpose of this paper is to empirically investigate the impact of more careful output specifications on estimates of the properties of the production technology in the transport industry. More specifically, we will compare the traditional homogeneous output approach with the use of hedonic output aggregators in terms of the technological characteristics they imply. We carefully evaluate differences in estimates of input substitution possibilities, returns to scale and the evolution of productivity growth over time. The empirical analysis uses data on Belgian railroads over the period 1950-1986. As the literature suggests that railroad companies may be unable to adjust input levels to their long-run cost minimizing levels and tend to operate with considerable excess capacity (Keeler (1974), Caves, Christensen and Swanson (1981)), the analysis will be based on short-run restricted cost functions rather than total cost models.

Structure of the paper is as follows. In Section 1 we review the derivation of expressions with respect to the technological characteristics of the firm, such as scale economies and productivity growth, on the basis of estimated short-run restricted cost functions. In Section 2 we describe alternative procedures that have been used in the literature to incorporate the multidimensionality of output and the potential impact of operating characteristics on costs. Two versions of a restricted translog cost function are presented in Section 3. The first one uses passenger- and tonkilometer as output measures, the second one is based on two hedonic aggregates that incorporate proxy variables for several important operating characteristics. The implications for the estimated properties of railroad technology derived from the two models are carefully discussed in Section 4. Finally, conclusions are summarized in Section 5.

1. Restricted cost functions, returns to scale, and productivity growth

In this section we briefly review the derivation of indices of returns to scale and productivity growth on the basis of a restricted cost function. For more details we refer to Caves, Christensen and Swanson (1981) and De Borger (1984).

Assume a firm produces a vector of outputs $Y = (Y_1, \ldots, Y_M)$ using a vector of variable inputs $X = (X_1, \ldots, X_N)$ and a fixed factor K that cannot be adjusted in the short-run. Let the transformation function describing the production process be given by

$$T(Y,X,K,t) = 0 \tag{1}$$

where t is time. It is included to allow the time dependency necessary to capture productivity changes over time.

Differentiating (1) yields, after some manipulation,

$$\sum_{m=1}^{M} T_{\bar{Y}_m}\, d\,\bar{Y}_m + \sum_{n=1}^{N} T_{\bar{X}_n}\, d\,\bar{X}_n + T_{\bar{K}}\, d\,\bar{K} + T_t dt = 0 \tag{2}$$

where

$$T_{\bar{Z}} = \frac{\delta T}{\delta \bar{Z}}$$

and $\bar{Z} = \ln Z$. Defining returns to scale (RTS) as the proportional increase in all outputs corresponding to a proportional increase in all inputs, equation (2) implies[1]

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[1] Note that, in order to distinguish scale economies from changes in productivity, time t is held constant in this derivation.

$$\mathrm{RTS} = - \frac{\sum_{n=1}^{N} T_{\bar{X}_n} + T_{\bar{K}}}{\sum_{m=1}^{M} T_{\bar{Y}_m}} \,. \tag{3}$$

We further define two indices of productivity growth. The first one, P1, is defined as the common rate at which outputs can grow over time with all inputs held constant. It follows from (2) that

$$P1 = - \frac{T_t}{\sum_{m=1}^{M} T_{\bar{Y}_m}} \tag{4}$$

A second index, P2 is defined as the common rate at which inputs can be reduced over time with all outputs remaining constant. Equation (2) implies

$$P2 = - \frac{T_t}{\sum_{n=1}^{N} T_{\bar{X}_n} + T_{\bar{K}}} \tag{5}$$

The indices P1 and P2 will generally differ. Inspection of (3), (4) and (5) reveals that P1 = P2 if and only if RTS = 1, the case of constant returns to scale.

Assume that the firm in the short-run minimizes the costs of the variable factors subject to the transformation function (1). It follows that there exists a restricted cost function with the usual properties

$$C_V(Y,p,K,t) = \min_{X_n} \sum_{n=1}^{N} p_n X_n \qquad \text{s.t. } (1), \tag{6}$$

where $p = (p_1, \ldots, p_N)$ is the vector of prices related to the variable inputs. Using the first-order conditions of the minimization problem on the right-hand side of (6) and the envelope theorem it can easily be shown that (3), (4), (5) can be written in terms of cost elasticities as follows[1]

$$RTS = \frac{1 - \dfrac{\delta \ln C_V}{\delta \ln K}}{\sum\limits_{m=1}^{M} \dfrac{\delta \ln C_V}{\delta \ln Y_m}} \tag{7}$$

$$P1 = \frac{- \dfrac{\delta \ln C_V}{\delta t}}{\sum\limits_{m=1}^{M} \dfrac{\delta \ln C_V}{\delta \ln Y_m}} \tag{8}$$

$$P2 = \frac{- \dfrac{\delta \ln C_V}{\delta t}}{1 - \dfrac{\delta \ln C_V}{\delta \ln K}} \tag{9}$$

These expressions will be used below to analyze the production structure of the Belgian railroad and the associated growth of productivity over time.

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[1] The envelope theorem implies

$$\frac{\delta \ln C_V}{\delta \ln Y_m} = - \lambda\ C_V\ T_{\bar{Y}_m}\ , \quad \frac{\delta \ln C_V}{\delta \ln K} = - \lambda\ C_V\ T_{\bar{K}} \text{ and } \frac{\delta \ln C_V}{\delta\ t} = -\lambda\ C_V\ T_t ,$$

where λ is the Lagrange multiplier corresponding to the constraint in (6).

The first-order conditions of (6) yield

$$\lambda = \frac{p_n\ X_n}{T_{\bar{X}_n}} \ .$$

Using these expressions in (3), (4) and (5) leads to (7), (8) and (9).

2. Output specification in the transportation industries

Researchers familiar with the transport sector are well aware of the multiplicity of services provided by the railroad and trucking industries and the importance of operating characteristics in explaining costs. It is not surprising that the transport sector has played a prominent role in the development and testing of new methodologies that allow a more satisfactory specification of outputs in cost analyses.

Both the heterogeneity of output and the potential impact of operating characteristics have been incorporated in a variety of different ways. With respect to the former some authors have reduced the number of distinct outputs by using 'natural' output classifications (see, e.g., Fuss and Waverman (1981), Gillen and Oum (1984). Others have defined a limited number of reasonably homogeneous output indicators by classifying each of a large number of disaggregate outputs in one of several categories according to ranges of shipment size and length of haul (see, e.g., Harmatuck (1981)). On the other hand, operating characteristics and quality attributes have been introduced into cost models in two distinct ways. The first approach just adds a set of relevant characteristics to the cost function specification, imposing no restrictions on the functional structure of the relation between operating variables, generic outputs (such as tonmiles) and input prices. However, especially when used in relation with flexible functional forms for the cost function, this procedure is highly parameter-intensive. Therefore, it can only be used with a relatively small set of operating characteristics, see, e.g., Harmatuck (1979) and Caves et al. (1981). A second approach to capture differences in the structure and composition of output through the introduction of operating characteristics and qualitative variables is to define hedonic output aggregator functions. Each aggregator is parametrically specified as a function of a physical output and a vector of related operating variables. For example, if there are M physical outputs the hedonic version of the variable cost function (6) can be written as

$$C_V^h \left(\phi_1(Y_1;q_1), \dots\dots\dots, \phi_M(Y_M;q_M), p, K, t\right) \qquad (10)$$

where $\phi_m(.)$: hedonic aggregator related to physical output m, m=1, ..., M

q_m : vector of operating and quality attributes related to physical output m, m=1, ..., M.

The $\phi_m(.)$ are assumed to be homogeneous of degree one in Y_m so as to be consistent with conventional aggregation theory. The parameters of the aggregators are typically estimated jointly with the cost function parameters. Applications include Spady and Friedlander (1978), Wang Chiang and Friedlander (1984) and Gillen and Oum (1984).

The advantage of hedonic cost models is that they allow incorporation of detailed output specifications in a way that is much less parameter-intensive than the more general approach previously discussed. This advantage does have its cost, however. The existence of output aggregates implies separability of the arguments within a given aggregate from all other arguments in the cost function[1]. In addition, in the case of the popular translog cost function an even stronger implicit assumption of the hedonic model has been revealed by Oum and Tretheway (1989). They indicate, using the results of Blackorby, Primont and Russell (1977), that

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[1] This may not be realistic in some cases. For an example, see Oum and Tretheway (1989, p. 10). These authors also show that for the translog case the hedonic specification is embedded within the general specification, which does not a priori impose separability, through a set of nonlinear restrictions on the parameters.

the hedonic specification is no longer capable of providing a second order approximation to any unknown arbitrary separable cost function and, therefore, that it must be considered an exact form of the cost function. However, as shown by Denny and Fuss (1977), the separable form of a translog function interpreted as an exact function must be either a Cobb-Douglas specification of translog aggregates or a translog function of Cobb-Douglas aggregates. It follows that if the hedonic cost function is translog then the aggregators embedded in it should be loglinear. This seriously restricts the generality of the hedonic model. However, given the parameter-intensiveness of the general cost function specification, hedonic aggregates provide an attractive and yet feasible tool to incorporate operating characteristics in empirical cost analyses.

3. The empirical model

In this section we estimate restricted variable cost functions for Belgian railroads over the period 1950-1986 using two alternative output specifications, and evaluate the differences in estimated characteristics of the cost structure and the evolution of productivity growth over time.

We assume the Belgian railroad company NMBS produces freight (F) and passenger (R) services using the variable inputs labor (L) and energy (E) and a fixed factor (K) that cannot be optimally adjusted in the short-run. Assuming that the firm's objective is to minimize short-run variable costs a restricted cost function

$$C_V(F,R,p_L,p_E,K,t) = \operatorname*{Min}_{L,E} p_L L + p_E E \quad \text{s.t. } T(F,R,L,E,K,t) = 0$$

exists, where p_i are the input prices of the variable inputs and t is time.[1]

We use the translog approximation to $C_V(.)$ for our empirical work. Given our two-variable-input-model the translog restricted cost function can be written, after imposing symmetry and linear homogeneity in input prices as

$$\begin{aligned}\ln\left(\frac{C_V}{p_E}\right) = {} & \alpha_0 + \alpha_L \ln\left(\frac{p_L}{p_E}\right) + \frac{1}{2}\alpha_{LL}\left[\ln\left(\frac{p_L}{p_E}\right)\right]^2 \\ & + \alpha_F \ln F + \alpha_R \ln R + \frac{1}{2}\alpha_{RR}(\ln R)^2 + \frac{1}{2}\alpha_{FF}(\ln F)^2 + \alpha_{RF}\ln R \ln F \\ & + \alpha_K \ln K + \frac{1}{2}\alpha_{KK}(\ln K)^2 + \alpha_{RK}\ln R \ln K + \alpha_{FK}\ln F \ln K \\ & + \alpha_{LF}\ln F \ln\left(\frac{p_L}{p_E}\right) + \alpha_{LR}\ln R \ln\left(\frac{p_L}{p_E}\right) + \alpha_{LK}\ln K \ln\left(\frac{p_L}{p_E}\right) \\ & + \alpha_t t + \alpha_{tL} t \ln\left(\frac{p_L}{p_E}\right) + \alpha_{tR} t \ln R + \alpha_{tF} t \ln F + \alpha_{tK} t \ln K \qquad (11)\end{aligned}$$

The associated factor shares are

$$s_L = \alpha_L + \alpha_{LL}\ln\left(\frac{p_L}{p_E}\right) + \alpha_{LF}\ln F + \alpha_{LR}\ln R + \alpha_{LK}\ln K + \alpha_{tL}t \qquad (12)$$

$$s_E = (1-\alpha_L) - \alpha_{LL}\ln\left(\frac{p_L}{p_E}\right) - \alpha_{LF}\ln F - \alpha_{LR}\ln R - \alpha_{LK}\ln K - \alpha_{tL}t \qquad (13)$$

The model consisting of (11), (12) and (13) was estimated using 2 alternative output specifications. In a first version F and R were simply defined as tonkilometers and passengerkilometers, respectively. Maximum likelihood estimates were obtained using iterative seemingly unrelated regression (SUR), where (13) was deleted from the system to avoid the singularity of the variance-covariance matrix of

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[1] Both the assumption of variable cost minimization and the choice of inputs may be subject to criticism. For details and for a justification of the approach chosen in this paper, see De Borger (1989).

the residuals. A second version was estimated in which F and R were specified as hedonic aggregators. Consistent with the theoretical restrictions discussed in Oum and Tretheway (1989) we specified the aggregates as Cobb-Douglas. Specifically, we used

$$\ln F = \ln y_F + \sum_{q=1}^{Q} a_q \ln Z_{Fq} \tag{14}$$

$$\ln R = \ln y_R + \sum_{p=1}^{P} b_p \ln Z_{Rp} \tag{15}$$

where y_F, y_R are tonkilometers and passengerkilometers, respectively.

$Z_F = (Z_{F1}, \ldots, Z_{FQ})$ is a vector of operating characteristiscs related to freight.

$Z_R = (Z_{R1}, \ldots, Z_{RP})$ is a vector of operating characteristics related to passengers.

Expressions (14) and (15) were inserted in (11), (12) and (13), and the resulting model, which is nonlinear in the parameters, was estimated by nonlinear iterative seemingly unrelated regression. The energy share equation was again deleted to account for the singularity of the variance-covariance matix of the residuals.

The data for the empirical analysis were taken from the company's annual reports and statistical reviews. The price of labor was obtained by dividing total labor expenditures by the aggregate quantity of labor input, measured in number of employees.[1] With respect to energy, a Divisia index for energy input was constructed based on three energy sources (electricity, fuel, coal) and total energy costs were divided by this aggregate input to obtain unit price p_E. A

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[1] Total man-hours were not available.

capital stock index was constructed by combining information on the initial value of five categories of capital (tracks, land, buildings, other structures, rolling stock and other equipment) with appropriate depreciation rates and gross investment figures for each category.

The operating characteristics to be included in the hedonic aggregates were selected from a limited set of potential candidates. With respect to freight we wanted to capture the output dimensions 'distance' and 'cargo' as well as some important demand characteristics, such as output composition and geographic dispersion. These latter variables together with the company's internal scheduling operations largely determine the (unfortunately unobserved) load factor, which is known to strongly affect transport costs.

Consistent with the above ideas we initially included, apart from generic output tonkilometer (TKM), the average length of haul (AVHAUL), the average load per train (AVTON) and the fraction of all tonkilometers due to bulk commodities (BULK). The former three variables capture the dimensions cargo and distance and provide a crude proxy for geographic dispersion of demand.[1] The fourth variable was intended to serve as a simple one-dimensional proxy for output composition.[2] Unfortunately, BULK turned out to be consistently insignificant and was deleted from the final specification.[3] In an effect to approximate variations in

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[1] Denoting total cargo by TON and the number of trainkilometer for freight by KMFR we have
AVHAUL = TKM/TON ; KMFR = TKM/AVTON
The variable AVHAUL may be considered a crude proxy for geographical demand variation over time. Together with TKM and AVTON it implicitly determines TON and KMFR. Inclusion of AVHAUL and TKM rather than TON and TKM seems to be more in line with previous studies.

[2] Given our time series data and the large number of parameters to be estimated more detailed specifications of output composition were not feasible.

[3] It may well be that the impact of output composition as measured by BULK is to a large extent captured through its correlation with included operating characteristics. The variable BULK was highly correlated with AVHAUL and especially AVTON. It may have been difficult, therefore, to separately identify the impact of output composition.

the load factor we did include one additional operating characteristic with which it is likely to be strongly correlated, viz. the number of times a ton of cargo capacity was actually used (TONCAP, defined as total cargo carried divided by carrying capacity). Holding AVHAUL, AVTON and TKM constant, variations in TONCAP reflect changes in the utilization of the rolling stock due to fluctuations in the load factor, or due to variations in the efficiency with which the company assigns the available loading capacity to freight trains. We therefore expect TONCAP to be a reasonable proxy for the unobserved load factor.

On an analogous basis we included passengerkilometer (RKM), average trip length (AVTRIP), average number of passengers per train (AVPASS), and the number of times a unit of seating capacity was actually used to serve passengers (PASSCAR) in the hedonic output aggregate for passengers. Together, these variables should provide reasonable approximations for distance, passenger-related expenditures, geographic dispersion and the load factor.

4. Empirical results : cost structure and productivity growth under alternative output specifications

Estimation results for the two alternative models are in Table 1. For the model with the generic outputs passenger- and tonkilometers slightly more than half the parameters are significantly different from zero. In the hedonic specification 17 parameters out of 26 are significant. Note that the hedonic model has somewhat higher explanatory power, especially with respect to the share equation.

With the exception of AVTRIP all operating characteristics in the hedonic aggregates have the expected sign and are highly significant. For example, the results suggest that the cost of producing a given quantity of tonkilometers substantially declines with higher length of haul, higher average load per train and better utilization of the rolling stock. Similarly, the cost of a passengerkilometer declines due to better utilization of available seating capacity and more passengers per train. Note that the insignificance of the average trip length may be interpreted as reflecting the unimportance of the total number of passengers in explaining costs. For a given value of passengerkilometers (RKM) variations in AVTRIP reflect variations in the number of passengers.[1] The insignificance of the passenger dimension may indicate that, at least for passenger transport, the majority of variable cost directly relates to running the trains, whereas marginal costs of serving extra passengers are unimportant.

To gain insight into the interpretation of the estimated output aggregates we considered the correlation of the hedonic outputs with several commonly used output indicators.[2] The results are presented in Tables 2A and 2B. With respect to passenger transportation, one observes that the estimated output aggregate is strongly **negatively** correlated with passengerkilometers and the number of passengers, whereas the correlation with the number of trainkilometer is large and positive. This suggests that the use of passengerkilometer as output indicator without correcting for variations in operating characteristiscs may lead to substantially misleading implications. Indeed,

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[1] Indeed, denoting the number of passengers by NPASS we have AVTRIP = RKM/NPASS.

[2] Note that the estimated output aggregators are given by

$R = RKM * AVTRIP^{0.4348} * AVPASS^{-1.2028} * PASSCAP^{-0.9194}$

$F = TKM * AVHAUL^{-1.5378} * AVTON^{-1.2451} * TONCAP^{-0.4657}$

reductions in passengerkilometers tend to have been accompanied by improvements in the operating characteristics which more than offset the reduction in generic output, leading to an increase in estimated hedonic output. The strong positive correlation between hedonic output and trainkilometer further confirms our earlier finding that variable costs are strongly related to operating the trains, but not to carrying passengers.[1].

The freight aggregate correlates negatively with tonkilometers, and hardly correlates at all with trainkilometers and total cargo. Again, improvements in operating characteristics imply that reductions in tonkilometers may result in increasing hedonic output. The regression results reported in Table 1 were used to evaluate the economic properties discussed in Section 1. Not surprisingly, most of these estimates showed substantial variability over time, but no systematic trends were found. Rather than reporting the results for each year in the sample we present estimates of the technological characteristics evaluated at the average values of all variables (factor shares, outputs, etc.) in three successive subperiods of approximately equal length. In the first subperiod, 1950-1962, passengerkilometers showed a slight upward trend which was not reflected in the estimated hedonic aggregate, however. The aggregate did not show any systematic pattern over the subperiod. Despite reasonably limited fluctuations in tonkilometers the estimated aggregate for freight slightly declined due to less favorable operating characteristics. The subperiod can further be characterized by a slow but steady increase in the share of labor in variable costs. The second subperiod, 1963-1974, showed a downward trend in the number of passengerkilometers. However, improvements in the operating

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[1] Our results suggest that trainkilometers is by far the best one-dimensional output indicator for passenger transport. It has been used by, e.g., De Borger and Deloddere (1982) and Van de Voorde (1985).

characteristics implied first a relatively stable and towards the end of the period a somewhat increasing value of the output aggregate R. Freight output first declined but then substantially increased towards the end of the subperiod, both in terms of tonkilometers and in terms of the aggregator F. The share of labor continued to rise although at a lower rate than in the first subperiod. The final subperiod, 1975-1986, includes the energy crises and related slowdown in economic growth. Passengerkilometers and tonkilometers, especially early in the period, declined. However, for passenger transport important changes in the firm's operations counteracted this evolution. The restructuring of the existing network in this subperiod implied better traffic scheduling and substantially improved load factors. Moreover, the financial austerity program imposed upon the company in the second half of the period further encouraged efficient use of the rolling stock via optimal scheduling operations. Despite the decline in passengerkilometers, the hedonic output aggregator R strongly increased. The freight aggregate F slightly declined, especially towards the end of the period. Finally, the share of labor in variable costs decreased somewhat as a consequence of the rise in energy prices.

In Table 3 we present estimates of the input price elasticities and the substitution elasticity between labor and energy for the two alternative output specifications.[1] Several remarks are in order. First, the hedonic cost model yields consistently larger and more accurately estimated price and substitution elasticities. In the generic output specification only the elasticities related to the first

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[1] The elasticity of substitution σ_{LE} is given by

$$\sigma_{LE} = \frac{-\alpha_{LL} + s_L s_E}{s_L s_E}.$$

See, e.g., Pindyck (1979).

subperiod are significantly different from zero, whereas the hedonic model implies very precise estimates in all subperiods. Moreover, the latter specification yields point estimates that are up to four times larger than those generated by the alternative specification. The input price elasticities based on the hedonic model are much more in line with other studies of railroad costs (see, e.g., Caves et al. (1981), Breautigam et al. (1984), De Borger (1989)). Labor demand is found to be extremely inelastic throughout the sample period; estimates vary between -0.05 and -0.11, depending on the subperiod considered. Energy demand elasticities range from -0.66 to -0.72. It is interesting to note that these estimates seem to be typical for the Belgian public transport sector. Indeed, very similar price elasticities were obtained in bus transportation (De Borger (1984)).

Table 4 contains estimates of the cost elasticities with respect to outputs and the fixed capital stock. To facilitate the comparison of the results derived from the two alternative models, note the double interpretation of the output cost elasticities based on the hedonic model. They can obviously be interpreted as the cost elasticities with respect to the hedonic output aggregates. However, the definition of the aggregates in (14) and (15) also allows us to interpret them as elasticities with respect to passenger- and tonkilometers, holding the vectors of operating characteristics constant. This latter interpretation makes it possible to directly compare with estimates based on the generic model.

The results in Table 4 provide some interesting information. First, with very few exceptions the hedonic model yields more precisely estimated cost elasticities. Secondly, the exclusion of the operating characteristics implies substantially biased estimates. The generic output specification leads to a consistently overestimated cost elasticity with respect to passengerkilometers, and to a large downward bias in the estimated impact of changes in tonkilometers on costs. Depending on the subperiod considered the cost elasticities for passenger output range from 0.6 to 0.9 for the generic output specification, and from 0.3 to 0.5 for the hedonic model. With respect to freight transportation exclusion of operating characteristics leads to small and insignificant cost elasticities. The hedonic model on the contrary yields significant estimates, which range from 0.3 to 0.7. It is clear, then, that ignoring the important role of the operating characteristics is a specification error which, for our data, implies a substantial upward bias in the marginal cost of passengerkilometers, and a downward bias in the marginal cost of freight output.

The results in Table 4 also indicate substantial differences between the two models in the variability of the output cost elasticities over time. This is hardly surprising. The translog specification implies that all elasticities vary with changes in outputs, capital stock, input prices, and the time trend. The regression results in Table 1 suggest that these variables affect the values of the elasticities in very different ways under the two alternative output specifications. The most remarkable differences are the signs and magnitudes of the coefficients α_{RR} and α_{FF}. In model 1 the estimate for α_{RR} is large and significantly negative, whereas in the hedonic specification it is significantly positive. The parameter α_{FF} is estimated to be negative in both models, but it is much larger and significantly different from zero only in the hedonic model. These differences are important because they directly affect the shape of the textbook marginal cost schedules of passenger and freight output under each of the two alternative output specifications.[1]

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[1] For example, one easily shows that the slope of the marginal cost schedule of passenger and freight output is given by

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To further investigate the shape of the implied marginal cost curves we first evaluated for each model and for a number of years in the sample how the marginal cost of an extra passengerkilometer varied with output, also measured in terms of passengerkilometers.[1] This simple exercise revealed remarkable differences : the marginal cost schedule based on the generic output specification was found to be consistently downward sloping over the relevant output range, whereas the corresponding marginal cost of extra passengerkilometers derived from the hedonic model was estimated to be strongly increasing at higher output levels. Realizing that passenger traffic is highly concentrated during peak-hours on a limited number of high demand routes, this latter finding is more realistic than the downward sloping schedule generated by the generic model.

We similarly evaluated the shape of the marginal cost curves of extra tonkilometers for the two models. In both cases we found downward sloping marginal cost schedules over the relevant output range. The hedonic model implied strongly decreasing costs at high output levels. Given the flexibility of accommodating extra freight demand during off-peak hours (including overnight) and the reservation of part of the track network for freight traffic only there are no severe capacity constraints to drive up marginal costs.

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$$\frac{\delta MC_R}{\delta R} = \frac{C_V}{R^2} [\alpha_{RR} + \varepsilon_R(\varepsilon_R - 1)]$$

and

$$\frac{\delta MC_F}{\delta F} = \frac{C_V}{F^2} [\alpha_{FF} + \varepsilon_F(\varepsilon_F - 1)]$$

where ε_R and ε_F are the respective output cost elasticities.

[1] When doing this excercise on the basis of the hedonic model the values of the operating characteristics were held constant at the observed values in any given year.

Related to Table 4 a final remark concerns the estimated cost elasticities with respect to the fixed capital stock. The estimates are quite similar in the first subperiod but differ wildly over the complete period 1963-1986. Evaluated at average values for all variables the elasticity derived from the generic output model is positive in the period 1975-1986, although it is insignificantly different from zero. The positive value is inconsistent with cost minimizing behavior. In the hedonic model all reported values are negative. It should be noted, however, that in the period 1963-74 the point estimate was positive for several sample years, but is was never statistically significant.

Estimates of scale economies and productivity growth are presented in Table 5. Given the observed differences in cost elasticities between the two alternative models it is not surprising to find similar differences in the estimates of returns to scale. The generic model indicates increasing returns to scale in the first two subperiods and diseconomies of scale in the final period 1975-86. It should be noted, however, that this latter finding is due to the positive cost elasticity with respect to the capital stock (see equation (7)) which was indicated to be inconsistent with the hypothesis of variable cost minimization. The hedonic model generates mild economies of scale in two subperiods and essentially constant returns in the third. Although these estimates are certainly within the range of those found in the railroad literature, it should be pointed out that they were never significantly different from one. As a consequence the hypothesis of constant returns to scale throughout the sample period cannot be rejected. It was argued elsewhere that the absence of strongly increasing returns to scale seems quite reasonable given the extremely high density of the existing railroad network (see De Borger (1989)).

The most dramatic differences between the two cost models are found when considering the estimated productivity indices P1 and P2. Independent of the particular index used the two specifications lead to a quite different evolution of productivity growth over time.[1] In the first subperiod they both indicate large positive changes in productivity. However, whereas the generic model suggests average annual increases in productivity of 3.5 % to almost 6 % depending on the index used, the hedonic model implies more moderate estimates of 2 % to 3 %. A completely different pattern emerges for the full period 1963-1986. Here the generic model indicates a substantial decline in productivity; estimates range between an average annual decrease of 2 % to 3.6 % depending on the subperiod considered and the productivity index used. The hedonic model, however, yields a steady growth in productivity of slightly more than 1 % annually over the whole period 1963-1986. The implications are clear : ignoring the substantial improvements in operating characteristics over this period leads to a significant underestimation of the growth in productivity. Since productivity was defined by comparing output levels over time for fixed levels of inputs (P1) or comparing input quantities for fixed outputs (P2), it is obvious that the hedonic specification allows one to more accurately capture productivity changes. Improvements in the operating characteristics will not affect estimates of productivity growth in the generic case, but in the alternative model they will directly affect the value of the hedonic outputs and therefore, given the definitions of P1 and P2, the estimates of productivity change.

A final observation with respect to productivity growth is in order. The regression results in Table 1 show that in the hedonic specification productivity growth is

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[1] The differences between P1 and P2 are due to nonconstant returns to scale, see Section 1.

significantly labor-using and energy-saving, as evidenced by the positive and significant parameter α_{LT}. This suggests that productivity growth has been driven by the massive electrification program rather than by improvements in labor productivity. Related to this we also found that it seems to be passenger transportation that has captured the largest benefits from technological progress, as is suggested by the significantly negative coefficient α_{RT}. This is not surprising because electricity is almost exclusively used on passenger routes.

To conclude this section, note that the empirical results presented in this paper clearly illustrate that ignoring the role of operating characteristics in railroad cost models may lead to substantially biased and totally misleading estimates of productivity growth over time. They reflect an obvious fact that is all too often ignored in empirical work, viz., that output (and input) measurement is of crucial importance in order to obtain meaningful estimates of productivity growth.

5. Summary and Conclusions

The purpose of this paper was to illustrate the importance of operating characteristics in estimating the cost structure and the evolution of productivity growth over time in the railroad industry. A generic cost function was compared with an alternative model in which a number of relevant operating characteristics were introduced through hedonic aggregator functions. The two models were estimated using data on Belgian railroad operations over the period 1950-1986.

The results indicated the significance of proxy variables for geographic dispersion, load factors, average length of haul etc. in explaining railroad costs. More importantly, they suggested large differences in estimates of the characteristics of the production technology. Elasticities of substitution, cost elasticities and estimates of returns to scale based on the generic model were found to be substantially biased. In addition, the hedonic model yielded much more precise and more reasonable estimates. Among other results, based on the hedonic model we found strongly increasing marginal costs of passenger output at high output levels, and substantially declining marginal costs of freight output. The hypothesis of constant returns to scale throughout the sample period could not be rejected.

The most drastic differences between the two cost models were found when considering estimates of productivity growth. The generic output specification implied annual increases in productivity of up to 6 % in the subperiod 1950-1962. However, a substantial annual decline of 2 % to 3,5 % was estimated for the complete period 1963-1986. The hedonic model suggested, however, that his latter finding is due to ignoring the improvements in operating characteristics over this period. Estimates based on the hedonic specification implied a growth in productivity of approximately 2 % - 3 % annually in the period 1950-1962, and a more moderate but steady increase of slightly more than 1 % for the rest of the sample period. These findings clearly illustrate that ignoring the role of operating characteristics in railroad cost studies may lead to seriously biased and misleading estimates of productivity growth.

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	Model 1 : Generic output specification		**Model 2 :** Hedonic output specification	
parameter	estimate	standard error	estimate	standard error
α_{O}	-0.1410	0.0231^{*}	-0.0016	0.0179
α_{L}	0.8892	0.0088^{*}	0.8946	0.0046^{*}
α_{LL}	0.0548	0.0187^{*}	0.0189	0.0121
α_{R}	1.0671	0.3032^{*}	0.3474	0.0521^{*}
α_{F}	0.2694	0.2283	0.2552	0.1501
α_{RR}	-5.3213	1.1138^{*}	0.5925	0.1993^{*}
α_{FF}	-0.7168	0.6476	-1.8658	0.6715^{*}
α_{RF}	-0.1162	1.1561	-0.4973	0.5811
α_{K}	-0.4092	0.1180^{*}	-0.3331	0.0961^{*}
α_{KK}	-0.9979	0.2140^{*}	-0.3577	0.2120
α_{RK}	0.0225	0.7649	-0.5028	0.1654^{*}
α_{FK}	0.8069	0.8261	-0.6497	0.5836
α_{t}	0.0074	0.0033^{*}	-0.0094	0.0032^{*}
α_{RT}	-0.0508	0.0325	-0.0275	0.0123^{*}
α_{FT}	-0.0183	0.0377	0.0425	0.0384
α_{KT}	0.0973	0.0130^{*}	0.0450	0.0149^{*}
α_{LR}	0.1318	0.0389^{*}	-0.1078	0.0103^{*}
α_{LF}	-0.0334	0.0292	-0.0162	0.0208
α_{LK}	0.0646	0.0270^{*}	0.0565	0.0127^{*}
α_{LT}	0.0023	0.0013	0.0041	0.0007^{*}

Model 1

R2 cost equation 0.9841

R2 share equation 0.8814

Model 2

R2 cost equation 0.9948

R2 share equation 0.9627

output aggregates		
AVTRIP	0.4348	2.5061
AVPASS	-1.2028	0.3929^{*}
PASSCAP	-0.9194	0.2177^{*}
AVHAUL	-1.5378	0.4257^{*}
AVTON	-1.2451	0.3461^{*}
TONCAP	-0.4657	0.1174^{*}

NOTE : * indicates significant at the 1 % level

Table 1 : Regression results variable cost models under alternative output specifications

	Train-kilometer	Passenger-kilometer	Passengers	Hedonic Aggregator
Trainkilometer	1			
Passengerkilometer	-0.5425	1		
Passengers	-0.7578	0.9449	1	
Hedonic aggregator	0.9250	-0.7818	-0.9134	1

Table 2A : Correlation between passenger output measures

	Train-kilometer	Ton-kilometer	Ton	Hedonic Aggregator
Trainkilometer	1			
Tonkilometer	0.8458	1		
Ton	0.8485	0.8273	1	
Hedonic aggregator	-0.1312	-0.5154	-0.0364	1

Table 2B : Correlation between freight output measures

	Model 1 : generic output specification			Model 2 : hedonic output specification		
	σ_{LE}	η_L	η_E	σ_{LE}	η_L	η_E
1950-1962	0.5233	-0.0693	-0.4540	0.8349	-0.1106	-0.7242
	(0.1287)	(0.0227)	(0.1060)	(0.0833)	(0.0147)	(0.0686)
1963-1974	0.1826	-0.0132	-0.1694	0.7168	-0.0518	-0.6650
	(0.2791)	(0.0202)	(0.2590)	(0.1806)	(0.0130)	(0.1676)
1975-1986	0.2134	-0.0161	-0.1973	0.7743	-0.0718	-0.7025
	(0.2130)	(0.0207)	(0.1922)	(0.1378)	(0.0134)	(0.1244)

Note : 1. σ_{LE} = elasticity of substitution between labor and energy;
η_L, η_E = price elasticities of demand for labor and energy, respectively.
2. Asymptotic standard errors calculated on the assumption of nonstochastic factor shares.

Table 3 : Estimated substitution and input price elasticities for alternative output specifications (asymptotic standard errors in parentheses)

	Model 1 : generic output specification			Model 2 : hedonic output specification		
	Passenger output	Freight output	Capital stock	Passenger output	Freight output	Capital stock
1950-1962	0.5888	0.1166	-0.1668	0.5072	0.3278	-0.1425
	(0.2522)	(0.1314)	(0.0542)	(0.0812)	(0.0967)	(0.0583)
1963-1974	0.6654	0.2624	-0.2558	0.2802	0.7370	-0.0044
	(0.2944)	(0.2718)	(0.0837)	(0.1061)	(0.3797)	(0.0121)
1975-1986	0.9093	0.2849	0.2557	0.4717	0.4920	-0.1825
	(0.3992)	(0.2644)	(0.1698)	(0.0919)	(0.2393)	(0.0701)

Table 4 : Estimated cost elasticities for alternative output specifications (asymptotic standard errors in parentheses)

	Model 1 : generic output specification			Model 2 : hedonic output specification		
	Economies of scale RTS	Product output P1(%)	Capital stock P2(%)	Passenger output RTS	Freight output P1	Capital stock P2
1950-1962	1.6539	5.93	3.58	1.3683	2.93	2.12
	(0.6318)	(2.23)	(1.41)	(0.4243)	(1.16)	(0.72)
1963-1974	1.3510	-3.03	-2.24	0.9874	1.06	1.07
	(0.6411)	(1.48)	(0.84)	(0.3898)	(0.37)	(0.49)
1975-1986	0.6232	-1.97	-3.61	1.2269	1.24	1.01
	(0.3549)	(0.93)	(1.24)	(0.4378)	(0.41)	(0.34)

Table 5 : Scale economies and productivity growth for alternative output specifications (asymptotic standard errors in parentheses)