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THE ECONOMIC ENVIRONMENT AND PUBLIC ENTERPRISE BEHAVIOR: BELGIAN RAILROADS 1950-1986*

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ABSTRACT

The purpose of this paper is to estimate the impact of variations in the economic environment on allocatively inefficient behavior by public enterprises, and to measure the implications of both allocative and technical inefficiency for the firm's costs and factor use. Empirical results for the Belgian railroad company suggest the importance of unemployment and the pressure experienced by managers to reduce the deficit as explanatory variables of allocative inefficiency. The implications of inefficiencies on factor use are found to be substantial, although the associated costs are surprisingly small.

1. Introduction

A variety of models have been proposed in the literature that suggest that public enterprises will not, and probably should not, produce output at minimum cost. At the risk of oversimplifying a substantial literature one might distinguish normative and positive models of public enterprise behavior. The normative literature shows that under some conditions it is not socially desirable for public firms to use the cost minimizing input combinations that correspond to observed factor prices. Similarly, positive models describe how the interaction of managerial preferences, labor unions and government controls may induce public firms to base input decisions on a set of shadow prices that deviate from observed factor prices.

The problem of deriving welfare optimal shadow prices to be used in public sector decisions has generated a substantial normative literature ever since the early work on project evaluation by, e.g., Little and Mirrlees (1968) and Sen (1972). They derive the optimal shadow price of labor to be imputed in cost-benefit analyses of industrial projects in developing countries. Assuming exogenously fixed wages above the market-clearing level in the industrial sector of the economy they generally find optimal shadow wages below the market wage. The implications for project evaluation were further developed by Bell and Devarajan (1983) under a variety of macroeconomic scenarios. More recently, Marchand et al.(1984) build upon earlier work and derive optimal shadow prices for labor and capital and optimal discount rates in a general disequilibrium model with unemployed labor. They find shadow wages below market wages as long as total employment in the economy rises with an increase in the demand for labor by the public sector. In a related paper (Marchand et al. (1985)) they extend the analysis to the case of disequilibria on both the labor and the capital market. Although the existence of unemployment will in many cases require the public sector to apply shadow wages below market wages, it is shown that this result does not necessarily hold when capital rationing occurs in the economy. Finally, Hagen (1983) considers the optimal behavior of public enterprises that are deficit-constrained. She shows that the firm's optimal choices are strongly affected by the tightness of the budget restriction and that they depend on the particular mix of financing instruments (borrowing versus taxation of labor and private capital) used.

Although the differences between shadow prices and their observed counterpart depend in a complex way on the parameters of the specific model used, previous studies all suggest that in periods of high unemployment it may be socially desirable for public enterprises to absorb part of the excess supply of labor. However, they all explicitly rely on exogenous wage rigidity to generate unemployment. In a recent paper, Boadway et al.(1989) relax this assumption and consider the problem of optimal public sector employment within the framework of efficiency wage models, in which unemployment follows from wages being endogenously set above the market-clearing level. They show that for the best known efficiency wage models, viz. the labor turnover model (see, e.g., Stiglitz (1974) and Salop (1979)) and the shirking model (Shapiro and Stiglitz (1984)), the desirability of expanding public employment to alleviate the unemployment problem can not be taken for granted. It is found that, depending on the parameters of the problem (quit probabilities and probabilities of being caught in the shirking model; the induced employment and turnover effects of public sector hirings in the turnover model), the optimal shadow price of labor may be above or below the market wage.

The previously discussed literature suggests that under conditions of unemployment public enterprises should be allowed to use input combinations that differ from the least costly factor combination corresponding to observed input prices. In this sense, they should be encouraged to behave in an allocatively inefficient manner. Most models suggest that under a wide variety of circumstances it is welfare-optimal to operate in an excessively labor-intensive way.

The possibility of allocative inefficiency in practical public enterprise operations is also implied by a limited number of positive models of public enterprise behavior. Both Rees (1984) and Bos (1986, Chapter 20) describe models in which managers of public firms and labor unions bargain about wages and employment subject to demand and technological restrictions, and control constraints imposed by the government. Managers are assumed to care about the firm's output, while union preferences depend on wages and employment. Under the most realistic assumptions the results of these analyses imply the enterprises will employ an excessively large labor force compared to the allocatively efficient situation. Moreover, they identify the weight of employment in union preferences and the tightness of the deficit constraint as major determinants of the deviation of the shadow wage from the observed wage.

Despite this fairly substantial theoretical literature on public enterprise behavior there is apparently no comparable flow of empirical studies in which the implications of the theory are confronted with observed behavior. Moreover, although the theory implies some testable hypotheses with respect to allocative inefficiency in public firms, the existing empirical analyses (see, e.g., Gathon (1989), Perelman and Pestieau (1988), Thiry and Tulkens (1988)) are exclusively concerned with estimating technical inefficiency. The main purpose of this paper is to fill a small part of this apparent gap in the literature. We explain the degree of allocatively inefficient behavior in a large Belgian public enterprise in terms of the determinants suggested by theoretical models of public enterprise behavior. In addition, we estimate the cost of allocative inefficiency and the implications of the firm's behavior for the quantities of input factors used in the production process. Finally, although our main focus is on testing the relevance of some potential determinants of allocative inefficiencies, we also estimate the cost and factor implications of (relative) technical inefficiency. It is indeed often argued that the political and institutional environment in which public firms tend to operate leads to inappropriate or underdeveloped incentive structures, conflicting objectives and excessive bureaucracy (see Stiglitz (1986, Chapter 7), and the references cited therein).

Structure of the paper is as follows. In the next section we present the methodology used to estimate the implications of public enterprise inefficiencies. Allocative inefficiency is introduced in a cost function framework by assuming that the firm acts as if it minimizes costs at unobservable shadow prices (see,e.g., Atkinson and Halvorsen (1984,1986)). Technical inefficiency is modeled by adding a one-sided residual to an appropriate stochastic cost frontier, as is common in the stochastic frontier literature (see, e.g., Aigner et al.(1977), Greene (1980), Jondrow et al.(1982)). In Section 3 we implement the empirical model to estimate inefficiencies in Belgian railroad operations. The unobservable shadow prices are parametrically specified as functions of a small number of explanatory variables suggested by the theoretical models previously discussed. Results are presented in Section 4. We interpret the parameters of the shadow price determinants, and derive the implications of both allocative and technical inefficiency for costs and factor use. Section 5 concludes the paper.

2. Estimating the effects of technical and allocative inefficiency: methodological issues

The literature reviewed in the introduction suggested that public enterprises may operate in an allocatively and technically inefficient way, and it identified several potential determinants of allocatively inefficient behavior. In this section we present the methodology used to estimate the implications of these inefficiencies for the firm's costs and factor use. To fix ideas, a firm is said to be allocatively inefficient if it operates on its production possibilities frontier but uses a suboptimal combination of inputs. In other words, it behaves as if it minimizes costs at the 'wrong' input prices. Technical inefficiency is said to occur if the firm operates within the boundary of its production possibilities set.

To model technical inefficiency we follow the standard approach in the stochastic frontier literature (see, e.g., Aigner et al. (1977) , Meeusen and Van Den Broek (1977) and Greene (1980)) and augment a stochastic cost model with a one-sided residual. However, the cost frontier faced by the firm does not correspond to the minimum cost frontier due to allocative inefficiency. The previous discussion suggested that public enterprises have strong incentives to base their input choice decisions on a set of shadow input prices. Therefore, following Atkinson and Halvorsen (1984,1986) the cost frontier is assumed to reflect the costs obtained by evaluating the firm's corresponding 'optimal' input choices at observed input prices. This results in a relation between actual costs and shadow prices, see below.

Most previous empirical models of allocative inefficiency (see, e.g., Atkinson and Halvorsen (1984), Lovell and Sickles (1983) and Toda (1976)) assume that the shadow prices determining firms' behavior are proportional to their observed counterparts. As a consequence, they only provide information on average allocative inefficiency in the sample, but fail to identify observation-specific inefficiencies. To avoid this shortcoming, we will specify the shadow prices in this paper as parametric functions of a small number of explanatory variables. A similar approach was proposed in a different context by Atkinson and Kerkvliet (1989).

Turning to specifics, assume a firm behaves as if it faces unobservable shadow prices p_i^* for its inputs and that it chooses the quantities X_i of N inputs so as to minimize the cost of producing given output levels Y_j (j=1,...,M). The firm behaves as if it solves

$$\underset{X_i}{Min} \quad \sum_i p_i^* X_i \quad s.t. S(X_1, \ldots, X_N; Y_1, \ldots, Y_M) = 0 \qquad (2.1)$$

where S(.) is the transformation function describing the production technology. Cost minimization yields optimal input quantities

$$X_i^* = X_i(p_1^*, \ldots, p_N^*; Y_1, \ldots, Y_M) \qquad (2.2)$$

and a corresponding optimal value for the objective function

$$C^* = C^*(p_1^*, \ldots, p_N^*; Y_1, \ldots, Y_N) = \sum_i p_i^* X_i^* \qquad (2.3)$$

where $X_i(.)$ is the system of factor demand equations and $C^*(.)$ is a 'shadow' cost function.

Suppose the firm actually pays p_i for its inputs. Then the actual cost corresponding to the input choices X_i^* is given by

$$C^A = \sum_i p_i X_i^* \qquad (2.4)$$

The relation between actual costs and shadow costs is easily established. First, rewrite (2.4) as

$$C^A = \sum_i p_i \frac{s_i^* C^*}{p_i^*} \tag{2.5}$$

where

$$s_i^* = \frac{p_i^* X_i^*}{C^*}$$

It follows from (2.5) that

$$\ln C^A = \ln C^* + \ln\left(\sum_i \frac{p_i s_i^*}{p_i^*}\right) \tag{2.6}$$

Using the fact that

$$\sum_i s_i^* = 1$$

it is clear that realized and shadow costs will coincide iff the firm actually minimizes costs at observed input prices, i.e., $p_i = p_i^*$.

The relation between realized factor shares

$$s_i^A = \frac{p_i X_i^*}{C^A}$$

and the unobservable 'shadow' shares s_i^* is also easily derived. The definitions of s_i^A and s_i^* imply

$$s_i^A = \frac{C^*}{C^A} \frac{p_i}{p_i^*} s_i^* \tag{2.7}$$

However, rearranging (2.6) yields

$$\frac{C^*}{C^A}=\frac{1}{\sum_i \frac{p_i s_i^*}{p_i^*}} \tag{2.8}$$

Combining (2.7) and (2.8) finally leads to

$$s_i^A=\frac{\frac{p_i s_i^*}{p_i^*}}{\sum_i \frac{p_i s_i^*}{p_i^*}} \tag{2.9}$$

Relations (2.6) and (2.9) give a deterministic cost frontier with associated factor share system that is consistent with the firm's hypothesized allocatively inefficient behavior.

Technical inefficiency as well as purely random effects may prevent the firm from operating on the frontier represented by (2.6) so that observed costs will deviate from C^A. We therefore specify the following stochastic equivalent to (2.6) and (2.9)

$$\ln C=\ln C^*+\ln\left(\sum_i \frac{p_i s_i^*}{p_i^*}\right)+\epsilon \tag{2.10}$$

$$s_i=\frac{\frac{p_i s_i^*}{p_i^*}}{\sum_i \frac{p_i s_i^*}{p_i^*}}+\mu_i \tag{2.11}$$

where C and s_i are observed costs and factor shares, respectively, and

$$\epsilon = v + \tau,\ \tau \geq 0 \ . \tag{2.12}$$

As indicated by (2.12), the error term of the cost model (2.10) consists of two components. First, v reflects white noise and corresponds to the classical symmetric disturbance in econometrics. The second component τ is a one-sided residual intended to capture the effect of technical inefficiency. Note that this specification implies the assumption that technical inefficiency does not affect factor shares.

The components v and τ are assumed to be independent. Moreover, for estimation purposes we impose the following stochastic assumptions

$$v \approx N(0,\sigma_v^2)$$

$$\tau \approx |N(0,\sigma_\tau^2)|$$

$$\mu_i \approx N(0,\sigma_i^2).$$

The technical inefficiency component τ is assumed to be the absolute value of a normally distributed random variable with mean zero and constant variance. Although there is no compelling theoretical justification for this half-normal distribution, it seems to be the most commonly used assumption (see, e.g., Aigner, Lovell and Schmidt (1977), Greene (1980), Jondrow et.al. (1982)). Also note that the independence assumption allows us to decompose the variance of the composite error term ϵ as

$$\sigma_\epsilon^2 = \sigma_\tau^2 + \sigma_v^2 \tag{2.13}$$

Under the above assumptions and allowing the error terms of v and μ_i of the cost function and factor shares to be correlated the system (2.10)-(2.11)-(2.12) can be consistently estimated by a two-step procedure (see, e.g., Greene (1980), Ferrier and Lovell (1988)). In a first step application of nonlinear iterative seemingly unrelated regression (NITSUR) yields unbiased and consistent estimates of all parameters in the system with the exception of the constant term of the cost frontier. In a second stage an unbiased and consistent estimate of this constant is obtained by substracting from the NITSUR estimate the estimated average technical inefficiency $\hat{E}(\tau)$. The latter can be calculated on the basis of the following expressions, which have been shown to hold under the assumption of a halfnormal distribution for τ (see, e.g., Greene (1982))

$$E(\tau) = \left(\frac{2}{\pi}\right)^{1/2} \sigma_\tau \tag{2.14}$$

$$\sigma_\tau^2 = \left\{ \left(\frac{\pi}{2}\right)^{1/2} \left(\frac{\pi}{\pi-4}\right) m_3 \right\}^{2/3} \tag{2.15}$$

$$\sigma_v^2 = m_2 - \left\{ \left(\frac{\pi-2}{\pi}\right) \sigma_\tau^2 \right\} \tag{2.16}$$

The m_2 and m_3 are the second and third moments of the distribution of the residuals of the cost function. The estimated residuals can be used to estimate average technical inefficiency based on (2.14) and (2.15). Expressions (2.15) and (2.16) further allows us to decompose the variance of ϵ into its random and technical inefficiency components.

Once the parameters of the model and the variances σ_τ^2 and σ_v^2 have been estimated it is straightforward to use the results to estimate the impact of technical and allocative inefficiency for each observation in the sample. The cost of allocative inefficiency is the excess cost incurred by minimizing costs at p_i^* rather than at observed prices p_i . It is the difference between the cost C^A as given by (2.6) and the efficient cost C^E, reflecting the minimal attainable costs given prices p_i. The cost C^A can be predicted on the basis of (2.6), i.e.,

$$\ln\hat{C}^{A}=\ln\hat{C}^{*}+\ln\left(\sum_{i}\frac{p_{i}\hat{s}_{i}^{*}}{\hat{p}_{i}^{*}}\right) \tag{2.17}$$

where $\hat{C}^*$, $\hat{s}_i^*$ and $\hat{p}_i^*$ are the estimated shadow cost, shadow share and shadow price functions evaluated at the corresponding observation. As the shadow cost function $C^*(.)$ reflects cost minimizing behavior the efficient cost C^E can be predicted for each observation by evaluating the estimated $C^*(.)$ at observed input prices, i.e.,

$$\hat{C}^{E}=\hat{C}^{*}(p_{i},\ldots,p_{N};Y_{1},\ldots,Y_{M}) \tag{2.18}$$

Similarly, to determine the excess usage of factors due to allocative inefficiency we need estimates of X_i^*, the quantities resulting from cost minimizing behavior at shadow prices p_i^*, and of the fully efficient quantities X_i^E. The latter are estimated as follows. By definition the efficient factor shares

$$s_{i}^{E}=\frac{p_{i}X_{i}^{E}}{C^{E}}$$

can be predicted by evaluating the shadow share functions s_i^* at observed prices p_i. We have therefore

$$\hat{s}_{i}^{E}=\hat{s}_{i}^{*}(p_{1},\ldots,p_{N};Y_{1},\ldots,Y_{M}) \tag{2.19}$$

Consequently, we can estimate efficient factor use as

$$\hat{X}_{i}^{E}=\frac{\hat{s}_{i}^{E}\,\hat{C}^{E}}{p_{i}}$$

Similarly, using (2.9) and (2.11) it follows that we can predict the quantities X_i^* as

$$\hat{X}_i^* = \frac{\hat{S}_i \, \hat{C}^A}{p_i} \tag{2.20}$$

where the $\hat{S}_i$ are obtained using (2.11).

To estimate the cost and factor implications of technical inefficiency for each observation we follow the suggestions of Jondrow et al. (1982). As an estimate of the extra cost they propose to use the mean of the conditional distribution of τ, given ϵ. This mean is given by

$$E(\tau|\epsilon) = \frac{\sigma_v \sigma_\tau}{\tau_\epsilon}\left\{\frac{f(-\frac{\epsilon\lambda}{\sigma_\epsilon})}{1-F(-\frac{\epsilon\lambda}{\sigma_\epsilon})} + \frac{\epsilon\lambda}{\sigma_\epsilon}\right\} \tag{2.21}$$

where f(.) and F(.) are the standard normal density and cumulative distribution functions, respectively, and

$$\lambda = \frac{\sigma_\tau}{\sigma_v}$$

is a measure of the relative variability of the two sources of error.

Finally note that the model assumes that technical inefficiency does not affect factor shares. Therefore, the percentage excess usage will be the same for all inputs, and it will equal the percentage excess costs.

3. The empirical model

The purpose of this section is to apply the methodology previously discussed in order to analyse the determinants of allocative inefficiency and to estimate the implications of both technical and allocative inefficiency in Belgian railroad operations. We consecutively discuss the nature of the firm, the choice of an appropriate shadow cost function, the specification of the shadow prices, and the data used in the empirical analysis.

The institutional environment imposes strong restrictions on the empirical model. First, railroad services are produced by a single enterprise, which forces us to rely on time series data. Second, the government heavily subsidizes investment in both fixed structures and rolling stock and actively participates in the decision-making process related to capital expenditures. As a consequence, decisions with respect to additions to the stock of capital are beyond the firm's control. Moreover, the subsidy rates vary substantially over time and are, unfortunately, unobservable in the company's annual reports. We preferred, therefore, to base the empirical analysis on a short-run restricted cost model that explicitly assumes the stock of capital to be exogenously given.

Given the above limitations we assume that the firm produces freight (F) and passenger (R) services using the variable inputs labor (L) and energy (E), and a capital stock (K) which is exogenously determined by the government, and treated as fixed in the short-run[1]. This empirical procedure has important implications for the interpretation of the results. First, our focus will be on the relative shadow prices of labor and energy only[2], as we will obviously be unable to identify the determinants of the shadow price of capital. Second, the estimates of technical inefficiency will have to be interpreted as deviations from a variable rather than a total cost frontier.

We assume that the railroad company implicitly faces the problem

$$\underset{L,E}{Min} \quad p_L^* L + p_E^* E \quad s.t. \quad \begin{array}{l} S(F,R,K,L,E,t)=0 \\ K=\overline{K} \end{array} \tag{3.1}$$

where the p_i^* are unobservable shadow prices, $\overline{K}$ is the exogenously fixed capital stock, and t is time. The latter is included to account for technological progress. The result of the constrained minimization process is a variable shadow cost function $C_V^*(p_L^*, p_E^*, F, R, \overline{K}, t)$.

The translog specification was chosen for C_V^* in view of the structure of the model summarized by (2.10)-(2.11). Given our two-variable-input framework it can be written as (see, e.g., Viton (1981)),

$$\ln C_V^* = \alpha_0 + \ln p_E^* + \alpha_L \ln\left(\frac{p_L^*}{p_E^*}\right) + \frac{1}{2}\alpha_{LL}\left[\ln\left(\frac{p_L^*}{p_E^*}\right)\right]^2 + \alpha_F \ln F + \alpha_R \ln R + \alpha_{RF} \ln F \ln R$$

$$+\frac{1}{2}\alpha_{FF}(\ln F)^2 + \frac{1}{2}\alpha_{RR}(\ln R)^2 + \alpha_K \ln\overline{K} + \frac{1}{2}\alpha_{KK}(\ln\overline{K})^2 + \alpha_{RK}\ln R \ln\overline{K}$$

$$+\alpha_{FK}\ln F \ln\overline{K} + \alpha_{LF}\ln F \ln\left(\frac{p_L^*}{p_E^*}\right) + \alpha_{LR}\ln R \ln\left(\frac{p_L^*}{p_E^*}\right)$$

$$+\alpha_{LK}\ln\overline{K}\ln\left(\frac{p_L^*}{p_E^*}\right) + \alpha_t + \alpha_{tL}\, t \ln\left(\frac{p_L^*}{p_E^*}\right) \tag{3.2}$$

This specification is entirely standard except for the introduction of technical change. Note that we allow the time trend to interact with relative prices but not with outputs and capital stock. Imposing these restrictions on the evolution of technical change was considered to be desirable to avoid multicollinearity problems associated with the more general specification.

The shadow shares s_i^* corresponding to (3.2) are derived by Shephard's lemma

$$s_L^* = \frac{\partial \ln C_V^*}{\partial \ln p_L^*} = \alpha_L + \alpha_{LL} \ln\left(\frac{p_L^*}{p_E^*}\right) + \alpha_{LF} \ln F + \alpha_{LR} \ln R + \alpha_{LK} \ln \bar{K} + \alpha_{tL} t \tag{3.3}$$

$$s_E^* = \frac{\partial \ln C_V^*}{\partial \ln p_E^*} = (1-\alpha_L) - \alpha_{LL} \ln\left(\frac{p_L^*}{p_E^*}\right) - \alpha_{LF} \ln F - \alpha_{LR} \ln R - \alpha_{LK} \ln \bar{K} - \alpha_{tL} \tag{3.4}$$

Substituting (3.2), (3.3) and (3.4) into (2.10), (2.11) and (2.12) leads to the stochastic econometric model to be estimated,

$$\ln C_V = \alpha_0 + \ln p_E^* + \alpha_L \ln\left(\frac{p_L^*}{p_E^*}\right) + \frac{1}{2} \alpha_{LL} \left[\ln\left(\frac{p_L^*}{p_E^*}\right)\right]^2 + \alpha_F \ln F + \alpha_R \ln R + \alpha_K \ln \bar{K}$$

$$+ \alpha_{FK} \ln F \ln \bar{K} + \alpha_{LF} \ln F \ln\left(\frac{p_L^*}{p_E^*}\right) + \alpha_{LR} \ln R \ln\left(\frac{p_L^*}{p_E^*}\right) + \alpha_{LK} \ln \bar{K} \ln\left(\frac{p_L^*}{p_E^*}\right)$$

$$+ \alpha_t t + \alpha_{tL} t \ln\left(\frac{p_L^*}{p_E^*}\right))\}$$

$$+\{\ln[\frac{p_L}{p_L^*}(\alpha_L+\alpha_{LL}\ln(\frac{p_L^*}{p_E^*})+\alpha_{LF}\ln F+\alpha_{LR}\ln R+\alpha_{LK}\ln\overline{K}+\alpha_{tL}t)$$

$$+\frac{p_E}{p_E^*}((1-\alpha_L)-\alpha_{LL}\ln(\frac{p_L^*}{p_E^*})-\alpha_{LF}\ln F-\alpha_{LR}\ln R-\alpha_{LK}\ln\overline{K}-\alpha_{tL}t)]\}$$

$$+\tau+v \tag{3.5}$$

$$s_L=\frac{\frac{p_L}{p_L^*}(\alpha_L+\alpha_{LL}\ln(\frac{p_L^*}{p_E^*})+\alpha_{LF}\ln F+\alpha_{LR}\ln R+\alpha_{LK}\ln\overline{K}+\alpha_{tL}t)}{[G]}+\mu_L \tag{3.6}$$

$$s_E=\frac{\frac{p_E}{p_E^*}(1-\alpha_L)-\alpha_{LL}\ln(\frac{p_L^*}{p_E^*})-\alpha_{LF}\ln F-\alpha_{LR}\ln R-\alpha_{LK}\ln\overline{K}-\alpha_{tL}t)}{[G]}+\mu_E \tag{3.7}$$

where

$$G=\frac{p_L}{p_L^*}(\alpha_L+\alpha_{LL}\ln(\frac{p_L^*}{p_E^*})+\alpha_{LF}\ln F+\alpha_{LR}\ln R+\alpha_{LF}\ln\overline{K}+\alpha_{tL}t)$$

$$+\frac{p_E}{p_E^*}((1-\alpha_L)-\alpha_{LL}\ln(\frac{p_L^*}{p_E^*})-\alpha_{LF}\ln F-\alpha_{LR}\ln R-\alpha_{LK}\ln\overline{K}-\alpha_{tL}t)$$

We now turn to the specification of the shadow prices p_L^* and p_E^*. In specifying the shadow wage we incorporated a few of its potential determinants as suggested by the theoretical literature reviewed in the introduction. The 'normative' models suggested the importance of unemployment in the economy to generate deviations between shadow wages and observed wages and indicated that the tightness of the deficit constraint may play a crucial role in determining the optimal magnitude of this deviation. The 'positive' models identified, among others, the weight of employment in unions' preferences and the pressure imposed on managers to reduce the deficit as important determinants of the deviation between shadow and observed wage. Although information on union preferences is scarce (for recent studies see Farber (1986) and Clark and Oswald (1989)) one suspects that in general public sector unions will put a larger weight on employment in periods of high unemployment. Consistent with both types of theoretical model we therefore included the unemployment rate and a crude proxy variable reflecting variations in the financial pressure imposed on the firm into the specification of the shadow wage.

The pressure exercized to limit the size of the firm's deficit is obviously unobservable. It was, admittedly in a rather unsophisticated way, captured by including a dummy variable equal to zero prior to 1982 and equal to one ever since 1982. Indeed, as noted in Thiry and Tulkens (1988), until 1982 financial pressure on the railroads was extremely weak and the resulting huge deficits were covered by the national budget without much public discussion. At that time policy towards public enterprises and the railroad company in particular drastically changed, however. The government proclaimed the reduction of the budget deficit as one of its major objectives and imposed severe financial pressure on public enterprises. At the same time top management of several large firms was substantially reorganized.

Finally, one additional explanatory variable was included in the specification of the divergence between shadow and observed wage. Given the high degree of linkages between the bureaucracy in public enterprises and political parties on the one hand, and between labor unions and political parties on the other hand, it is conceivable that political considerations may also affect the firm's employment policy. It could be argued that different political parties may tolerate allocative inefficiencies to a different extent and that, therefore, the relative power of different parties might have an effect on the shadow wage. We constructed the following indicator variable[3]

$$POL=\sum_{i=1}^{3}\frac{iP_i}{3} \qquad (3.8)$$

where $P_1 = 1$ if the liberal party participated in the government coalition, $P_1 = 0$ otherwise;

$P_2 = 1$ if the Christian Democratic Party participated in the government coalition, $P_2 = 0$ otherwise;

$P_3 = 1$ if the Socialist Party participated in the government coalition, $P_3 = 0$ otherwise.

To summarize the above discussion, the shadow price p_L^* was expressed as

$$p_L^*=g(p_L,u,POL,D) \qquad (3.9)$$

where u is the unemployment rate, POL is defined by (3.8), and D equals one from 82 to 86, and zero in all other years. Although we experimented with other parametric representations of (3.9), the results presented in this paper are based on the following specification[4]

$$p_L^*=\delta_0 p_L (u)^{\delta_1}(POL)^{\delta_2}e^{\delta_3 D} \qquad (3.10)$$

This specification is highly convenient given the translog shadow cost model. It implies a loglinear relation between the ratio of shadow wage to observed wage and the explanatory variables. Note that it does not impose any restrictions on the value of the shadow price. In particular, it does not imply $p_L^* \leq p_L$.

With respect to energy neither economic theory nor a priori intuition offer strong arguments to suspect deviations of the shadow price from the market price. Obviously, the energy crises resulted in large increases in the price of energy over the second half of the sample period. Energy use substantially declined, partly because of energy substitution. It could be hypothesized that on top of these reactions to price changes additional energy-saving measures may have been taken by the company in view of a general conservation policy by the government. However, in some preliminary empirical work no such effects were found. As a consequence, we simply specified

$$p_E^* = p_E \tag{3.11}$$

in our empirical model.

Unless otherwise noted all data were taken from the firm's annual reports. The price of labor was obtained by dividing total labor expenditures by the aggregate labor input, measured in number of employees[5]. With respect to energy, a Divisia index 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 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.

Several authors, including Wang Chiang and Friedlander (1984) and Oum and Tretheway (1989), have pointed at the multi-dimensionality of output in the transportation industry and the impact of operating characteristics on costs. Following their suggestions we constructed two hedonic output aggregates (one for passenger and one for freight output) in previous work (De Borger (1989b)). Each aggregator function was assumed to be homogeneous of degree one in the corresponding generic output. The generic outputs used were passenger- and tonkilometer, respectively. The operating characteristics included in the aggregator functions captured the effects of distance, load factors, geographic dispersion and traffic composition on costs. In the present paper we used the constructed aggregates as output measures in the empirical analysis.

4. Efficiency in Belgian railroad operations: empirical results

The model obtained after substituting the shadow price functions (3.10)-(3.11) into equation system (3.5)-(3.6)-(3.7) was estimated by nonlinear iterated seemingly unrelated regression. To account for the singularity of the covariance matrix of the residuals the energy share equation was deleted from the system. Moreover, as we treated the translog specification as an approximation to an arbitrary cost function at the sample mean all price, output, capital stock and cost variables were divided by their respective sample means prior to estimation, and the time trend was set equal to zero in the midpoint of the sample period 1950-1986.

Regression resuts are presented in Table 1. For purposes of comparison the table also contains parameter estimates of the translog cost model based on the assumption of cost minimization at observed input prices, i.e., the model obtained by substituting $p_i^*=p_i$ in (3.5)-(3.6)-(3.7). Note that the two models have excellent explanatory power and that the majority of the parameters is significantly different from zero. Interestingly, they do not differ much as far as the estimated first-order effects are concerned (α_L, α_R, α_F, α_K, α_t).

Consider the estimated parameters δ_i of the shadow wage function. The coefficient δ_1 of the unemployment rate is significantly negative, indicating the firm's willingness to employ more labor at high levels of unemployment. The effect is small, however. For example, the results suggest that, for a given observed wage, doubling the unemployment rate reduces the shadow wage by slightly more than 6 %. Despite this relatively small effect one expects substantial variations in the shadow wage because of the huge variability in the unemployment rate over the sample period. It ranged between less than 3 % in 1963-1966 to 15 % towards the end of the sample period.

The parameter δ_3 measuring the effect of increased financial pressure on the firm since 1982 is estimated to be significantly positive. It suggests that the extra pressure has increased, ceteris paribus, the shadow wage by almost 14%. Finally, the coefficient δ_2 of the political indicator variable is negative but insignificantly different from zero. The sign of the parameter suggests that governments in which the socialist party participates tend to be more willing to allow allocative inefficiency and to maintain a larger than efficient labor force at the expense of other variable inputs. Taking the magnitude of the coefficient at face value the estimate implies that a Socialist-Christian Democratic coalition (POL=2.5) induces the firm to apply a shadow wage which is approximately 7 % below the one in effect under a Liberal-Christian Democratic coalition (POL=1.5).

The information given in Table 2 provides some insight into the evolution of the shadow wage relative to the observed wage. The shadow wage p_L^* varies from as little as 65 % of observed wage in the period 1979-1981, characterized by relatively high and rising unemployment and a Socialist-Christian Democratic coalition, to more than 82 % in 1964 when unemployment reached its sample minimum. The substantial increase in p_L^* relative to p_L over the period 1982-1986 is mainly due to increased financial pressure.

The value of the constant term in the shadow wage function (δ_0=0.8211) and the fact that the shadow wage was situated below the observed wage even in periods of very low unemployment and relatively 'inefficiency-averse' coalition governments suggests that some allocative inefficiency persists independently from the variables included in the shadow wage function. This may reflect managerial preferences in favor of a large labor force. Alternatively, it may be the result of factor price uncertainty. For example, Stewart (1978) shows that risk-averse managers faced with factor price uncertainty will substitute the relatively riskless inputs for the risky ones. More recently, Perrakis (1980) found that assuming ex post observed input prices to be known with certainty ex ante, a procedure which is common in empirical work, will result in allocative bias even if managers are risk neutral[6]. In most cases of practical intrest it leads to a heavier use of the relatively riskless input. Realizing that the sample period has been characterized by extremely large relative energy price uncertainty, the allocative bias in favor of labor may to some extent be due to ignoring the role of uncertainty in the empirical procedure.

Despite substantial deviations between the shadow wage and its observed counterpart the two cost models presented in Table 1 imply technological characteristics of the production process that are quite similar. In Table 3 we summarize some average estimates of the production technology for each model. Given the similar first-order effects it is not surprising to find that the differences are small. The 'shadow price model' yields a slightly higher wage elasticity and both a smaller energy price elasticity and substitution elasticity[7].

The output and capital stock cost elasticities are also quite similar, as is the indicator of returns to scale[8]. The latter suggests, at least evaluated at the sample mean, increasing returns to scale. One should be careful not to draw too strong conclusions from this finding, however. Although no trendwise evolution in RTS was observed over the sample period the indicator did vary strongly over time, and it dropped slightly below unity in several years of the last decade. In other words, evaluated at the most recent observations it seems as if the railroads have exhausted whatever scale economics were available in the past[9].

Table 3 finally includes estimates of average productivity growth over the sample period as implied by the two alternative models. The index P1 is defined as the common percentage annual increase in all outputs, holding input levels constant. The alternative index P2 measures the percentage annual reduction in all inputs that can be realized holding output levels constant. The relevant formulas to estimate these productivity indices on the basis of a variable cost function have been derived by Caves et al. (1981)[10]. Again note the similar results for the two models. They imply average increases in productivity growth of about 2 % per year.

The conclusion to be drawn from Table 3 is obvious. If one were only interested in estimating the technological characteristics of the production process, ignoring allocative inefficiency may not be too harmful.

We now turn to an analysis of the costs of technical and allocative inefficiency, and of the corresponding implications of inefficiencies for factor usage. First, using the moments of the cost function residuals we evaluated (2.15)-(2.16) to obtain consistent estimates of the variances σ_τ^2 and σ_v^2. We found

$$\hat{\sigma}_\tau = 0.025,\ \hat{\sigma}_v = 0.014,\ \text{implying}\ \hat{\sigma}_\epsilon = 0.0287.$$

This yielded a relative variability of the two sources of error

$$\hat{\lambda}=\frac{\hat{\sigma}_\tau}{\hat{\sigma}_v}=1.787,$$

indicating that the variance due to technical inefficiency was much more important than the variance due to random fluctuations in the cost frontier itself. Next we estimated average technical inefficiency according to (2.14). We found $\hat{E}(\tau)=0.0199$. Subtracting this figure from the regression estimate of the constant term in the cost function yields a consistent estimate of the constant of the cost frontier.

The estimated average technical ineffeciency of about 2 % is surprisingly small. Stories in the popular press and the results of the report of the consulting firm SOBEMAP (1984) lead one to believe that very large technical inefficiencies exist. It should be emphasized, however, that the econometric procedure used in this paper to estimate technical inefficiency is only based on within-sample information and that, as a consequence, it will only detect relative inefficiencies[11]. Intuitively, if even the most efficient observations in the sample happen to be still quite inefficient relative to the true 'out-of-sample' frontier, the econometric approach will not allow us to measure these absolute inefficiency levels.

An index of technical efficiency was calculated as $e^{-\hat{E}(\tau/\epsilon)}$, where $\hat{E}(\tau/\epsilon)$ was estimated for each observation according to (2.21). We found the sample mean of $\hat{E}(\tau/\epsilon)$ to be 0.01987, which is extremely close to the estimated mean of the unconditional distribution of τ, previously reported to be $\hat{E}(\tau)=0.01990$.

The technical efficiency index is presented in Table 4 along with some other relevant results. It suggests that the cost of technical inefficiency varies between almost zero (e.g. 1978) to more than 5 % of the technically efficient cost (e.g. 1975). Expressed in Belgian Francs the cost of technical inefficiency was situated between as little as 66 million to almost 1.5 billion. There is no interpretable pattern in the evolution over time. Relatively efficient years are 1959, 1964-65, 1967 and 1977-78. Inefficient observations are those related to the years 1955-56, 1958, 1962, 1975-76 and 1985-86.

The percentage excess use of labor and energy varies between 0.4 % and 5.4 %[12]. Expressed in terms of the number of workers it implies excess labor of less than 500 people in 1964-65 to approximately 3000 in 1955-56. On average over the sample period surplus labor of almost 1300 workers is attributable to technical inefficiency. Note that with respect to energy we obviously find a similar evolution over time but that the energy aggregate, constructed as a Divisia index of three energy sources, does not have a straightforward interpretation.

Estimated implications of allocative inefficiency are summarized in Table 5. An index of allocative inefficiency was constructed as $\hat{C}^E/\hat{C}^A$. At first sight, the results are startling. Despite large deviations between the shadow wage and observed wage (see Table 2) the extra cost due to allocative inefficiency is trivial. Indeed, it amounted to slightly more than 1 % early in the sample period and declined to less than 0.5 % of efficient cost throughout the sixties and early seventies. High unemployment in 1975-1981 somewhat increased the cost to almost 1 % in 1981. Then the financial pressure imposed on the firm again pushed the shadow wage closer to observed wage, resulting in smaller allocative inefficiency costs. Note that the excess costs due to the firm's reaction to shadow prices rather than observed prices never exceeds 1.5 % of efficient costs.

An explanation for this seemingly surprising result becomes apparent when we consider the effect of allocative inefficiency on factor use. Indeed, the figures in Table 5 suggest that the extra costs of labor due to the deviation of shadow wages from observed wages may be largely compensated by the savings that result from the correspondingly lower energy consumption. On average over the sample period allocative inefficiency is responsible for a labor force that exceeds the efficient quantity of labor by almost 3000 workers. In percentage terms average excess labor amounts to 4.43 %. This is however counteracted by an average 'insufficient' use of energy of approximately 20 %.

The railroad company is apparently able to generate nontrivial extra labor at an extremely small cost. Excessive use of labor due to allocative inefficiency varies from almost 2 % to about 10 %. In absolute terms it yields a labor force which exceeds the efficient number of workers by at least 1000 people in the period 68-72 and at most 8000 people early in the sample period. The evolution of excess labor over time is obviously closely related to the estimated time pattern of the shadow wage relative to observed wage, although it also captures the effect of the variability of the estimated price elasticity of labor demand over the sample period. We observe a slow decline in excess labor until the early seventies when rising unemployment yields a significant increase up to the early eighties. The upward trend is reversed in the period 1982-86 as a consequence of increased financial pressure.

The relatively large price elasticity of energy demand reported in Table 3 explains our finding of much more pronounced effects of allocative inefficiency on energy demand. The firm is induced to use between 15 % and 25 % less energy than the allocatively efficient quantity. The insufficient use of energy probably largely reflects the use of suboptimal combinations of different energy types. The energy aggregate constructed in this paper was substantially affected by the substitution of coal by fuel and the partial substitution of fuel by electricity. Inefficient energy substitutions can easily lead to less than efficient quantities for the energy aggregate.

Finally, Table 6 summarizes the joint effects of technical and allocative inefficiency. It confirms the reasonably small inefficiency cost and provides no evidence that the firm operated more efficiently towards the end of the sample period. The overall impact on factor use is clearly dominated by the effects of allocative inefficiency. It is estimated that depending on the period considered 3 % to 12 % of the labor force is superfluous. Over the last five years of the sample period approximately 5 % or 2300 workers are estimated to be unnecessary from a strict efficiency viewpoint.

It should finally be stressed that our analysis has been strictly positive in nature. We have measured inefficiencies as differences between observed and strictly cost minimizing behavior. It cannot be overemphasized, however, that inefficient behavior by the firm in the above sense may well be desirable from a social welfare viewpoint. Indeed, the normative literature discussed in the introduction to this paper shows that under some circumstances excessive labor-intensity is consistent with maximizing social welfare.

5. Summary and conclusion

The purpose of this paper was to try to explain the degree of allocatively inefficient behavior in a large Belgian public enterprise, viz. the national railroad company. Moreover, we estimated the implications of both technical and allocative inefficiency for the firm's costs and factor use over the period 1950-1986. Allocative inefficiency was introduced by assuming that the railroad company behaved as if it minimized costs at unobservable shadow prices for the production factors. Observed costs were written as the sum of shadow costs and a correction factor due to the deviation of shadow prices from observed prices. The shadow input prices were specified as parametric functions of a set of explanatory variables. Technical inefficiency on the other hand was modelled by adding a one-sided residual to a stochastic cost frontier.

In the empirical analysis we specified a translog restricted 'shadow' cost function describing the railroad's choice of the variable factors labor and energy. The shadow wage was specified as a simple loglinear function of observed wage, the unemployment rate, a dummy variable for the financial pressure experienced by the firm since 1982, and a political indicator variable reflecting the political environment in which the firm has to operate.

The empirical results implied relatively small but significant effects of the unemployment rate and the financial pressure variable on the deviation of the shadow wage from observed wage. It was found that doubling the unemployment rate reduces the shadow wage by some 6%. Increased financial pressure on the firm since 1982 increased the shadow wage by almost 14%. The political indicator variable suggested that Socialist-Christian Democratic coalitions seem to be somewhat more willing to accept allocatively inefficient behavior than Liberal-Christian Democratic governments, although the estimated coefficient was not statistically significant.

The shadow wage varied from 65% of observed wage to more than 80% depending on the values of the explanatory variables. The perceived low relative price of labor results in an inefficiently large labor force and an 'insufficient' use of energy. It was estimated that allocative inefficiency implied a labor force that exceeded the efficient number of workers by between 1000 and 8000 units, with a mean over the sample period of 3000. This amounts to excessive labor ranging between 2% and 10%, depending on the sample year. Due to the much larger estimated price elasticity of energy demand the effects on energy consumption are much more pronounced. Allocative inefficiency is estimated to be responsible for 15% to 25% lower energy consumption than the efficient quantity, mainly due to inefficient combinations of different types of energy.

Despite substantial effects on the use of the variable factors the costs of allocative inefficiency are surprisingly small. Over the sample period the estimated extra costs generated as a result of the firm's reaction to the 'wrong' input prices never exceed 1.5% of the efficient cost level. It appears as if the substitution of labor for energy allows the firm to employ a labor force which is substantially larger than the cost minimizing quantity of labor at an almost trivial cost. If substituting labor for other factors is deemed desirable from a social welfare viewpoint our results seem to suggest that it can be done at a very low extra cost to the firm.

Average relative technical inefficiency was estimated to be surprisingly small, approximately 2%. The cost of technical inefficiency varied between less than 1% to slightly more than 5% of efficient cost with a corresponding excessive use of the variable factors of production. On average over the sample period surplus labor of almost 1300 workers was attributed to relative technical inefficiency.

Footnotes

[1] Note that the appropriate capital input in the production process is the service flow generated by the stock rather than the stock itself. Although models have been developed that specify costs in terms of capital services (see Kim (1988) for an innovative application), we followed the procedure implicit in almost all empirical cost models (see, e.g., Caves et al. (1981), Kim and Spiegel (1987), Keeler (1974)) and used the stock to measure the capital input.

[2] Our model does not include a materials input. For an explanation and a justification of our approach, see De Borger (1989a).

[3] Variables such as POL are commonly used to measure the impact of the political composition of the government on a variety of economic phenomena in Belgium (see, e.g., De Grauwe (1985) and Janssens (1987)). Several other indicator variables were tried with quite similar results. I am grateful to I. Janssens for providing the data necessary to construct the political indicators.

[4] Very similar results were obtained using a logistic specification for g(.).

[5] Total man-hours were not available. This is very unfortunate because the average workweek undoubtedly declined over the sample period. As a consequence, we may have underestimated the price elasticity of labor demand. Moreover, to the extent that the average workweek is correlated with the included determinants of the shadow wage, the use of workers instead of man-hours may have somewhat biased our estimates of the shadow wage function.

[6] Note that in this paper we have constructed input prices by dividing ex post observed expenditures by observed quantities. We have treated these input prices as if they were known by managers prior to making input decisions.

[7] For the relevant formulas see, e.g., Pindyck (1979). Note that for the shadow price model the appropriate cost function from which to derive input price and substitution elasticities is the shadow cost function $C^*(.)$.

[8] The appropriate expression to calculate returns to scale RTS from the variable cost model is given by, see Caves et al. (1981),

$$RTS = \frac{1-\epsilon_K}{\epsilon_R+\epsilon_F}$$

where ϵ_j is the cost elasticity with respect to j. Increasing returns to scale are said to exist if RTS>1. Note that for the case of the shadow price model the cost elasticities are the elasticities of observed costs, not the elasticities of the shadow cost function $C^*(.)$. Differentiating (2.10) with respect to output or capital stock j implies that the cost elasticities can be written as $\epsilon_j=\epsilon_j^*+\alpha_{jL}Z$, where ϵ_j^* is the cost elasticity of $C^*(.)$ with respect to j and

$$Z=\frac{\frac{p_L}{p_L^*}-1}{1+\alpha_L(\frac{p_L}{p_L^*}-1)}$$

[9] See De Borger (1989a) for further discussion.

[10] They show that

$$P_1=-\frac{\epsilon_t}{\epsilon_R+\epsilon_F}$$

and

$$P_2=-\frac{\epsilon_t}{1-\epsilon_K}$$

where

$$\epsilon_t=\frac{\partial \ln C_V}{\partial t}$$

is the rate of variable cost diminution. It follows that $P_1=P_2$ if and only if there are constant returns to scale (RTS=1).

[11] In particular, note from (2.14)-(2.15)-(2.16) that average technical inefficiency only depends on the information provided by the cost function residuals.

[12] Remember that we have assumed technical inefficiency not to be factor-specific so that the percentage excess use of labor and energy are equal. Both equal the percentage excess cost due to technical inefficiency which can be calculated to be $100 * (e^{E(\tau/\epsilon)}-1)$.

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	Model based on shadow prices		Model based on observed prices	
α_0	0.1059	(0.0113)*	0.1016	(0.0122)*
α_L	0.8499	(0.0360)*	0.8851	(0.0045)*
α_{LL}	0.0193	(0.0162)	0.0134	(0.0098)
α_R	0.4648	(0.0419)*	0.5002	(0.0360)*
α_F	0.3337	(0.1005)*	0.2898	(0.1083)*
α_{RR}	0.1146	(0.0890)	0.1781	(0.1564)
α_{FF}	-1.1324	(0.5295)*	-2.3619	(1.1262)*
α_{RF}	0.1734	(0.1965)	0.4545	(0.1756)*
α_K	-0.0935	(0.0500)*	-0.0936*	(0.0475)*
α_{KK}	0.2462	(0.0825)*	0.5823*	(0.1686)*
α_{RK}	-0.1757	(0.1254)	-0.1374	(0.1193)
α_{FK}	0.0755	(0.2978)	0.1067	(0.3123)
α_{RL}	-0.1516	(0.0382)*	-0.1095	(0.0101)*
α_{FL}	-0.0502	(0.0267)*	-0.0108*	(0.0199)
α_{KL}	0.0662	(0.0204)*	0.0588	(0.0123)*
α_t	-0.0196	(0.0020)*	-0.0191	(0.0022)*
α_{tl}	0.0055	(0.0017)*	0.0040	(0.0007)*
δ_0	0.8211	(0.2815)*	-	
δ_1	-0.0629	(0.0200)*	-	
δ_2	-0.1089	(0.0794)	-	
δ_3	0.1380	(0.0614)*	-	
R_{adj}^2 cost function	0.9913		0.9909	
R_{adj}^2 share equation	0.9660		0.9625	
Standard error cost function	0.0312		0.0318	
Standard error share equation	0.0079		0.0084	

Note: * indicates significant at the 5 % level

Table 1 : Regression results (standard errors in parentheses)

year	p_L^* (10^6 Belgian Francs)	p_L (10^6 Belgian Francs)	$100 * (\frac{p_L^*}{p_L})$
1950	0.047427	0.070783	67.00397
1951	0.054327	0.078580	69.13631
1952	0.053592	0.079414	67.48454
1953	0.054228	0.080646	67.24224
1954	0.057460	0.081947	70.11907
1955	0.058491	0.081585	71.69325
1956	0.063172	0.086393	73.12234
1957	0.064349	0.091284	70.49316
1958	0.069713	0.100365	69.45910
1959	0.072660	0.102616	70.80737
1960	0.077873	0.107061	72.73753
1961	0.081418	0.108909	74.75758
1962	0.086622	0.117161	73.93467
1963	0.097654	0.128502	75.99420
1964	0.109646	0.133345	82.22740
1965	0.115601	0.146854	78.71800
1966	0.134564	0.177071	75.99419
1967	0.138589	0.185490	74.71501
1968	0.147119	0.198385	74.15865
1969	0.154671	0.210048	73.63592
1970	0.167547	0.225478	74.30757
1971	0.185155	0.247527	74.80187
1972	0.206497	0.283841	72.75079
1973	0.227936	0.314674	72.43565
1974	0.259842	0.357291	72.72575
1975	0.284684	0.404062	70.45557
1976	0.306968	0.444671	69.03262
1977	0.324550	0.475565	68.24516
1978	0.340411	0.513450	66.29880
1979	0.354137	0.546083	64.85040
1980	0.364902	0.566548	64.40791
1981	0.391296	0.605852	64.58607
1982	0.457850	0.635351	72.06252
1983	0.498484	0.658844	75.66046
1984	0.551414	0.729637	75.57368
1985	0.581644	0.765699	75.96250
1986	0.614293	0.806990	76.12148
Mean	0.212345	0.295892	71.99225

Table 2 : The shadow wage relative to the observed wage

	Model based on shadow prices	Model based on observed prices
σ_{LE}	0.8284	0.8665
η_L	-0.1271	-0.0982
η_E	-0.7058	-0.7684
ϵ_R	0.4201	0.5002
ϵ_F	0.3189	0.2898
ϵ_K	-0.0740	-0.0936
RTS	1.4549	1.3843
P1	2.44 %	2.38 %
P2	1.68 %	1.86 %

Notes: 1. σ_{LE} = elasticity of substitution between labor and energy

η_i = price elasticity of demand for input i

ϵ_j = cost elasticity with respect to j

RTS = indicator of returns to scale

P1,P2 = two alternative productivity indices

2. Estimates for P1, P2 are average percentage increases in productivity. Estimates of all other technological effects have been evaluated at the sample mean.

Table 3 : Estimates of the production technology

year	Index technical inefficiency	Excess Labor units due to technical inefficiency	Excess Energy units due to technical inefficiency	Percentage excess Labor and Energy due to technical inefficiency
1950	0.984146	1440.516	242.4502	1.610974
1951	0.983863	1392.750	257.9805	1.640180
1952	0.989811	884.2969	152.5898	1.029391
1953	0.981172	1528.016	243.2998	1.918961
1954	0.977629	1736.359	278.9795	2.288306
1955	0.957535	3228.914	464.5908	4.434776
1956	0.962890	2860.891	413.7695	3.854016
1957	0.983593	1295.773	159.0107	1.668065
1958	0.971632	2156.898	248.4111	2.919585
1959	0.992325	572.2031	67.67285	0.773449
1960	0.984807	1052.680	118.9888	1.542779
1961	0.982306	1186.563	123.8252	1.801211
1962	0.972275	1773.367	179.5210	2.851572
1963	0.986498	864.1406	77.38672	1.368717
1964	0.993082	438.6602	36.26563	0.696626
1965	0.992850	442.5703	30.55322	0.720139
1966	0.976441	1376.422	69.81592	2.412748
1967	0.992712	424.3984	20.68408	0.734173
1968	0.981100	1056.590	49.39404	1.926369
1969	0.981983	1005.371	45.15698	1.834731
1970	0.975537	1381.102	62.58691	2.507692
1971	0.981506	1090.820	50.23682	1.884216
1972	0.976839	1363.152	69.74683	2.371072
1973	0.983708	956.6914	53.94190	1.656233
1974	0.971720	1659.461	80.82422	2.910332
1975	0.948956	2961.203	128.6321	5.378912
1976	0.977774	1302.090	60.92310	2.273076
1977	0.992247	467.7422	24.08008	0.781388
1978	0.995964	250.5000	15.47095	0.405239
1979	0.982298	1088.898	61.44507	1.802040
1980	0.983742	1068.605	52.21606	1.652679
1981	0.979314	1390.008	62.15283	2.112251
1982	0.983440	1094.664	50.62207	1.683849
1983	0.978281	1368.500	61.52588	2.220080
1984	0.990411	593.6797	28.61890	0.968208
1985	0.970440	1708.000	73.49609	3.046028
1986	0.972697	1487.121	68.76099	2.806900
Mean	0.980365	1295.936	115.82770	2.013161

Table 4 : Estimated effects of technical inefficiency

year	Index allocative inefficiency	Excess labor due to allocative inefficiency	Excess energy due to allocative inefficiency	Percentage excess labor due to allocative inefficiency	Percentage excess energy due to allocative inefficiency
1950	0.986405	8394.813	-4620.640	10.36088	-23.48989
1951	0.988589	7177.938	-4443.560	9.233675	-22.02778
1952	0.987557	7387.039	-4523.410	9.408102	-23.38033
1953	0.988048	6396.125	-4033.359	8.734162	-24.13461
1954	0.990522	5330.063	-3453.440	7.555056	-22.07392
1955	0.991818	4633.859	-2850.181	6.796997	-21.38767
1956	0.992612	4537.852	-2700.290	6.511149	-20.09677
1957	0.990979	5246.766	-2649.030	7.243467	-21.74602
1958	0.990748	4845.453	-2546.653	7.019198	-23.03602
1959	0.992006	4385.609	-2422.590	6.301609	-21.68419
1960	0.993881	3251.246	-1999.780	5.003343	-20.58976
1961	0.995182	2644.504	-1626.767	4.182268	-19.13558
1962	0.995245	2344.082	-1575.282	3.916921	-20.01429
1963	0.996187	2068.012	-1255.014	3.386460	-18.16484
1964	0.998050	1401.879	-794.4209	2.276982	-13.23949
1965	0.997426	1497.641	-802.7471	2.497793	-15.91060
1966	0.997387	1208.738	-630.9519	2.164678	-17.90151
1967	0.996775	1458.719	-655.1760	2.588786	-18.86751
1968	0.997009	1234.172	-609.8919	2.301932	-19.21529
1969	0.997250	1094.379	-587.0440	2.037864	-19.25839
1970	0.997487	1025.410	-574.5449	1.897178	-18.71258
1971	0.997535	1081.430	-598.5249	1.903554	-18.33324
1972	0.997308	1075.078	-720.8350	1.905630	-19.68185
1973	0.996982	1210.801	-821.7290	2.141029	-20.14716
1974	0.996700	1336.602	-712.4282	2.400375	-20.41582
1975	0.995903	1479.059	-700.7451	2.760828	-22.66195
1976	0.995444	1634.898	-816.5940	2.937913	-23.35272
1977	0.994823	1908.047	-968.8760	3.292437	-23.91916
1978	0.993441	2368.231	-1313.581	3.983761	-25.59958
1979	0.992383	2577.879	-1267.346	4.456300	-27.09684
1980	0.991246	3166.941	-1199.456	5.150168	-27.51750
1981	0.991076	3315.270	-1114.223	5.305137	-27.46618
1982	0.994849	2444.570	-815.0569	3.907246	-21.32881
1983	0.996231	1951.730	-631.2080	3.269767	-18.55103
1984	0.996091	2019.750	-668.1428	3.406122	-18.43675
1985	0.996484	1664.000	-544.5801	3.058317	-18.41401
1986	0.996938	1353.129	-542.9829	2.620932	-18.14365
Mean	**0.994178**	**2923.019**	**-1588.9482**	**4.430216**	**-20.94954**

Table 5 : Estimated effects of allocative inefficiency

year	Index total inefficiency	Percentage excess use of labor due to inefficiency	Percentage excess use of energy due to inefficiency
1950	0.970766	12.13876	-22.25735
1951	0.972636	11.02530	-20.74891
1952	0.977495	10.53434	-22.59163
1953	0.969445	10.82073	-22.67876
1954	0.968363	10.01624	-20.29072
1955	0.949700	11.53320	-17.90140
1956	0.955777	10.61611	-17.01731
1957	0.974720	9.032358	-20.44069
1958	0.962643	10.14371	-20.78899
1959	0.984392	7.123798	-21.07846
1960	0.978781	6.623312	-19.36465
1961	0.977574	6.058810	-17.67903
1962	0.967652	6.880187	-17.73344
1963	0.982736	4.801528	-17.04476
1964	0.991145	2.989470	-12.63510
1965	0.990295	3.235920	-15.30503
1966	0.973889	4.629654	-15.92068
1967	0.989510	3.341965	-18.27186
1968	0.978166	4.272645	-17.65908
1969	0.979283	3.909985	-17.77699
1970	0.973086	4.452446	-16.67416
1971	0.979087	3.823637	-16.79445
1972	0.974209	4.321887	-17.77747
1973	0.980739	3.832723	-18.82461
1974	0.968514	5.380565	-18.09967
1975	0.945069	8.288242	-18.50201
1976	0.973320	5.277769	-21.61046
1977	0.987110	4.099551	-23.32468
1978	0.989432	4.405144	-25.29808
1979	0.974816	6.338645	-25.78310
1980	0.975130	6.887962	-26.31958
1981	0.970575	7.529446	-25.93408
1982	0.978375	5.656888	-20.00411
1983	0.974594	5.562439	-16.74280
1984	0.986539	4.407308	-17.64704
1985	0.967028	6.197502	-15.92887
1986	0.969719	5.501399	-15.84602
Mean	**0.974657**	**6.532204**	**-19.35752**

Table 6 : Total effect of allocative and technical inefficiency

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