The Journal of Productivity Analysis, 7, 41–62 (1996)

Radial and Nonradial Measures of Technical Efficiency: An Empirical Illustration for Belgian Local Governments Using an FDH Reference Technology*

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Abstract

This paper serves two purposes. First, we argue that radial efficiency measures are inappropriate for the Free Disposal Hull (FDH) technology, and we provide a comparative analysis of alternative nonradial measures. In particular, using information on Belgian local government expenditures and output indicators we implement various radial and nonradial measures on the FDH reference technology, and we investigate to which extent these efficiency measures imply different distributions and rankings. Second, we analyze the patterns of measured technical efficiency implied by the various indices. Specifically, we investigate whether different measures make any substantial difference for the explanation of the calculated inefficiencies. The empirical results suggest that more important differences in rankings exist between radial and nonradial measures than between different nonradial alternatives; moreover, the radial and the nonradial efficiency measures do yield a somewhat different pattern of explanation.

Keywords: Technical efficiency measures, FDH, local government.

1. Introduction

Two issues are of crucial importance when calculating technical inefficiency in practice. First, the reference technology, describing the production possibility set and its boundary, must be carefully specified. Second, in order to measure technical inefficiency some concept of distance is required to relate observed input and output vectors to the postulated boundary. This paper is concerned with the second of these issues in the context of nonparametric efficiency frontiers, viz., the choice between alternative measures of technical efficiency calculated for a given reference technology. Almost the whole empirical literature has been inspired by the radial efficiency measures as proposed by Debreu (1951) and Farrell (1957). These measures define the degree of inefficiency of an observation in terms of its distance from the isoquant, whereby quantities are adjusted proportionally in all relevant dimensions. However, based on Koopmans' (1951) notion of technical efficiency Färe and Lovell (1978) initiated an axiomatic literature in which efficiency is defined in terms of

*This is a revision of a paper presented at the 38th Conference of the Applied Econometrics Association in Athens (April 12–13, 1993). Comments of R. Goudriaan, Henry Tulkens, and two anonymous referees are gratefully acknowledged.

the efficient subset as opposed to the isoquant [see, e.g., Zieschang (1984), Bol (1986), and Russell (1988)]. Consistent with this view, radial efficiency measures are inadequate, as they implicitly project inefficient observations onto the isoquant, but not necessarily onto the efficient subset. The potential seriousness of this deficiency of radial measures is likely to be most pronounced whenever the efficient subset is a relatively small subset of the isoquant.

In response to this problem a number of alternative, nonradial measures have been proposed successively by Färe (1975), Färe and Lovell (1978), and Zieschang (1984). Unfortunately, they have largely been ignored in empirical work. The purpose of this paper is to provide a systematic comparison of the use of nonradial efficiency measures using empirical data on Belgian local governments. We calculate different radial and nonradial measures of technical efficiency using the Free Disposal Hull (FDH) reference technology, introduced by Deprins, Simar and Tulkens (1984). Moreover, we consider the input, the output and the graph orientation of measurement. We first investigate the extent to which different measures lead to different rankings of local governments. Next we analyze the patterns of measured technical efficiency implied by the various indices. Specifically, we investigate whether the use of different measures makes any substantial difference for the explanation of the calculated inefficiencies.

The structure of the paper is as follows. In the first section we present the FDH reference technology, and we illustrate the distinction between the isoquant and the efficient subset. In Section 3 we argue that radial efficiency measures are inappropriate given the FDH technology, and we review a number of alternative efficiency measures proposed in the literature. In the fourth section we implement the radial efficiency measure and three nonradial alternatives on the FDH technology using information on all 589 Belgian municipalities. The characteristics of the distributions of the various measures are carefully analyzed. In Section 5 the calculated inefficiencies are explained using a variety of economic, political and institutional variables. We investigate the extent to which the empiricial results are robust with respect to the choice of efficiency measure. A final section concludes.

2. The Free Disposal Hull Reference Technology

The FDH is a nonparametric reference technology that is based on slightly milder assumptions than the more widely used DEA reference technologies.[1] In addition to the usual regularity axioms—no free lunch, possibility of inactivity, boundedness, closedness—FDH only imposes strong free disposability in both the inputs and the outputs. These assumptions imply that an increase in inputs never results in a decrease in outputs, and that any reduction in outputs remains producible with the same amount of inputs.[2] Important is that FDH—contrary to DEA models—does not impose convexity on the technology. Recently FDH has gained popularity as a useful alternative to DEA [see, e.g., the discussion in Lovell (1993)]. The theoretical, empirical and managerial pros and cons of FDH relative to the DEA-family have been carefully analyzed [see, e.g., Tulkens (1993), Lovell (1993), and Lovell and Vanden Eeckaut (1994)].

In this section we briefly review the FDH, and we illustrate the distinction between the isoquant and the efficient subset for this technology. Although there are other alternatives, we define the FDH in terms of an output correspondence $P(x)$.[3] Specifically, let $y = (y_1, y_2, \ldots, y_n) \in \mathbb{R}^n_+$ be the n non-negative outputs produced by using various combinations of the m non-negative inputs $x = (x_1, x_2, \ldots, x_m) \in \mathbb{R}^m_+$. The output correspondence P describing the technology maps inputs $x \in \mathbb{R}^m_+$ into subsets $P(x) \subseteq \mathbb{R}^n_+$ of outputs. The level set or section $P(x)$ is for each input vector x defined as the set of all output vectors y producible from the input vector x. The FDH output correspondence is a piecewise linear technology, constructed from k observations of productive activities, that satisfies the above mentioned axioms:

$$P(x)^{FDH} = \{y \mid y \in \mathbb{R}^n_+, z'N \geq y, z'M \leq x, I_k'z = 1, z_i \in \{0, 1\}, i = 1, \ldots, n\}, \quad (1)$$

where z is a $k \times 1$ vector of intensity parameters, N and M are the $k \times n$ respectively $k \times m$ matrices of observed outputs and inputs, and I_k is a $k \times 1$ vector of ones.[4] To allow for variable returns to scale, the intensity vector is restricted to sum to one. Additionally, to avoid imposing convexity, the intensity vector contains either zeros or ones. Note that this nonconvex nature also allows us to compute efficiency scores by means of an exhaustive data classification algorithm based on vector dominance reasoning [see Tulkens (1993) for details].

A graphical illustration provides an intuitive understanding of the construction of the FDH reference technology. Reflecting free disposal in inputs and outputs, with each observation is associated an orthant, positive in the inputs and negative in the outputs, which is assumed to be part of the production possibility set. The FDH reference technology is then the boundary of the union of all such orthants. Its output isoquants typically have a staircase form. Figure 1 represents such an isoquant in the output space.

The vector dominance reasoning used to construct the FDH frontier is easily illustrated. Consider observation **b** in Figure 1. It is technically inefficient because it uses the same

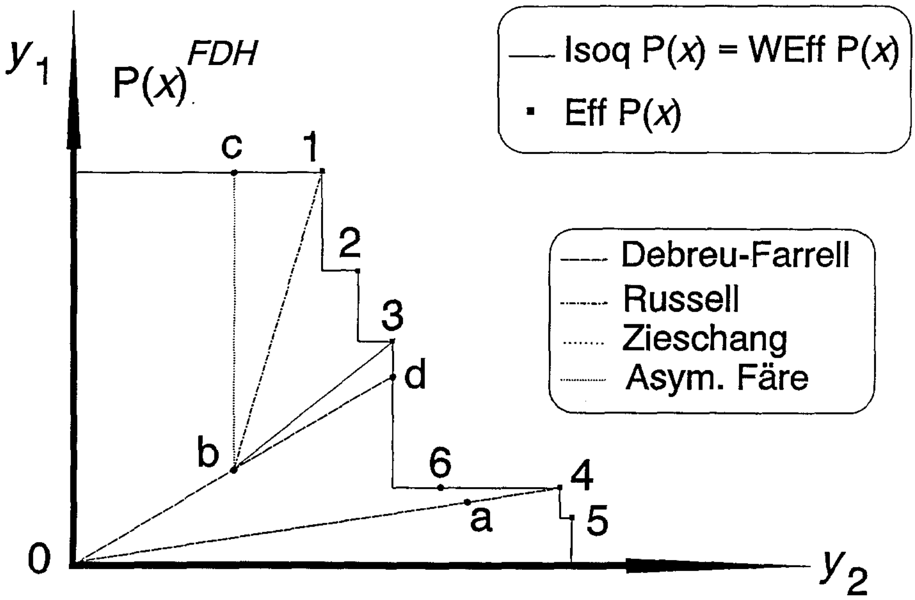

Figure 1. FDH output correspondence and efficiency measures.

input vector to produce less of both outputs compared to observations 1, 2 and 3. Hence it is dominated by these observations. Inversely, observations 1, 2 and 3 are technically efficient because they are not dominated by any other observation. Within the subset of efficient observations, it is common in the FDH literature to further distinguish observations which are efficient by default. These are observations which neither dominate nor are dominated by others. An example is observation 5. Finally observe the effect of not imposing convexity. Observations 2 and 3 are efficient although, had convexity been assumed, they would have been dominated by some (unobserved) convex combination of the observations 1 and 4.

In view of the discussion in the following section it is useful to distinguish between three subsets of the production technology all of which denote production units on the boundary of the technology [see Färe, Grosskopf and Lovell (1994)]. First, the output isoquant of $P(x)$ is:

$$\text{Isoq } P(x) = \{y \mid y \in P(x),\ \theta y \notin P(x),\ \theta > 1\}. \tag{2}$$

Second, the weak efficient subset of $P(x)$ is defined as:

$$\text{WEff } P(x) = \{y \mid y \in P(x),\ y' >^{*} y \Rightarrow y' \notin P(x)\}. \tag{3}$$

Finally, the efficient subset of the output correspondence is:

$$\text{Eff } P(x) = \{y \mid y \in P(x),\ y' \geq y \Rightarrow y' \notin P(x)\}. \tag{4}$$

The efficient subset is clearly a subset of the weak efficient subset. The latter subset is contained in the isoquant, which in turn is part of the output correspondence ($P(x) \supseteq \text{Isoq } P(x) \supseteq \text{WEff } P(x) \supseteq \text{Eff } P(x)$).

These subsets are illustrated on the FDH output correspondence in Figure 1. It is clear that for the FDH reference technology the efficient subset only contains the isolated points 1 to 5. The isoquant and the weak efficient subset coincide due to the strong disposability of outputs [see Färe, Grosskopf and Lovell (1994)]. They are graphically indicated by the line representing the frontier. Observation 6 is clearly an element of the isoquant and the weak efficient subset, but not of the efficient subset. It is evident that the distinction between the isoquant and the efficient subset is much more pronounced for the FDH technology compared to DEA reference technologies due to the former's nonconvexity. Assuming convexity would imply that all convex combinations of observations 1 and 4 belong to the efficient subset.

3. Alternative Measures of Technical Efficiency

In this section we discuss the potential problems of radial efficiency measures, and review some of the alternatives presented in the literature. All measures considered will be illustrated using the FDH reference technology. The discussion in this section concentrates on the measurement of output efficiency. The corresponding measures of input and graph efficiency can be analyzed analogously [see Färe, Grosskopf and Lovell (1994); they are reported in Appendix A].

In the case of output efficiency, the radial indicator introduced by Debreu (1951) and Farrell (1957) measures the maximum proportional increase in all outputs producible from given inputs:

$$DF_o(x, y) = max\{\theta \mid \theta \geq 1, \theta y \in P(x)\}. \tag{5}$$

Graphically the index measures the distance from the inefficient observation to the isoquant along a ray through the origin. It is larger than or equal to one, with unity representing efficient production.

It is clear that the Debreu-Farrell measure scales up inefficient observations to the isoquant, but not necessarily to the efficient subset. For example, observation **b** in Figure 1 is scaled up by the ratio 0d/0b to point **d** on the isoquant, which is not an element of the efficient subset. Only those observations (e.g., observation **a**) on a ray through one of the elements in the efficient subset will be scaled up to this efficient subset. The probability of the latter situation occurring in empirical FHD applications is of course negligible.[5]

However, following Koopmans (1951), much of the axiomatic literature on efficiency measurement, initiated by Färe and Lovell (1978), does require efficient production units to be elements of the efficient subset [see, e.g., Zieschang (1984), and Russell (1988)].[6] Specifically, in their seminal contribution Färe and Lovell (1978) suggested the following four desirable properties of efficiency measures: (1) technical efficiency requires membership of the efficient subset; (2) inefficient observations need to be compared with respect to elements of the efficient subset; (3) homogeneity of degree minus one; (4) strict negative monotonicity.

Clearly, any reference technology for which the isoquant diverges from the efficient subset is bound to lead to a conflict between the proposed axioms and the traditional radial measure of technical efficiency. The problem may be quite important for nonparametric reference technologies such as FDH, for which the efficient subset is very small relative to the isoquant. Consequently, use of a radial efficiency measure is inappropriate for the FDH reference technology.

In response to the axioms stated by Färe and Lovell a number of alternative efficiency measures have been suggested. Three measures have been thoroughly discussed in the literature, viz. the Russell measure [Färe and Lovell (1978)], the Zieschang (1984) measure, and the asymmetric Färe measure [Färe (1975), Färe, Lovell, Zieschang (1983)].[7] In the further analysis we focus on these three alternatives.[8] The Russell output measure of technical efficiency is defined as follows:

$$R_o(x, y) = \max \left\{ \sum_{i=1}^{n} \theta_i/n \mid (\theta_1 y_1, \ldots, \theta_n y_n) \in P(x), \theta_i \geq 1 \right\}. \tag{6}$$

It looks for the maximum arithmetic mean of proportional increases in all individual outputs and therefore allows us to scale each output in a different proportion. The Zieschang output measure of technical efficiency is:

$$Z_o(x, y) = R_o(x, y \cdot DF_o^+(x, y)) \cdot DF_o^+(x, y)$$

$$\text{where } DF_o^+(x, y) = \max\{\theta \mid \theta \geq 1, \theta y \in P^+(x) = P(x) + \mathbb{R}^n_+\}. \tag{7}$$

It essentially combines the Debreu-Farrell and the Russell measures. It first radially scales up the inefficient observation to the isoquant, and then expands the output vector until the efficient subset is reached. Finally, the asymmetric Färe measure of technical efficiency is defined as:

$$AF_o(x, y) = \max\{AF_o^j(x, y)\}$$

$$j = 1, \ldots, n$$

$$\text{where for each } j\text{: } AF_o^j(x, y) = \max\{\theta_j \mid (y_1, \ldots, \theta_j y_j, \ldots, y_n) \in P(x)\}. \tag{8}$$

It scales up only one output holding all other outputs fixed, and thereafter selects the maximum over n of these scalings. It has been shown that for a given reference technology these efficiency measures are related as follows: $1 \leq DF_o(x, y) \leq Z_o(x, y) \leq R_o(x, y) \leq AF_o(x, y)$.[9]

The three alternative indexes defined above take account of the potential divergence between the isoquant and the efficient subset. The Russell and the Zieschang measures satisfy both of the first two axioms; the asymmetric Färe measure satisfies the first but not the second axiom, i.e., inefficient observations need not be scaled up to the efficient subset but only to the boundary of $P(x)$. The radial and the Zieschang efficiency measure are homogeneous of degree -1; while the Russell and the asymmetric Färe indexes only meet a weaker version of this property. All efficiency measures fulfill a weak negative monotonicity property, except the Zieschang which is nonmonotonous when output changes in a single dimension.[10]

We illustrate the various efficiency measures for the inefficient observation **b** on Figure 1. The Debreu-Farrell efficiency measure calculates technical inefficiency radially. This leaves some slack in the first output y_1, i.e., the distance from **d** to 3. In this particular example the Russell efficiency measure relates the inefficient observation to observation 1. The Zieschang measure will relate the inefficient observation to observation 3, as it adjusts the radial efficiency measure for the remaining slack in the first output. Finally, the asymmetric Färe efficiency measure selects point **c** as a reference point, because performance is worst in the first output. This leaves slack in the second output, i.e., the distance from **c** to 1.

It is important to emphasize that the theoretical literature has not generated a definite conclusion with respect to the choice between the alternative measures.[11] Of course, the defect of the radial efficiency measure relative to the first two axioms is pertinent, especially on the FDH technology. Empirical studies confirm that the amount of unmeasured technical efficiency or slacks is pervasive in FDH [see, e.g., Fried, Lovell and Vanden Eeckaut (1993)]. In this respect the radial measure is clearly inferior relative to its alternatives. On the other hand, it has a more straightforward interpretation than the other measures, which may not be unimportant for managerial applications. Therefore, a crucial question concerns the degree to which the use of Debreu-Farrell measures leads to misleading rankings of observations in terms of their efficiency. Empirical analysis may provide some insight into the answer to this question by illustrating the practical relevance of choosing among the various alternatives.[12]

4. Computing Technical Efficiency Measures for Belgian Municipalities

A substantial number of recent studies have analyzed the technical efficiency of state and local governments in the provision of local public services, both for the U.S. [see, e.g., Deller (1992) and Hayes and Chang (1990)] and for Belgium [see Vanden Eeckaut and Tulkens (1989), Vanden Eeckaut, Tulkens and Jamar (1993), De Borger et al. (1994)].[13] In this section we illustrate the consequences of using radial versus various nonradial efficiency measures (Russell, Zieschang, Asymmetric Färe) by evaluating the technical efficiency of Belgian municipalities in the provision of local public services.

Research on technical efficiency of Belgian municipalities was initiated by Vanden Eeckaut and Tulkens (1989). The data used in this analysis are inspired by this initial contribution. They are described in more detail in De Borger et al. (1994). The data set comprises information on total current municipal expenditures and on six output indicators for each of the 589 Belgian local governments in 1985. Given the fixed salary profiles of municipal personnel and municipalities' access to the same capital markets it is implicitly assumed that input prices are the same across municipalities. As a consequence, technical input efficiency and cost efficiency coincide. Therefore, municipal expenditures were used rather than inputs. In other words, the application analyzes efficiency by comparing observed expenditures and the corresponding output levels across all municipalities. The output indicators intend to capture important aspects of local production in the field of education, transportation, social and recreational services, and overall administrative tasks. The following outputs were used:

(i) the surface of municipal roads;
(ii) the number of beneficiaries of minimal subsistence grants;
(iii) the number of students enrolled in local primary schools;
(iv) the surface of public recreational facilities;
(v) the total population; and
(vi) the fraction of the population aged 65 and above.[14]

It is obvious from this list that its items are, at best, to be considered as proxies for the services delivered by municipalities rather than direct output measures [see Vanden Eeckaut and Tulkens (1989)]. Moreover, for some of the outputs substantial unobservable quality differences may exist. Unfortunately, more direct output measures are not available.

As previously indicated we consider in our empirical application input, output, and graph oriented measures of efficiency. Although many contributions to the performance literature on the local public sector have focused on input efficiency measures [e.g., Hayes and Chang (1990), Vanden Eeckaut, Tulkens and Jamar (1993)], the input orientation is by no means the only choice [see, e.g., Deller (1992), Färe, Grosskopf and Weber (1989)]. In principle, the choice of orientation should be inspired by the postulated underlying behavioral model. If one assumes that local governments take outputs as exogenous (for example, determined by citizens' demands) and have substantial control over inputs, then an input oriented measure seems most appropriate. Input measures can then detect failures to minimize costs resulting from discretionary power and incomplete monitoring, and they provide an indication of possible cost reductions. If on the other hand municipalities have limited control over inputs and face fixed budgets, then an output oriented approach may be quite informative. Output measurement can then identify municipalities that fail to maximize the quantity of the local public services subject to the budget they face, and provide indications of the increase in outputs that could potentially be realized.[15]

The theoretical literature remains largely inconclusive with respect to the appropriate model to describe public sector behavior in general, and the behavior of municipalities in particular. Various goals have been attributed to the public sector ranging from cost minimization to budget maximization to output maximization [see, e.g., Bös (1986), Niskanen (1974), Oakland (1987)]. Given the existence of soft budget constraints and given the importance of intergovernmental grants it is at least conceivable that the local public sector lacks an interest to minimize its input usage, or that local bureaucrats have a tendency to expand outputs. Moreover, there is no general agreement in the literature concerning the policy variables under control of the local governments. In Belgium municipalities have at least some flexibility with respect to both inputs and outputs, but this flexibility is limited in both cases. For instance, on the input side strict rules govern the process of hiring and (especially) firing civil servants. On the output side one should realize that the direct outputs are only indirectly linked to citizen's demands, and that, as a consequence, inefficiencies in the indicators used here proxy for inefficiencies in the underlying direct outputs. It is obvious that there is some discretion with respect to particular outputs (e.g., the municipal road system, recreational facilities) but less with respect to others (e.g., beneficiaries of subsistance grants).

In view of the uncertainty related to the appropriate behavioral model, we have chosen not to restrict the analysis to measurement in one direction. Our choice was in addition inspired by a second argument, namely that input and output measures need not coincide on a nonconstant returns to scale technology such as FDH. From a practical viewpoint, it may therefore be useful to determine the amount of technical inefficiency in all of the orientations so as to obtain a more complete view of local public sector performance. Accordingly, in the empirical application we look at output, input and graph oriented measurement.[16]

In what follows we denote the various radial and nonradial input, output, and graph efficiency measures using the subscripts i, o, and g. For instance, the graph oriented measures are denoted $DF_g(x, y)$, $R_g(x, y)$, $Z_g(x, y)$, and $AF_g(x, y)$. Remark that due to the use of a single input (viz. costs), all radial and nonradial input oriented efficiency measures coincide (i.e., $DF_i(x, y) = R_i(x, y) = Z_i(x, y) = AF_i(x, y)$).

Our computational procedure is as follows. First, observations are labeled as efficient or inefficient using the weak vector dominance reasoning previously illustrated on Figure 1 [see also Tulkens (1993)]. A municipality is declared efficient if no other municipality exists with equal or lower expenditures and equal or larger (for at least one) outputs, i.e., it is undominated. All other observations are dominated and therefore inefficient. Second, for the inefficient observations the efficiency measures were calculated by applying their respective definitions. However, in the empirical application all output measures were redefined so as to be situated between zero and one, with unity indicating efficiency. This is common in the literature as it facilitates the interpretation and comparison with the input and graph measures which are always defined to be smaller than unity [see, e.g., Färe, Grosskopf, Logan and Lovell (1985) and Tulkens and Vanden Eeckaut (1995)].[17]

Application of this procedure on this data set resulted in 152 inefficient observations (25.8%). This small number of inefficient observations illustrates the conservative nature of the FDH technology [see Tulkens (1993), Lovell (1993)]. Its nonconvex nature guarantees prudence when labeling activities as inefficient. Of the remaining municipalities 186 (31.6%) were found to actually dominate at least one other observation; they are declared efficient. Finally, 251 observations (42.6%) were found to be efficient by default.

Summary statistics for the efficiency measures are reported in Table 1 both for all observations and for the inefficient observations only. For the output orientation, the Debreu-Farrell efficiency measure has the largest mean (.972), followed by the Zieschang (.908), the Russell (.901), and finally the asymmetric Färe (.810) measure. Considering the graph measures the same ranking of the four means can be observed. These rankings follow the theoretical ordering between the efficiency measures indicated earlier. All efficiency distributions have long left tails since they are negatively skewed, except the asymmetric Färe efficiency measures when only the inefficient observations are considered. The positive kurtosis for all efficiency measures is an indication of fat tailed distributions relative to the normal distribution. The differences between the three orientations are notable. The amount of technical inefficiency in the outputs is larger than in the single input dimension, at least if the former are evaluated nonradially. The graph oriented measures tend to average both extremes out. Observe that the distributions of the output- and graph-oriented asymmetric Färe efficiency measures are identical, implying that the performance of the input dimension is never worst for any observation. Figures 2 and 3 present the distributions of the input and output respectively the graph efficiency measures.

The different efficiency measures may not only have distribution of different shapes, they can also imply different rankings of the individual activities. Therefore, we compare in

Table 1. Summary statistics for the efficiency measures.

	Mean	Std. Dev.	Skew.	Kurt.	Minimum	Maximum
All observations (N = 589)						
$DF_o(x, y)$	.972	.063	−2.684	10.348	.619	1.000
$AF_o(x, y)$	.810	.331	−1.284	2.855	.012	1.000
$R_o(x, y)$	.901	.175	−1.395	3.343	.391	1.000
$Z_o(x, y)$	.908	.163	−1.394	3.373	.392	1.000
$DF_i(x, y)$	.954	.103	−2.491	8.750	.441	1.000
$DF_g(x, y)$	.981	.044	−2.872	11.929	.709	1.000
$AF_g(x, y)$	.810	.331	−1.284	2.855	.012	1.000
$R_o(x, y)$	.912	.155	−1.374	3.256	.454	1.000
$Z_g(x, y)$	.919	.142	−1.362	3.261	.454	1.000
Inefficient observations only (N = 152)						
$DF_o(x, y)$	.893	.083	−.904	3.447	.619	.9o99
$AF_o(x, y)$	.266	.158	.499	2.417	.012	.678
$R_o(x, y)$	.619	.102	−.161	2.396	.391	.855
$Z_o(x, y)$	.645	.093	−.346	2.804	.392	.855
$DF_i(x, y)$	.820	.132	−.717	2.719	.441	.999
$DF_g(x, y)$	.927	.060	−1.093	4.077	.709	1.000
$AF_g(x, y)$	.266	.158	.499	2.417	.012	1.000
$R_g(x, y)$	.660	.087	−.159	2.308	.454	1.000
$Z_g(x, y)$	.688	.076	−.487	3.169	.454	1.000

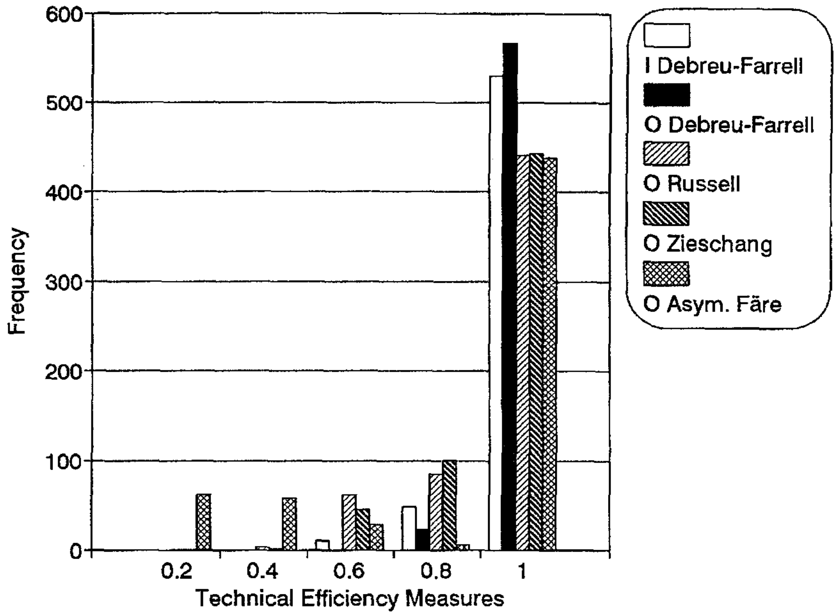

Figure 2. Histogram of input and output efficiency measures for Belgian municipalities.

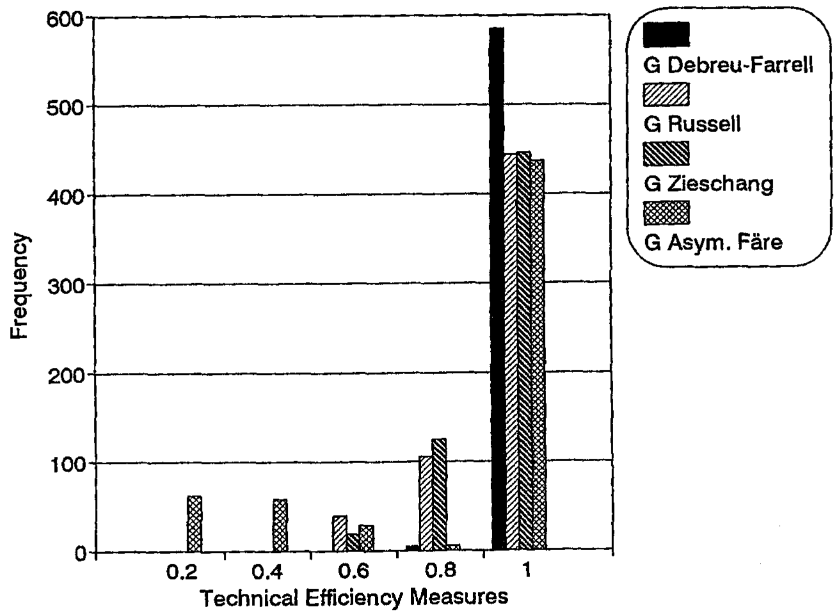

Figure 3. Histogram of graph efficiency measures for Belgian municipalities.

Table 2. Correlation matrix for the efficiency measures.

	$DF_o(x, y)$	$AF_o(x, y)$	$R_o(x, y)$	$Z_o(x, y)$	$DF_i(x, y)$	$DF_g(x, y)$	$AF_g(x, y)$	$R_g(x, y)$	$Z_g(x, y)$
All observations (N = 589)									
$DF_o(x, y)$	1.000								
$AF_o(x, y)$	.806	1.000							
$R_o(x, y)$	.856	.983	1.000						
$Z_o(x, y)$	.841	.980	.989	1.000					
$DF_i(x, y)$	.780	.791	.935	.813	1.000				
$DF_g(x, y)$	.898	.788	.835	.808	.826	1.000			
$AF_g(x, y)$	.806	1.000	.983	.980	.791	.733	1.000		
$R_g(x, y)$	.850	.983	.999	.989	.844	.835	.983	1.000	
$Z_g(x, y)$	.815	.980	.984	.987	.824	.808	.980	.987	1.000
Inefficient observations only (N = 152)									
$DF_o(x, y)$	1.000								
$AF_o(x, y)$	.528	1.000							
$R_o(x, y)$	.743	.787	1.000						
$Z_o(x, y)$	.672	.739	.876	1.000					
$DF_i(x, y)$	.494	.323	.554	.441	1.000				
$DF_g(x, y)$	.780	.506	.697	.572	.613	1.000			
$AF_g(x, y)$	.528	1.000	.787	.739	.323	.596	1.000		
$R_g(x, y)$	.727	.774	.991	.873	.610	.714	.774	1.000	
$Z_g(x, y)$	.554	.706	.803	.843	.509	.588	.706	.826	1.000

Table 2 the Pearson product-moment correlation coefficients between the efficiency measures. To avoid a biased interpretation due to the large number of efficient observations, we also report the correlation coefficients calculated solely on the inefficient observations. Within a given orientation, the highest correlation can be found between the Russell and Zieschang efficiency measures, while the lowest correlations in the matrix are those between the radial and the asymmetric Färe measures. The latter low correlations (.528 and .506) imply that the choice of efficiency measure is apparently not without consequences for the ranking of production units. Across orientations correlations are highest between similar efficiency measures. As a matter of fact, in this sample the choice among efficiency measures has about an equal effect on rankings as the choice of orientation. For instance, the lowest correlations in the sample containing the inefficient observations only are found between the input and output oriented measures. These results underscore the importance of selecting an efficiency measure as well as an appropriate orientation of measurement, even when the aim is to use the efficiency results solely for ranking purposes.

5. Explaining Measures of Technical Efficiency: Empirical Results

The selection of a model to explain the calculated efficiency differences should take account of the characteristics of the distribution of the efficiency measures. As the latter are bounded above by unity the use of a censored regression model (Tobit) seems appropriate [as indicated in Lovell (1993)]. Moreover, as mentioned before, the exact status of municipalities declared *efficient by default* remains unclear. Their efficiency may well be due to data sparsity in the sample, resulting in a lack of similar observations to compare their relative performance.[18] In the analysis that follows, we therefore present results based on the sample after deletion of the observations declared efficient by default.[19]

The standard Tobit model is defined in terms of a latent or index variable y_i^*. It reads: $y_i^* = \beta' x_i + \epsilon_i$, where ϵ_i are assumed to be i.i.d. drawings from $N(0, \sigma^2)$. However, the latent variable y_i^* is not directly observable. Instead, the efficiency index y_i is observed which is censored at the limit level of 1, thus partly masking the true value of y_i^*. For y_i^* less than 1 both y_i and x_i are observed; while for $y_i^* \geq 1$ the x_i are observed and the y_i equal the limit value of 1.

Given this statistical model, we proceed by specifying the variables to be included in the analysis. Here we closely follow De Borger et al. (1994) who develop a preliminary explanatory analysis of the radial measure. We therefore limit the discussion to a brief overview; for more details we refer to the above-mentioned paper.

First, it is well known that the incomes and wealth of citizens affect the incentives of both politicians and taxpayers to monitor expenditures. These factors largely determine the fiscal capacity of municipalities. Higher fiscal revenue capacity may increase the on-the-job leisure of politicians and public managers and affect the possibilities to operate inefficiently [see, e.g., Spann (1977), and Silkman and Young (1982)]. On the other hand, due to the high opportunity cost of time citizens of high-income municipalities may be less motivated to effectively monitor expenditures. These effects are proxied by including average personal income (INCOME) in each municipality in the specification.

Second, two variables were introduced to capture differences in the financing of local expenditures. First, we included a proxy variable for the tax price in each municipality. Previous studies have postulated that for a given level of service provision high tax prices increase the voters' attention for controlling public expenditures [see, e.g., Spann (1977)]. This is especially true if cost comparisons between municipalities are easy. In Belgium the two main municipal taxes are a local income tax and the property tax. Only the latter tax rate (HTAX) was finally included, as the former yielded consistently insignificant results. Second, about 20% of local government operations are funded by block grants. Although this is of course not directly implied by the well-known flypaper effect associated with such grants, it can be hypothesized that there is a negative relation between grants and technical efficiency. Silkman and Young (1982) actually found some evidence for this phenomenon in the U.S. We therefore added the size of the per capita block graph (GRANT) as an explanatory variable.

Third, both the theory of property rights and recent principal-agent models suggest the possibility that politicians and public managers may pursue goals independent from the constituency they represent and from the organization in which they operate. A number of reasons have been suggested as to why they may lack incentives to effectively audit and control expenditures. The public choice literature suggests that the process of political decisionmaking itself may impede the effective control of the public sector [Mueller (1989); Borcherding, Pommerehne and Schneider (1982); Bartel and Schneider (1991)]. In addition, political rationality may imply the use of explicit or implicit (e.g., logrolling) *side payments* in the decision-making process. One therefore suspects that the size and composition of political coalitions may affect technical efficiency. Indeed, arbitrage in the bargaining process may require more side payments the larger the number of parties in the coalition, and different ideological views may tolerate inefficiencies to a different extent. Following Vanden Eeckaut and Tulkens (1989) and Vanden Eeckaut, Tulkens and Jamar (1993), two sets of variables were constructed to approximate the above ideas, viz. the number of parties in a municipal coalition (CPAR), and a set of dummy variables indicating the presence of a particular political family in the ruling coalition (CLIB and CSOC for the liberal and socialist parties, respectively).

Fourth, an active political participation of the citizens may enhance the performance of a municipality. While political participation is hard to directly quantify, there is some evidence in the literature that it is related to education [see Mueller (1989: 121–122)]. We included the share of the adult population holding a degree of higher education as an explanatory variable (HEDUC).[20]

Table 3 presents the Tobit regression estimates obtained by maximum likelihood techniques. Standard errors are between brackets. Space limitations induced us to report only one common specification for each of the efficiency measures. However, the results with respect to the most important explanatory variables were quite robust across different specifications. Since the output- and graph-oriented asymmetric Färe efficiency measures have identical distributions, the Tobit results are also identical.

Table 3. Tobit results for the efficiency measures ($N = 338$).

	$DF_o(x, y)$	$AF_o(x, y)$	$R_o(x, y)$	$Z_o(x, y)$	$DF_i(x, y)$	$DF_g(x, y)$	$AF_g(x, y)$	$R_g(x, y)$	$Z_g(x, y)$
CONSTANT	1.403	2.983	2.077	2.020	1.746	1.286	2.983	1.980	1.911
	(.096)**	(.491)**	(.257)**	(.240)**	(.155)**	(.067)**	(.491)**	(.228)**	(.208)**
HTAX	.24E-04	.19E-03	.10E-03	.87E-04	.26E-04	.13E-04	.19E-03	.85E-04	.78E-04
	(.20E-04)	(.10E-03)*	(.53E-04)*	(.49E-04)*	(.32E-04)	(.14E-04)	(.10E-03)*	(.47E-04)*	(.43E-04)*
INCOME	−.22E-02	−.12E-01	−.64E-02	−.60E-02	−.39E-02	−.15E-02	−.12E-01	−.58E-02	−.54E-02
	(.54E-03)**	(.27E-02)**	(.14E-02)**	(.13E-02)**	(.86E-03)**	(.38E-03)**	(.27E-02)**	(.13E-02)**	(.12E-02)**
GRANTS	−22.136	−127.756	−72.352	−65.206	−43.597	−16.304	−127.756	−65.754	−60.232
	(4.45)**	(27.77)**	(14.52)**	(13.57)**	(8.769)**	(3.773)**	(27.77)**	(12.90)**	(11.77)**
CLIB	−.22E-02	−.54E-01	−.29E-01	−.22E-01	−.13E-01	.49E-02	−.54E-01	−.25E-01	−.18E-01
	(.20E-01)	(.101)	(.53E-01)	(.49E-01)	(.32E-01)	(.14E-01)	(.101)	(.47E-01)	(.43E-01)
CSOC	.32E-01	.145	.79E-01	.69E-01	.52E-01	.27E-01	.145	.69E-01	.60E-01
	(.19E-01)*	(.95E-01)	(.49E-01)	(.46E-01)	(.30E-01)*	(.13E-01)*	(.95E-01)	(.44E-01)	(.40E-01)
HEDUC	.36E-02	.23E-01	.13E-01	.12E-01	.77E-02	.26E-02	.23E-01	.11E-01	.11E-01
	(.27E-02)	(.13E-01)*	(.71E-02)*	(.66E-02)*	(.43E-02)*	(.18E-02)*	(.13E-01)*	(.63E-02)*	(.57E-02)*
LogL	−23.69	−282.39	−182.71	−172.65	−94.95	33.01	−282.39	−164.87	−151.02

*Significant at the 10% level.
**Significant at the 5% level.

The tax price (HTAX) has a positive and mostly significant impact, consistent with the interpretation given above. The per capita block grant variable (GRANT) yields a negative coefficient. Interpreting this result literally suggests that grants may not only encourage local service provision, but that they also stimulate technical inefficiency. The income variable (INCOME) yields a significantly negative coefficient, consistent with the interpretation of this variable as affecting both politicians' and taxpayers' incentives to monitor local expenditures. The estimates further suggest that the presence of the liberals (CLIB) tends to decrease technical efficiency, while the socialist party (CSOC) seems to have a positive effect. Although several of the political dummies are estimated to be statistically insignificant it is interesting to note that similar results were found for Belgian national government expenditure and tax policies [see De Grauwe (1985)].[21] Finally, the education variable has consistently the expected positive sign, and is significant in the case of the three different nonradial efficiency measures.[22]

Comparing the estimates for the various efficiency measures obviously reveals some quantitative differences in coefficients. First, the similarity between the Russell and Zieschang measures and the dissimilarity between the radial and the asymmetric Färe measures are confirmed in the parameter estimates. Secondly, the effect of measurement orientations shows up in the relative magnitudes of the coefficients. For instance, the similarity between the Russell and the Zieschang equations is stronger within a given orientation than between orientations. Qualitatively, however, observe that all parameters of the explanatory variables have consistently the same sign across all equations. The significance levels of the most important variables are quite similar as well.

It is clear that if one restricts the comparison to the nonradial measures the general qualitative conclusions do not differ substantially. However, some differences in interpretation do exist if one compares the radial versus the nonradial measures. For instance, somewhat different conclusions with regard to the impact of the tax rate and the education variable would emerge from the radial measure in comparison with its alternatives. Solely relying on the Debreu-Farrell efficiency measure could suggest that these variables do not have any significant impact. The other measures do yield statistically significant effects. Therefore, although the results with respect to the nonradial measures are remarkably robust, this robustness does not apply to the same extent if one compares the Debreu-Farrell efficiency indexes with the nonradial measures.

Summarizing the empirical results leads to the following conclusions. First, the various measures were found to imply substantially different rankings of municipalities. Second, the explanatory analysis suggest the importance of carefully checking the robustness of the results with respect to different definitions of inefficiency. Given these findings and the theoretical arguments mentioned above the traditional emphasis on radial measurement in the empirical literature may not be entirely warranted. In addition, the analysis illustrates the effect of choosing among different measurement orientations.

6. Conclusions

The purpose of this paper was twofold. First, based on the free disposal hull (FDH) reference technology we compared a variety of radial and nonradial measures of productive efficiency using a data set of 589 Belgian local governments. The FDH technology was selected because it makes minimal assumptions with respect to the production technology and is relatively easy to implement. The importance of the choice of technical efficiency measures was argued from a theoretical perspective and three alternatives to the classical radial measure were discussed. Specifically, apart from the radial Debreu-Farrell measure, indices proposed by Russell, Zieschang and Färe were defined and implemented. Second, within the framework of a censored regression model we checked whether these different measures made any difference in the explanation of inefficiencies. To investigate this issue a Tobit analysis was performed relating the inefficiencies to a number of economic, social and political characteristics of the municipalities, while in addition controlling for the choice of measurement orientation.

Two types of results emerged from the empirical analysis. First, there are indications that depending on the efficiency index used substantial differences in the ranking of individual observations are possible. It was found that the differences in ranking between radial and nonradial measures were more pronounced than those among the nonradial alternatives. As was to be expected, for any given efficiency measure the differences between orientations of measurement are substantial. Second, some evidence was found that the fiscal revenue capacity and the per capita block grant are important determinants of efficiency. The financing mechanism of local public service provision and to a lesser extent the political characteristics of municipal governments were also estimated to affect inefficiencies. Although the qualitative results were indicated to be fairly robust for the various nonradial inefficiency measures, the same degree of robustness did not apply to the comparison of the radial measure with its nonradial alternatives. Although these results need to be confirmed by further empirical research, both the theoretical arguments and the empirical analysis presented here suggest the need to at least carefully consider alternatives to the usual radial measure.

Appendix A: Input and Graph Oriented Efficiency Measures

We shortly review the input-based efficiency measures which are very similar to their output counterparts in the main text, except that the former are defined on the interval (0, 1] relative to the input correspondence of the technology $L(y)$ [see Färe, Grosskopf and Lovell (1994) for details]. The input-based radial measure of technical efficiency is given by:

$$DF_i(x, y) = \min\{\lambda \mid \lambda \geq 0, \lambda x \in L(y)\}.$$

The Russell input measure of technical efficiency is:

$$R_i(x, y) = \min\left\{ \sum_{i=1}^{m} \lambda_i/m \mid (\lambda_1 x_1, \ldots, \lambda_m x_m) \in L(y), \lambda_i \in (0, 1] \right\}.$$

Zieschang's input measure of technical efficiency is:

$$Z_i(x, y) = R_i(x \cdot DF_i^+(x, y), y) \cdot DF_i^+(x, y)$$

where $DF_i^+(x, y) = \min\{\lambda \mid \lambda \geq 0, \lambda x \in L^+(y) = L(y) + \mathbb{R}_+^m\}$.

Finally, the asymmetric Färe input measure of technical efficiency is defined as:

$$AF_i(x, y) = \min_{j=1,\ldots,m}\{AF_i^j(x, y)\}$$

where for each j: $AF_i^j(x, y) = \min\{\lambda_j \mid (x_1, \ldots, \lambda_j x_j, \ldots, x_m) \in L(y)\}$.

The graph versions of these four efficiency measures are straightforward generalizations of the previous definitions which attempt to decrease inputs and increase outputs simultaneously. These measures are defined relative to the graph of the input and the output correspondences GR and are again defined on the interval (0, 1] [see Färe, Grosskopf and Lovell (1994)]. The Debreu-Farrell graph measure of efficiency is:

$$DF_g(x, y) = \min\{\lambda \mid \lambda \geq 0, (\lambda x, \lambda^{-1}y) \in \text{GR}\}.$$

The Russell graph measure is:

$$R_g(x, y) = \min\left\{\left[\sum_{i=1}^{m}\lambda_i + \sum_{j=1}^{n}\mu_j\right]/(m+n) \mid (\lambda_1 x_1, \ldots, \lambda_m x_m, \mu_1^{-1}y_1, \ldots, \mu_n^{-1}y_n) \in GR, \lambda_i, \mu_j \in (0, 1]\right\}.$$

The Zieschang graph measure is:

$$Z_g(x, y) = R_g(x \cdot DF_g^+(x, y), y \cdot DF_g^+(x, y)^{-1}) \cdot DF_g^+(x, y)$$

where $DF_g^+(x, y) = \min\{\lambda \mid \lambda \geq 0, (\lambda x, \lambda^{-1}y) \in \text{GR}^+\}$,

where GR^+ is the graph of a technology satisfying strong input and output disposability. Finally, the asymmetric Färe graph measure of technical efficiency is given by:

$$AF_g(x, y) = \min_{j=1,\ldots,m+n}\{AF_g^j(x, y)\}$$

where for each $j = 1, \ldots, m$:

$$AF_g^j(x, y) = \min\{\lambda_m \mid (x_1, \ldots, \lambda_j x_j, \ldots, x_m, y_1, \ldots, y_n) \in GR\},$$

and for each $j = m + 1, \ldots, m + n$:

$$AF_g^j(x, y) = \min\{\mu_n \mid (x_1, \ldots, x_m, y_1, \ldots, \mu_j^{-1}y_j, \ldots, y_n) \in GR\},$$

and $\lambda_j \in (0, 1]$ for $j = 1, \ldots, m$ and $\mu_j^{-1} \in (0, 1]$ for $j = m + 1, \ldots, m + n$.

Appendix B: Tobit Results for the Complete Sample

Tobit estimates for the complete sample are reported in Table B.1. Comparing the results on the complete sample and on the limited sample shows that there are no changes in the

Table B.1. Tobit results for the efficiency measures ($N = 589$).

	$DF_o(x, y)$	$AF_o(x, y)$	$R_o(x, y)$	$Z_o(x, y)$	$DF_i(x, y)$	$DF_g(x, y)$	$AF_g(x, y)$	$R_g(x, y)$	$Z_g(x, y)$
CONSTANT	1.209	2.014	1.537	1.519	1.371	1.147	2.014	1.491	1.456
	(.091)**	(.513)**	(.267)**	(.250)**	(.149)**	(.062)**	(.513)**	(.239)**	(.219)**
HTAX	.36E-04	.25E-03	.13E-03	.12E-03	.52E-04	.22E-04	.25E-03	.12E-03	.10E-03
	(.20E-04)*	(.12E-03)**	(.62E-04)**	(.58E-04)**	(.34E-04)	(.14E-04)	(.12E-03)**	(.55E-04)**	(.51E-04)**
INCOME	−.12E-02	−.66E-02	−.35E-02	−.33E-02	−.20E-02	−.82E-03	−.66E-02	−.31E-02	−.29E-02
	(.55E-03)**	(.31E-02)**	(.16E-02)**	(.15E-02)**	(.90E-03)**	(.38E-03)**	(.31E-02)**	(.14E-02)**	(.13E-02)**
GRANTS	−1.168	−8.982	−6.649	−5.239	−4.049	−.955	−8.982	−5.905	−5.728
	(3.87)	(21.74)	(11.29)	(10.56)	(6.234)	(2.654)	(21.74)	(10.05)	(9.190)
CLIB	.12E-02	−.25E-01	−.13E-01	−.86E-02	−.37E-02	.56E-02	−.25E-01	−.10E-01	−.64E-02
	(.21E-01)	(.120)	(.63E-01)	(.59E-01)	(.35E-01)	(.15E-01)	(.120)	(.56E-01)	(.51E-01)
CSOC	.24E-01	.110	.60E-01	.52E-01	.38E-01	.19E-01	.110	.52E-01	.47E-01
	(.20E-01)	(.113)	(.60E-01)	(.55E-01)	(.33E-01)	(.14E-01)	(.113)	(.53E-01)	(.48E-01)
HEDUC	.35E-02	.23E-01	.13E-01	.11E-01	.67E-02	.25E-02	.23E-01	.11E-01	.10E-01
	(.28E-02)	(.16E-01)	(.83E-02)	(.78E-02)	(.46E-02)	(.19E-02)	(.16E-01)	(.74E-02)	(.68E-02)
LogL	−138.30	−411.09	−312.23	−301.67	−215.36	−81.05	−411.09	−294.87	−281.70

*Significant at the 10% level.
**Significant at the 5% level.

signs of the estimates. Furthermore, it reveals that the significance levels drop for some of the explanatory variables, such as, for instance, the political variables. The latter finding is consistent with our interpretation that the efficiency status of these observations, which neither dominate nor are dominated, is unclear.

Notes

1. See Grosskopf (1986) and Seiford and Thrall (1990) for a review of DEA-reference technologies and their assumptions; Tulkens (1993) carefully reviews the FDH approach. An analysis of efficiency and productivity issues in DEA and FDH is found in Tulkens and Vanden Eeckaut (1995). Note that the assumptions postulated in the nonparametric literature are generally less restrictive than those used in the parametric approaches.
2. Note that these strong disposability assumptions preclude backward bending isoquants. Therefore, FDH may not be appropriate when congestion is present.
3. Alternatively, we can define the FDH in terms of the input correspondence, or in terms of the graph of input and output correspondences. These definitions are generally equivalent. In principle, the choice of measurement orientation is independent of the definition of technology [see Färe, Grosskopf and Lovell (1994)].
4. Vector inequality conventions: $x \geq y$ if and only if $x_i \geq y_i$ for all i; $x \geq \mathfrak{y}$ if and only if $x_i \geq y_i$ for all i and $x \neq y$; $x > y$ if and only if $x_i > y_i$ for all i; and $x >^* y$ if and only if either $x_i > y_i$ or $x_i = y_i = 0$ for all i.
5. Also note that in principle an observation can be efficient without belonging to the efficient subset. For instance, in Figure 1 it can be seen that observation 6 belongs to the isoquant and is denoted as efficient because it cannot be radially expanded. This observation does not belong to the efficient subset.
6. Koopmans (1951) actually insists on a simultaneous membership in the efficient subsets of both the input and the output correspondence. On this issue, see also Lovell (1993: 13) and Section 4 below.
7. The name Russell measure was suggested in Färe and Lovell (1978). We use the same name to avoid confusion. Also note that the asymmetric Färe measure is also known as the overall asymmetric measure of technical efficiency [see Färe, Lovell and Zieschang (1983)].
8. The efficiency measures are defined for strictly positive input and output vectors. For semipositive input and output vectors the definitions must be somewhat adapted: see Färe, Lovell and Zieschang (1983) for details.
9. See Kerstens and Vanden Eeckaut (1995) for details.
10. Additional arguments on the use of efficiency measures are found in Lovell and Schmidt (1988) and Lovell (1993). Furthermore, it has recently been pointed out that the radial measure is vulnerable to manipulation as it cannot reveal more inefficiency when dimensions are added to the analysis [Thrall (1989); see De Borger, Ferrier and Kerstens (1995) for an empirical illustration]. An up to date review is found in Kerstens and Vanden Eeckaut (1995).
11. It turns out that none of the proposed measures can ever satisfy all four axioms simultaneously for the broad class of technologies considered [see, e.g., Bol (1986) and Russell (1988)]. Of course, despite this finding still other desirable features of efficiency measures have been suggested in the literature, e.g., invariance to units of measurement. The latter may be especially important in empirical work.
12. Recently, nonradial efficiency measures have been applied to U.S. banking data: see De Borger, Ferrier and Kerstens (1995) for an application using FDH, and Ferrier, Kerstens and Vanden Eeckaut (1994) for an application on DEA. Note that these studies make no attempt to explain measured inefficiencies.
13. Vanden Eeckaut and Tulkens (1989) and Vanden Eeckaut, Tulkens and Jamar (1993) previously reported FDH-results for the subset of Walloon municipalities, and De Borger et al. (1994) applied FDH for all Belgian municipalities. Note, however, that all these papers were restricted to radial efficiency evaluation.
14. The source of the data is a more elaborate database on municipalities constructed at the research institute CADEPS (Free University of Brussels) on the basis of information from the Nationaal Instituut voor de Statistiek (NIS) and from the Gemeentekrediet van België (GKB). Note that our study uses to some extent different output indicators from the ones used by Vanden Eeckaut, Tulkens and Jamar (1993). While beneficiaries of minimal subsistence grants, students, total population and people aged 65 and above are common to both analyses, we use public recreational surface and road surface whereas they use the crime rate and road length.

We prefer the former variables because we feel that they are more direct indicators than the latter variables (but this may be open for discussion). Furthermore, most of our data refer to the fiscal year 1985 while Vanden Eeckaut, Tulkens and Jamar (1993) use 1986 figures (with one exception).

15. This is also the main motivation for the cost indirect output correspondence presented in Färe, Grosskopf and Lovell (1994). Note that in the case of identical input prices the latter is, except for the integer constraints, formally analogous to the model based on costs and outputs considered here.
16. Actually, since Koopmans (1951) insisted that technical efficiency requires membership in the efficient subsets of both the input and the output correspondence, one can argue that graph oriented measurement should be given priority (see footnote 6 above). Recently, Atkinson and Cornwell (1994) also pleaded for a careful consideration of the choice of orientation in a stochastic, parametric frontier context with panel data.
17. For example, the output-oriented Debreu-Farrell measure becomes:

$$DF_o^*(x, y) = \min\{\theta' | 0 < \theta' \leq 1, y/\theta' \in P(x)\}.$$

The other output efficiency measures can be likewise adapted.

18. Similarly, in DEA there exist observations which are efficient, but which are never in the basis of any inefficient observation.
19. Including the observations declared *efficient by default* did not have any impact on the signs of the explanatory variables; only the numerical values of the parameter estimates and their significance levels were somewhat affected for some variables. The Tobit results for the complete sample are presented in Appendix B.
20. There is no claim that our list of explanatory variables is complete. For instance, it has been argued that the degree of unionization of municipal personnel, the possibility to obtain certain publicly provided goods from private suppliers, and the public sector's tendency toward an excessively large bureaucracy may enhance technical efficiency [see Bartel and Schneider (1991), Boardman and Vining (1989), and Niskanen (1974)]. Unfortunately, no information concerning these potential determinants was available.
21. The number of coalition partners (CPAR) did not have the expected sign and was totally insignificant. It was not included in the reported specifications.
22. We also included dummy variables for the Walloon (REG1) and the Brussels (REG2) region in a previous version of the paper. Given the federalist structure of the Belgian State such dummies are common in studies of Belgian government expenditures. However, the results never indicated statistically significant regional differences in performance. Therefore, the regional dummy variables were not included in the final specifications.

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