Theory matters! Efficiency measurement and water utilities

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Abstract As is the case of other infrastructure sectors the availability of efficiency estimation software based on statistical inference – freely distributed via the internet and relatively easy to use – recently inflated the number of corresponding applications in the water sector. The robustness of regulatory measures based on inferences from efficiency measures nevertheless crucially depends on theoretically well-founded estimates. This is illustrated by using an empirical example of an inconsistent technical efficiency frontier for water utilities in Germany.

Keywords Efficiency measurement; microeconomic theory; water utilities

Introduction
Besides scarce water resources, water supplying companies in international water sectors are exposed to decreasing financial resources. Increasing investment needs as well as declining water consumption rank the question for the economic performance of the individual supplier first with respect to scientific observers. Stochastic frontier analysis presents a statistical tool to detect the different forms of efficiency for an individual production unit. It is now widely applied in international studies on water utilities by regressing on freely available econometric ‘black-box software’. The application of the econometric methods provided by these ‘black box’-tools are rarely accompanied by a thorough theoretical interpretation. The estimation results are further used without a critical assessment with respect to the literature on theoretical consistency, flexibility and the choice of the appropriate functional form. The robustness of policy suggestions based on inferences from efficiency measures nevertheless crucially depends on proper estimates. Most applications, however, do not adequately test for whether the estimated function has the required regularities, and hence run the risk of making improper policy recommendations. This contribution discusses crucial implications and exemplifies this by using data on rural water suppliers in Germany.

The magic triangle: theoretical consistency, functional flexibility and domain of applicability
One of the essential objectives of empirical research is the investigation of the relationship between an endogenous (or dependent) variable $y$ and a set $i$ of exogenous (or independent) variables $x_{ij}$ where subscript $j$ denotes the $j$-th observation:

$$y_j = f(x_{ij}, \beta_i) + e_j$$

In general, the researcher has to make two basic assumptions with regard to the examination of this relationship. The first assumption specifies the functional form expressing the endogenous variable as a function of the exogenous variables. The second assumption specifies a probability distribution for the residual $e$ capturing the difference between the actual and the predicted values of the endogenous variable. These two major assumptions about the underlying functional form and the probability distribution of the error term are...
usually considered as maintained hypotheses (Fuss and McFadden, 1978). Statistical procedures such as maximum likelihood estimation are used to estimate the relationship, i.e. the vector of the parameters $\beta_i$.

**Lau’s criteria**

In general, economic theory provides no a priori guidance with respect to the functional relationships. However, Lau (1986) has formulated some principle criteria for the ex ante selection of an algebraic form with respect to a particular economic relationship.

*Theoretical consistency.* The algebraic functional form chosen must be capable of possessing all of the theoretical properties required by the particular economic relationship for an appropriate choice of parameters. With respect to a production possibility set this would mean that the relationship in (1) is single valued, monotone increasing as well as quasi-concave implying that the input set is required to be convex. However, this indicates no particular functional form.

*Domain of applicability.* Most commonly the domain of applicability refers to the set of values of the independent variables $x_i$ over which the algebraic functional form satisfies all the requirements for theoretical consistency. If, for given $\beta$, the algebraic functional form $f(x_i, \beta)$ is theoretically consistent over the whole of the applicable domain, it is said to be globally theoretically consistent or globally valid over the whole of the applicable domain.

*Flexibility.* A flexible algebraic functional form is able to approximate arbitrary but theoretically consistent economic behaviour through an appropriate choice of the parameters. The production function in (1) can be said to be second-order flexible if at any given set of non-negative (positive) inputs the parameters $\beta$ can be chosen so that the derived input demand functions and the derived elasticities are capable of assuming arbitrary values at the given set of inputs subject only to theoretical consistency.

*Computational facility.* This criterion implies the properties of ‘linearity-in-parameters’, ‘explicit representability’, ‘uniformity’ and ‘parsimony’. For estimation purposes the functional form should therefore be linear-in-parameters, possible restrictions should be linear. With respect to the ease of manipulation and calculation the functional form as well as any input demand functions derivable from it should be represented in explicit closed form and linear in parameters. Different functions in the same system should have the same ‘uniform’ algebraic form but differ in parameters. In order to achieve a desired degree of flexibility the functional form should be parsimonious with respect to the number of parameters. This to avoid methodological problems such as multi-collinearity and a loss of degrees of freedom.

*Factual conformity.* The functional form should be finally consistent with established empirical facts with respect to the economic problem to be modelled.

**The concept of flexibility**

It is important to have a more detailed look at the concept of flexibility. A functional form can be denoted as ‘flexible’ if its shape is only restricted by theoretical consistency. This implies the absence of unwanted a priori restrictions and is paraphrased by the metaphor of ‘providing an exhaustive characterization of all (economically) relevant aspects
of a technology’ (Fuss and McFadden, 1978). Each relevant aspect of the concept of second order flexibility is assigned to exactly one parameter: the level parameter, the gradient parameters associated with the respective first order variable, and the Hessian-parameters associated with the second order terms. Hence a valid flexible functional form must contain at least $1/2(n + 2)(n + 1)$ independent parameters. Finally it has been shown that the function value as well as the first and second derivatives of a primal function can be approximated as well by the dual behavioural representation of the same technology.

**The magic triangle**

Hence, it is evident that the quality of the estimation results crucially depends on the choice of the functional form. The latter has to be chosen so that:

- it provides all economically relevant information about the economic relationship(s) investigated,
- it shows a priori consistency with the relevant economic theory on producer behaviour to the greatest possible extent,
- it includes no, or as few as possible, unwanted a priori restrictions, i.e. is flexible,
- it is relatively easy to estimate,
- it is parsimonious in parameters,
- it is robust towards changes in variables with respect to intra- as well as extrapolation, and
- it finally includes parameters which are easy to interpret.

However, as was already noted by Lau, one should not expect to find an algebraic functional form satisfying all of these criteria (in general cited as Lau’s ‘incompatibility theorem’). As one should not compromise on (at least) local theoretical consistency, computational facility or flexibility of the functional form, he suggests the domain of applicability as the only area left for compromises with respect to functional choice. Hence, even if a functional form is not globally theoretically consistent, it can be accommodated to be theoretically consistent within a sufficiently large subset of the space of independent variables. Even so it has to be stressed that the surest way to obtain a theoretically consistent representation of the technology is to make use of a dual concept such as the profit, cost or revenue function. It can be summarized that for most functional forms there is a fundamental trade-off between flexibility and theoretical consistency as well as the domain of applicability. Production economists propose two solutions to this problem, depending on what kind of violation shows to be more severe (Lau, 1986; Chambers, 1988):

- the choice of functional forms which could be made globally theoretically consistent by corresponding parameter restrictions; here the range of flexibility has to be investigated;
- to opt for functional flexibility and check or impose theoretically consistency for the proximity of an approximation point only (usually at the sample mean).

However, a globally theoretically consistent as well as flexible functional form can be considered as an adequate representation of the production possibility set. Locally theoretically consistent as well as flexible functional forms can be considered as an $i$-th order differential approximation of the true production possibilities. Hence, the translog function is considered as a second order differential approximation of the true production possibilities.

**The case of the translog production function**

A prominent textbook example as well as the most often used functional form with respect to efficiency measurement is the Cobb–Douglas production function:

$$\ln y = \alpha_o + \sum_{i=1}^n \alpha_i \ln x_i$$

(2)
This function shows theoretical consistency globally if \( \alpha_i = 0 \), but fails with respect to flexibility as there are only \((n - 1)\) free parameters. Similarly often used with respect to stochastic efficiency measurement the translog production function has to be noted:

\[
f(x) = \alpha_o + \sum_{i=1}^{n} \alpha_i \ln x_i + 1/2 \sum_{j=1}^{n} \alpha_{ij} \ln x_i \ln x_j
\]

where symmetry of all Hessians by Young’s theorem implies that \( \alpha_{ij} = \alpha_{ji} \). It has \((n^2 + 3n + 2)/2\) distinct parameters and hence just as many as required to be flexible. By setting \( A_{ij} = \sum_{j=1}^{n} \alpha_{ij} \) equal to a null matrix reveals that the translog function is a generalization of the Cobb Douglas functional form. The theoretical properties of the second order translog are well known (Lau, 1986): it is easily restrictable for global homogeneity as well as homotheticity, correct curvature can be implemented only locally if local flexibility should be preserved, the maintaining of global monotonicity is impossible without losing second order flexibility. Hence, the translog functional form is fraught with the problem that theoretical consistency can not be imposed globally. This is subsequently shown by discussing the theoretical requirements of monotonicity and curvature.

**Monotonicity**

As is well known with respect to a (single output) production function monotonicity requires positive marginal products with respect to all inputs:

\[
\frac{\partial y}{\partial x_i} > 0
\]

and thus non-negative elasticities. However, until most recent studies showed that the monotonicity requirement is by no means automatically satisfied for most functional forms, moreover violations are frequent and empirically meaningful, the issue of assuring monotonicity was neglected. In the case of the translog production function the marginal product of input \( i \) is obtained by multiplying the logarithmic marginal product with the average product of input \( i \). Thus the monotonicity condition given in (4) holds for the translog specification if the following equation is positive:

\[
\frac{\partial y}{\partial x_i} = \frac{y(x)}{x_i} \ast \frac{\partial}{\partial y} \ln y \ln x_i = \frac{y(x)}{x_i} \ast (\alpha_i + \sum_{j=1}^{n} \alpha_{ij} \ln x_i) > 0
\]

Since both \( y \) and \( x_i \) are positive numbers, monotonicity depends on the sign of the term in parenthesis, i.e. the elasticity of \( y \) with respect to \( x_i \). If it is assumed that markets are competitive and factors of production are paid their marginal products, the term in parenthesis equals the input \( i \)’s share of total output, \( s_i \). By adhering to the law of diminishing marginal productivities, marginal products, apart from being positive, should be decreasing in inputs implying the fulfillment of the following expression:

\[
\frac{\partial^2 y}{\partial x_i^2} = [\alpha_{ii} + (\alpha_i - 1 + \sum_{j=1}^{n} \alpha_{ij} \ln x_j) \ast (\alpha_i + \sum_{j=1}^{n} \alpha_{ij} \ln x_j)](y/x_i) < 0
\]

Again, this depends on the nature of the terms in parenthesis. These should be checked a posteriori by using the estimated parameters for each data point. However, both restrictions (i.e. \( \frac{\partial y}{\partial x_i} > 0 \) and \( \frac{\partial^2 y}{\partial x_i^2} < 0 \)) should hold at least at the point of approximation.

**Curvature**

Whereas the first order and therefore non-flexible derivative of the translog, the Cobb–Douglas production function, can easily be restricted to global quasi-concavity by imposing \( \alpha_i \geq 0 \), this is not the case with the translog itself. The necessary and sufficient condition for a specific curvature consists in the semi-definiteness of its bordered Hessian matrix as the Jacobian of the derivatives \( \frac{\partial y}{\partial x_i} \) with respect to \( x_i \); if \( \nabla^2 Y(x) \) is negatively semi-definite, \( Y \) is quasi-concave, where \( \nabla^2 \) denotes the matrix of second order partial derivatives with respect to \( \partial \). The conditions of quasi-concavity are related to the fact that
this property implies a convex input requirement set (Chambers, 1988). Hence, a point on
the isoquant is tested, i.e. the properties of the corresponding production function are eval-
uated subject to the condition that the amount of production remains constant. Hence, con-
trary to the Cobb–Douglas function, quasi-concavity can not be checked for by simply
considering the parameter estimates. A matrix is negative semi-definite if the determinants
of all of its principal submatrices are alternate in sign, starting with a negative one (i.e.
\((-1)^k D_k \geq 0\) where D is the determinant of the leading principal minors and
\(k = 1, 2, \ldots, n\)). However, this criterion is only rationally applicable with respect to
matrices up to the format \(3 \times 3\), the most operational way of testing square numerical
matrices for semi-definiteness is the eigen - or spectral decomposition. Following this pro-
cedure the magnitude of the \(m + n\) eigenvalues of the bordered Hessian have to be deter-
mined. With respect to the translog production function curvature depends on the input
bundle, as the corresponding bordered Hessian BH for the 3 input case shows:

\[
BH = \begin{pmatrix}
0 & f_1 & f_2 & f_3 \\
f_1 & f_{11} & f_{12} & f_{13} \\
f_2 & f_{21} & f_{22} & f_{23} \\
f_3 & f_{31} & f_{32} & f_{33}
\end{pmatrix}
\]

(7)

where,

- \(f_i\): given in (5),
- \(f_{ii}\): given in (6), and
- \(f_{ij}\): is

\[
\frac{\partial^2 y}{\partial x_i \partial x_j} = [\alpha_j + (\alpha_i + \sum_{j=1}^{m} \alpha_{ij} \ln x_j)] \ast [\alpha_j + \sum_{i=1}^{m} \alpha_{ji} \ln x_j] \ast (y/x_i x_j) < 0
\]

(8)

For some bundles quasi-concavity may be satisfied but for others not and hence what can
be expected is that the condition of negative-semidefiniteness of the bordered Hessian is
met only locally or with respect to a range of bundles. As the translog function consists
of quadratic terms it shows a parabolic form implying increasing as well as decreasing
branches by definition causing inconsistencies regarding the monotonicity requirement
\((\partial y/\partial x_i > 0)\). Further violations of the curvature condition are caused by the logarithmic
transformation of input variables. All functional forms showing these properties are
finally subject to possible violations of their theoretical consistency.

**Theoretical consistency and flexibility**

The preceding discussion hence shows that there is a trade-off between flexibility and
theoretical consistency with respect to the translog as well as most flexible functional
forms. Economists propose different solutions to this problem: a) Imposing globally
theoretical consistency destroys the flexibility of the translog as well as other second-
order flexible functional forms, as e.g. the generalized Leontief. However, theoretical
consistency can be locally imposed on these forms by maintaining their functional flexi-
bility. Further, Ryan and Wales (2000) even argue that a sophisticated choice of the refer-
ence point could lead to satisfaction of consistency at most or even all data points in the
sample. Jorgenson and Fraumeni (1981) firstly propose the imposition of quasi-concavity
through restricting \(A\) to be a negative semidefinite matrix. However, by imposing global
consistency on the translog functional form Dievert and Wales (1987) note that the
parameter matrix is restricted leading to seriously biased elasticity estimates. Hence, the
translog function would lead its flexibility. b) Functional forms can be chosen which
could be made globally theoretically consistent through corresponding parameter restric-
tions and by simultaneously maintaining flexibility. This is shown for the symmetric
generalized McFadden cost function by Diewert and Wales (1987) following a technique initially proposed by Wiley et al. (1973). Like the generalized Leontief, the symmetric generalized McFadden is linearly homogenous in prices by construction, monotonicity can either be implemented locally only or, if restricted for globally, the global second-order flexibility is lost. However, if this functional form is restricted for correct curvature the curvature property applies globally. Furthermore regular regions following Gallant and Gollup (1984) numerical approach to account for consistency by using, e.g., Bayesian techniques can be constructed with respect to flexible functional forms.

Implications for stochastic efficiency measurement

In recent years a shift of the research focus in production economics can be observed. No longer the structure and change of the production possibilities is of primary interest but the technical and allocative efficiency of netput bundles. A typical representation of the production possibilities is given by the production frontier:

$$y = f(x) - \varepsilon, \text{ with } 0 < \varepsilon < \infty$$

This trend is accompanied by a shift in the interpretation insofar as the estimated results are not interpreted for the approximation point but for all input values. This is a necessary consequence of the shift of the research focus. While it is possible to investigate the structure of the production possibilities at any virtual production plan, efficiency considerations can only be performed for the individual observations. However, this in turn requires that the properties of the production function have to be investigated for every observable netput vector. The consequences of a violation of theoretical consistency for the relative efficiency evaluation will be discussed using Figures 1 and 2 by showing the effect on the random error term.

As becomes clear the estimated relative inefficiency equals the relative inefficiency for the production unit A with respect to the real production function. As the estimated function violates the monotonicity criteria for parts of the function the estimated relative inefficiency of production unit B understates the real inefficiency for this observation. The same holds for production unit C which actually lies on the real production frontier, whereas the estimated relative inefficiency for production unit D again understates the real inefficiency. Figure 2 shows the implications as a result of irregular curvature of the estimated efficiency frontier. The dotted line describes an isoquant of the estimated production function. The relative inefficiency of the input combination at production unit B measured against the estimated frontier (at B') understates the real inefficiency which is obtained by measuring the input combination against the real production frontier at point A.
Observation A lies on the estimated isoquant and is therefore measured as full efficient (point A). Nevertheless this production unit produces relatively inefficient with respect to the real production frontier (see point A\(^0\)). The same holds for production unit D (real inefficiency has to be measured at point D\(^0\)). Finally relative inefficiency of observation C detected at the estimated frontier (C\(^0\)) corresponds to real inefficiency for this production unit as the estimated frontier is theoretically consistent. The graphical discussion clearly shows the implications for efficiency measurement: theoretically inconsistent frontiers over- or understate real relative inefficiency and hence lead to severe misperceptions and finally inadequate as well as counterproductive policy measures with respect to the individual production unit in question. However, a few applications exist considering the need for theoretically consistent frontier estimation: e.g. Pierani and Rizzi (2001), Christopoulos et al. (2001), Craig (2002) as well as Sauer and Frohberg (2005) estimated a symmetric generalized McFadden cost frontier by imposing concavity and checking for monotonicity. Here global curvature correctness is assured by maintaining functional flexibility. O’Donnell (2002) applies Bayesian methodology to impose regularity constraints on a system of equations derived from a translog shadow cost frontier. However, the vast majority of existing efficiency studies use the error components approach by applying an inflexible Cobb–Douglas production function or a flexible translog production function without checking or imposing monotonicity as well as quasi-concavity requirements.

### Theoretically inconsistent efficiency estimates – the case of rural Germany

Water supplying firms in rural areas of East and West Germany extract, treat, transport and distribute potable water and are increasingly restricted by scarce raw water resources as well as tight financial budgets. They are basically subject to the regulatory constraints set by the legal framework of the water market. To exemplify the validity of our concerns we determine a stochastic production frontier by using the mainstream error-components approach and applying a single-product translog function, using the variable inputs labour, energy and chemicals:

\[
\ln y_i = \beta_0 + \alpha_{ni} \ln x_{ni} + 1/2 \sum_n \sum_k \beta_{nk} \ln x_{ni} \ln x_{ki} + \gamma_i \ln z_i + \nu_i + u_i \quad (10)
\]

where,

- \(y\): denotes water output,
- \(x_{ni}\): is the respective input,
- \(z\): denotes the quasi-fixed input equity capital,
as the traditional error component, 
$\nu$: for the non-negative inefficiency component, 
$I$: stands for the $i$-th supplier in the sample and $n$, 
k: denotes the various inputs used.

Symmetry and linear homogeneity are imposed by constraining (10) to:

$$\beta_{nk} = \beta_{kn} \text{ and } \Sigma_{\alpha}a_{\alpha} = 1, \Sigma_{\alpha}\beta_{nk} = 0$$

By a one-step estimation approach the efficiency estimates were further related to the exogenous factors number of connections, net length and share of groundwater intake. The data used was collected by a survey among water suppliers in rural areas of East and West Germany for the financial year 2000/01 (Table 1).

To the background of the situation in the German water sector (Sauer, 2004) the efficiency scores for the individual suppliers seem to be plausible. They are shown in Figure 3. The technical efficiency scores range from 0.243 to 0.976 with an average technical efficiency of about 0.822. The parameter estimates of the translog frontier are mostly significant at the 1%-level of significance; the same holds for the inefficiency determining parameter. Following these empirical results a sector regulating authority would consequently apply a relatively more restrictive policy on utility no. 26 (technical efficiency score $= 24.3\%$) than on utility no. 35 (97.6%). However, by following the theoretical explanations made above

<table>
<thead>
<tr>
<th>Table 1 Descriptive statistics variables</th>
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<tbody>
<tr>
<td>Variable</td>
</tr>
<tr>
<td>Water output</td>
</tr>
<tr>
<td>Labour</td>
</tr>
<tr>
<td>Energy</td>
</tr>
<tr>
<td>Chemicals</td>
</tr>
<tr>
<td>Equity capital</td>
</tr>
<tr>
<td>Number of connections</td>
</tr>
<tr>
<td>Net length</td>
</tr>
<tr>
<td>Share of groundwater intake</td>
</tr>
</tbody>
</table>

Figure 3 Suppliers’ efficiency scores
Table 2 Exemplary inconsistent region observation 1–10 (out of 47)/numerical details

<table>
<thead>
<tr>
<th>Observation</th>
<th>Monotonicity first derivatives ((\frac{\partial y}{\partial x_i} &gt; 0))</th>
<th>Diminishing marginal productivity second derivatives ((\frac{\partial^2 y}{\partial x_i^2} &lt; 0))</th>
<th>Quasi–concavity Eigenvalues of bordered Hessian matrix ((E_i \leq 0))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Input 1</td>
<td>Input 2</td>
<td>Input 3</td>
</tr>
<tr>
<td>1</td>
<td>165,369.1</td>
<td>0.44848</td>
<td>-376.3206</td>
</tr>
<tr>
<td>2</td>
<td>73,972.25</td>
<td>0.50755</td>
<td>-98.59108</td>
</tr>
<tr>
<td>3</td>
<td>60,892.75</td>
<td>0.67822</td>
<td>-199.8471</td>
</tr>
<tr>
<td>4</td>
<td>10,403.53</td>
<td>1.39591</td>
<td>-1,025.754</td>
</tr>
<tr>
<td>5</td>
<td>89,984.23</td>
<td>0.62493</td>
<td>-168.6118</td>
</tr>
<tr>
<td>6</td>
<td>188,306</td>
<td>0.80621</td>
<td>-400.3169</td>
</tr>
<tr>
<td>7</td>
<td>34,159.02</td>
<td>0.44367</td>
<td>-362.5563</td>
</tr>
<tr>
<td>8</td>
<td>284,743.6</td>
<td>1.27367</td>
<td>-739.4977</td>
</tr>
<tr>
<td>9</td>
<td>74,187.42</td>
<td>1.08403</td>
<td>-176.434</td>
</tr>
<tr>
<td>10</td>
<td>70,033.88</td>
<td>0.50078</td>
<td>-57.41953</td>
</tr>
</tbody>
</table>

(bold – not consistent with economic theory)
and testing for monotonicity and quasi-concavity of the estimated function it became evident
that none of the estimated efficiency estimates are consistent with the underlying economic
principles (see Table 2 for exemplary test results and Sauer, 2004).

To make it clear: by imposing regulative constraints on the water suppliers the regulator
follows and calls for economic behaviour by the individual firm (i.e. cost minimisation or
output maximisation). But by using the relative estimates given above the regulator would
apply a standard which is itself not being based on these economic principles!

**Policy implications**

Whether there would be efficiency gains at all and if yes, how great such gains are if
regulatory measures would be imposed, cannot be answered by these (theoretically inconsis-
tent) results. If the estimated relative ‘efficiency position’ of a water supplier is at $P_1$
in **Figure 4** its estimated efficiency score (graphically the distance between $P_1$ and $P'_1$)
evidently understates its real relative inefficiency (graphically the distance between $P_1$
and $P_1^0$). If the estimated relative ‘efficiency position’ of a water supplier is at $P_2$ and
hence on the estimated frontier its estimated efficiency score does not account for its real
relative inefficiency (graphically the distance between $P_2$ and $P_2^0$). In both cases positive
efficiency effects by regulatory measures are much smaller in reality and hence performance
improvements of firms on average are also lower. If such improvements can be
linked to preceeding policy actions remains unclear and cannot be answered by such
results. The same holds with respect to the possibility of passing cost savings by suppliers
to the final water consumers via lower water prices. Global efficiency measures as e.g.
multivariate stochastic efficiency frontiers are superior to partial productivity indicators
(as e.g. input/output benchmarks) as long as they are adhering to the requirements by
economic theory. Regulatory measures based on theoretically consistent partial perform-
ance indicators are superior to efficiency estimates invalid because of theoretical inconsis-
tencies. Finally, it is true that the quality of the available data on a specific performance
measurement problem is crucial for the significance of the policy inferences made.
However, the specification of the efficiency model should be at first oriented at ensuring
that the production possibility set ensures the aforementioned requirements of monotoni-
city and quasi-concavity of the estimated efficiency frontier.

**Conclusion**

Existing black box estimation tools foster incorrect and unsound efficiency estimations
not only for water supplying firms. Such estimates lack theoretical consistency and hence
lead to inadequate and potentially counterproductive regulatory policy actions. The preceding discussion hence aims at highlighting the compelling need for a critical assessment of efficiency estimates with respect to the current evidence on theoretical consistency, flexibility as well as the choice of the appropriate functional form. The application of a flexible functional form as the translog specification by the majority of technical efficiency studies is adequate with respect to economic theory. However, most applications do not adequately test for whether the estimated function has the required regularities of monotonicity and quasi-concavity, and hence run the risk of making improper policy recommendations. The researcher has to check a posteriori for the regularity of the estimated frontier which means checking these requirements for each and every data point with respect to the translog specification. If these requirements do not hold they have to be imposed a priori to estimation as briefly outlined in the text. Furthermore one should always check for a possibility of using dual concepts such as the profit or cost function with respect to the efficiency measurement problem in question. The widespread practice of international organisations to encourage national authorities around the world to use such unreflected frontiers to design regulative policies (Coelli et al., 2003) is to be clearly branded as counterproductive and misleading.

References
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