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THE PERFORMANCE OF AUCTION HOUSES SELLING PICASSO PRINTS [*]

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Abstract. It has been observed that similar prints can obtain quite different prices at different auctions within the same auction period. Previous works applying hedonic price technique to determine the formation of auction prices of objects of art have found no conclusive result about the impact of auction houses on final prices. In these studies the object of art has been the unit, and influence of auction houses is analysed by testing whether auction house impact on price is significant or not within a framework of central tendencies. In order to focus on auction houses as a unit we have applied a benchmarking technique, DEA, developed for efficiency studies. Performance indexes are defined and calculated giving an insight into auction house differences difficult to obtain using hedonic price approach.

Key words: Performance, auction house, Picasso prints, hedonic price, benchmarking, best practice, DEA.

JEL classification: C61, D24, Z11.

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1. Introduction

An impression from the edition of 250 of the Picasso' first published print, *Le Repas Frugal*, was sold for 374,000 US dollars at Christie's New York in November, 1990. Two weeks later an impression of this print was sold at Christie's London for 189,980 US dollars. Hence, an intriguing question arises about whether there is a relationship between the price and the auction house where the work of art is sold.

There is some evidence on influence of auction houses in the literature. Pesando (1993), using information on repeat sales of identical prints, shows that there is a tendency for prices paid by buyers to be systematically higher at certain auction houses. In particular, prints sold at Sotheby's in New York perform average prices 14 per cent higher than the prices of identical prints sold at Christie's in New York for the period 1985-1992.

The only approach that has been developed so far to address this issue is the hedonic price technique. The hedonic price technique has been used extensively to investigate the investment value of visual art collectibles, such as paintings (Anderson (1974), Frey and Pommerehene (1989), Buelens and Ginsburgh (1993), Chanel et al. (1996), Agnello and Pierce (1999), Renneboog and Van Houtte (2002), Picci and Scorcu, 2002), prints (Pesando (1993) and Pesando and Shum, 1999), and sculptures (Locatelli-Biey and Zanola, 2002).

In the hedonic price model the influence on the auction price of single art objects of various variables is found by regressing the auction price on this set of variables regarded as determinants of price. The variables are both categorical variables, like reputation of artist, condition of object, style, provenance and exhibitions, authenticity (signed or not), medium, and continuous variables, like size measured in various ways. The auction house handling the art object is one of the categorical variables that have been used when trying to determine their influence (Czujack, 1997). The partial impact on price of each variable including characteristics or attributes are then associated with parameters of the estimated regression function.

However, the hedonic technique only represents an *indirect* approach to analyse the eventual existence of a relationship between price and auction house since it does not focus on the latter as unit of observation, but on the individual art object. An alternative way of addressing the performance of auction houses is to cast the auction house activity in a production setting: art objects of various characteristics are received as inputs and the auction prices obtained are then the outputs[1]. For a given set of art objects an auction house is performing better the higher the auction price is. In order to compare an auction house with the best performing ones and to estimate how much better results an auction house could have if it is as good as the best, a *benchmark* in the form of a *best practice* production function can be established[2]. One could argue that it is the general demand for the type of art object under investigation that determines the price and not the auction house. But data shows that even for the same year prices for similar art objects differ between auction houses, and concerning development over time one could claim that an auction house should advice a client as to when the client should sell or buy. The auction houses compete for customers. Art objects are not perishable goods! Predicting booms and through years may be considered as a part of being efficient[3].

The purpose of this paper is to systematically investigate auction house performance, what Pesando calls “noise”. We analyse one segment of the art market: the market for Picasso prints as drawn from auctions held during the period of sale 1988-1995 as registered in the 1995 edition of the Mayer International Auction Records on CD-ROM. We adapt a non-parametric model for calculating efficiency scores known in literature as the *DEA* model (see e.g. Coelli et al. (1999) for an introduction). The DEA model uses linear programming techniques to construct a non-parametric piecewise linear frontier. The frontier envelops all the observations as tight as possible, subject to some basic assumptions on the production technology. This approach provides insights into the performance differences hidden behind average price figures.

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[1] Notice that we do not model the service production proper of auction houses. For such an exercise the internal inputs such as labour of different skills, offices, etc., should be regarded, and some volume description of auctions formulated as outputs, e.g. number of art objects sold of various types, and also considering services such as evaluation and authentication.

[2] An alternative could be to focus on the difference between pre-auction estimates and realised prices as a source of inefficiency. However, pre-auction estimates are not readily available to us.

[3] However, a client may force an auction house to sell against its advice.

In so doing, however, we have to deal with the fact that the number of auction houses is quite lower than the number of art objects. This may lead to a potential problem of degrees of freedom. This implies that one may be forced to reduce the number of variables which are suggested to influence the sales price of items. Even if such omissions seem to waste information compared to the hedonic modeling method, the purpose here is to give a type of insight into auction house performances that the hedonic pricing method cannot accommodate. Furthermore, we only focus on Picasso prints which tend to be of similar quality and condition (Pesando, 1996), so that number of quality variables can be kept low.

The rest of the paper is organised as follows. In Section 2 we present the non-parametric benchmark model (DEA) used in this paper, and introduce some new measures of performance, building on outputs from efficiency- and productivity models. Data and choice of variables are described in Section 3. The results from applying the described methodology are presented in Section 4. Section 5 concludes.

2. The methodological approach

The basis for measuring performance of an auction house is to adapt a non-parametric model for calculating efficiency scores termed the *DEA* model. We will then cast the auction house activity in a production setting with sales of prints made by different techniques as outputs and the dimensional description and type of technique as inputs. The unit is an auction house observed for a sales period, i.e. an auction house is formally split into units for each period for which the house has sales. The “technology” of converting prints with physical descriptions into sales values is expressed by the following production possibility set:

$$S = \{(x, y) : \text{y can be produced by x}\} = \{(x, y) : \sum_{j=1}^{J} \lambda_j y_{mj} \geq y_m \forall m,\ x_n \geq \sum_{j=1}^{J} \lambda_j x_{nj}\ \forall n,\ \lambda_j \geq 0\ \forall j\} \quad (1)$$

where x is the input vector and y is the output vector. In the last expression defining the envelopment of data points, the J observations, indexed j, are introduced with an index m for type of output and index n for type of input. The variables l_j are non-negative weights or intensity variables defining points on the production surface. Constant returns to scale is assumed. Basic properties are that the production set is convex, includes all observed points and envelopment is done with minimum extrapolation, i.e. the fit is as "tight" as possible.

We see from the definition of production possibilities (1) that an observation (auction house activity for a specific period) may produce less than the maximal possibilities, and may employ more inputs than necessary. Shortfall of outputs or excess of inputs is defined as inefficiency in economics. A scalar measure of inefficiency, f_i, based on shortfall of outputs is calculated by solving the following linear program for a unit, i, with i = 1,…,J: [4]

$$
\begin{aligned}
& Max\ f_i \\
& s.t. \\
& \sum_{j=1}^{J} l_{ij} y_{mj} - f_i y_{mi} \geq 0 \ , \ m = 1,..,M \\
& x_{ni} - \sum_{j=1}^{J} l_{ij} x_{nj} \geq 0 \ , \ n = 1,..,N \\
& l_{ij} \geq 0 \ , \ j = 1,..,J
\end{aligned}
\qquad (2)
$$

Each type of output is scaled up with the same factor, f_i, until the production function is reached. The scalar, f_i, must be greater or equal to one. If the value one is obtained, then the observation in question is on the production surface. The observation will then be defined as *best practice*.

In hedonic regression models for art object prices the set of explanatory variables usually include categorical ones. The categorical information is handled by using dummy variables (i.e. 0 if the unit does not have the characteristic in question, 1 otherwise), and

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[4] In efficiency analyses the measure $1/f_i$ is called the output oriented Farrell (1957) measure of technical efficiency.

the partial impact on the dependent variable of each characteristic may be identified (relative to a reference type or group). The analogy with our production formulation is that the dependent variable is a single output, and that the explanatory variables are the inputs.

In the DEA model a general way of handling categorical variables, parallel to the treatment of dummy variables in hedonic price regressions, is to interpret them as different types of inputs and/or outputs. Let z_{kj} be a categorical characteristic k $(k=1,..,K)$ of unit j $(j=1,..,J)$ regarding types of inputs, and let x_{nj} be continuous input variables of type n $(n=1,..,N)$. We then have $K \times N$ different types of inputs; each continuous variable is assigned to each of the K types of inputs. Each unit may employ fewer characteristics than the total number available, resulting in a value of zero for the non-observed types of inputs. Treatment of categorical output characteristics is analogous. Following this approach when defining variables the standard DEA model (2) can be used[5].

The outputs and inputs must now be distinguished according to auction house, a, type of print technique, m, and sales period, t. Thus we write y^t_{ma}, x^t_{ma} for the output- and input vectors of a unit. Thus each unit is identified by $a \in A$ and $t \in T$, where A and T are the set of auction houses and sales periods respectively. The mark-up variable is written in (2) as ϕ_i. It is now changed to f^t_o when solving for the unit from auction house $o \in A$ at period t, and both the auction house index a and time period index t are running when defining the benchmark in (2).

We need both contemporaneous and inter-temporal performance indexes. For the former, the score calculated by solving the programming model (2) is used directly with a modification for periods without best practice units. Let us introduce J^t as the set of auction houses with positive activity in period t. The *Contemporaneous Performance Index*, p_{at}, for auction house a in period t, is defined as follows:

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[5] In the DEA literature a hierarchical structure has been imposed on models with categorical variables, see Banker and Morey (1986), and further developments in Kamakura (1988) and Charnes et al. (1994). See Førsund (2002) for a discussion of the approach followed here.

$$p_{at} = \frac{f_a^t}{Min_{j\in J^t}\{f_j^t\}} \text{ , } a \in A, t \in T \tag{3}$$

The Contemporaneous Performance Index shows the performance of an auction house relative to the best performance that period. The index has to be greater or equal to one. A number for the index, say 1.05, means that the auction house in question could have had 5% higher sales, based on its observed inputs, if it had been as good as the best performer of the period.[6]

It may also be of interest to characterise the performance of an auction house for a specific period against a standard for all periods together. A possibility is to have a fixed basis for comparison. A natural base is the geometric mean, $\bar{f}$, of all scores, $f_a^t \ (a \in A, t \in T)$ calculated by solving (2). A bilateral *Inter-temporal Performance Index* may then be defined as:[7]

$$\bar{p}_{at} = \frac{\bar{f}}{f_a^t} \text{ , } a \in A, t \in T \tag{4}$$

The index shows the auction house performance against the inter-temporal total mean. The values may be both greater and smaller than one. A number, say 1.05, is now showing that the auction house *a* for period *t* has 5% higher sales value than the mean performance, while a number 0.95 shows that the auction house has a sales value of 5% less than the mean performance.

An overall ranking of the performance of the auction houses may be obtained by taking averages of the contemporaneous indices in (3). However, since the base varies this procedure is not recommendable. A better alternative is to use (4) and compare the geometric means of each auction house with the total geometric mean, the auction house

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[6] In the efficiency and productivity literature this index is called the output oriented bilateral *Malmquist productivity index* between auction house, *a*, and the most productive auction house for the period in question, see Caves et al. (1982).

[7] This index may also be interpreted as a bilateral Malmquist productivity index, see previous footnote.

Overall Performance Index:

$$\bar{p}_a = \frac{\bar{f}}{\bar{f}_a}\ ,\ a \in A \qquad (5)$$

The indices (3) – (5) all show performance based on all types of outputs. Since auction houses will have a different mix of types of prints both relative to each other and over time, we should also develop a type of index that enables us to study performance for each type of output. Keeping the perspective of all time periods, we can develop an inter-temporal performance index measuring the actual sales as compared to the potential sales the auction house could have done in each period if it has been as efficient as the best performer. This index is then specific for each type of output. We construct hypothetical sales values for under-performing units by employing the mark-up scores from the solution of programme (2). For each type of print we can compare the sales performance over all the auction periods for each auction house by forming the ratio of actual sales values over calculated efficient sales values. An *Overall Output-specific Performance Index*, PI_{ma} is defined as:

$$PI_{ma} = \frac{\sum_{t=1}^{T} y_{ma}^{t}}{\sum_{t=1}^{T} f_a^t y_{ma}^{t}}\ ,\ a \in A \text{ and } m = 1,..,M \qquad (6)$$

This index may also be aggregated over type of output to yield a ranking of auction houses similar to (5).[8] However, since the purpose of the index is to reveal differences as to type of output, such an aggregation does not seem appropriate.

[8] The difference between these two indices will then be that (6) uses the share of total sales in one period relative to the total for all periods as weight for the mark-up factors, while in (5) the geometric means of the relevant factors are used directly.

3. Data and choice of model

3.1 Data

The definition of an auction house in the study is the local branches of the two big auction houses Sotheby's and Christie's, and aggregates of national auction houses for France, Germany and Switzerland, and then other EU countries, other US houses and other houses in the rest of the world.

The data are compiled from biannual auctions held during the sale period 1988-1995 as reported in the 1995 edition of the Mayer International Auction Records on CD-ROM. Prices are gross of the buyers' and sellers' transaction fees paid to auction houses. No information is provided on the origin of the prints. In order to reduce the possibility of heterogeneous items, in this study we only include editions of 50 total printed issues.[9] All prints are priced in U.S. dollars deflated by using the U.S. consumer price index (end of 1990 = 100) to remove the general trend of inflation. For the sake of simplicity, we assume that all sales occur at the end of each half- year period.

3.2 Choice of model

The purpose of this study is to analyse the performances of auction houses by studying the performance of "transforming" an art object with physical characteristics and attributes into auction prices. However, since we have only 10 units of analysis, in order to achieve results of interest we assume that the same frontier technology is valid for all periods. This can be defended because technological change is not so relevant for the special type of production process we are dealing with. We are therefore assuming an *inter-temporal frontier* according to the terminology of Tulkens and van den Eeckaut (1995). As the unit of analysis we will then use an auction house observed for a specific sales period. We have 16 sales periods and 10 auction houses, so this gives us 160 units of analysis as a

[9] The data set then comprises 905 prints, out of a total of 1895 prints, issued in editions of 50 prints.

maximum if all houses have sales in each sale period.[10] There are periods when some auction houses do not have sales leaving us with 125 units in the analysis.

It could be argued that the assumption of no technical change could be invalid if there is systematic movements over time, i.e. price increases constituting technical progress and price declines regress. On an average level we definitely have systematic price trends, as shown in Pesando (1993) and Pesando and Shum (1999). However, firstly, we are focussing on development of best practice prices, so use of total averages may not be relevant. Secondly, we are directly interested in identifying if some periods dominate the performance measures we have set up. The ability to predict and give customers quality advice is part of our performance concept.

The number of units created in such a way gives us some scope for introducing variables of interest. The surface is used as a factor affecting the final price of Picasso prints.[11] The rationale is that the higher the total square centimetres the higher the auction price is.[12] The print techniques are also suggested in the literature to influence the print quality and hence affecting the final price. There may be distinct markets for different techniques. Five different techniques are considered: etching, litho, drypoint, aquatint, and linocut.[13]

The aggregated auction sales within each group of prints are used as outputs. Restricting ourselves to five techniques will yield to five different types of outputs. These represent the categorical variables. For each type we have the surface yielding five continuous input variables, leaving us with five input variables and ten variables in total. The surface variable is aggregated over prints within each technique category.

[10] In the first application of the model based on Picasso oil paintings the total number of auction houses was only five (Førsund and Zanola, 2002).

[11] Additional factors, which are suggested to affect cost (Locatelli and Zanola, 2002), such as signature, production period, Zervos catalogue raisonné number, exhibition, resells, and provenance, have not been considered in this study due to data and dimensionality problems. Hence, a word of caution for the interpretation of the DEA results.

[12] This effect is obvious and significant for paintings, but may be not of equally importance for prints.

[13] These five techniques represent over 95 per cent of total number of prints.

Table 1. Descriptive statistics of 905 Picasso prints in editions of 50 traded during 1988-1995 (1990 US dollars)

Technique	Variable	No. Obs.	Mean	St. Dev.	Min	Max
	Inputs					
Etching	surface	243	1297	2061	44	31520
Litho	surface	302	2863	1019	416	9506
Drypoint	surface	35	1411	834	122	3425
Aquatint	surface	86	1674	1151	51	4112
Linocut	surface	233	2968	1109	364	4882
	Outputs					
Etching	sale values	243	4894	5722	884	75456
Litho	sale values	302	18980	24703	1054	214231
Drypoint	sale values	35	6438	11414	560	69228
Aquatint	sale values	86	13355	23187	1533	147114
Linocut	sale values	233	35555	49417	2830	311535

Table 1 lists the variables and the summary statistics for the individual prints involved.[14] The highest number sold is of lithographs, while drypoint and aquatint are sold in markedly fewer numbers than the other techniques. On average linocut displays the highest sales value per print, while the other print techniques have considerably less sales values, especially drypoint and etching. The maximum sales values also roughly follow this pattern, and also the mean areas of the prints. Etching displays both the minimum and maximum surface values.

4. Results

The key variables generating performance results are the scores, f_a^t, computed by solving (2) for each auction house in each sales period. The model, comprising five input- and output variables is solved using the *FrischDEA* software package[15]. Since the scores are computed within a linear programming model the presentation of statistical measure of reliability of results is not so straightforward. What is usually done in studies using this approach is to perform a sensitivity analysis. The basis for such an analysis is presented in an appendix.

[14] Statistics on auction house sales of different types of prints are shown in Appendix.
[15] This package is developed at the Frisch Centre, Oslo.

4.1 The contemporaneous performance index

The Contemporaneous Performance Index, p_{at}, defined in (3), is set out in Table 2. Of the 125 units (auction house with a positive sale in a sales period), 25 show maximal performance, i.e. they are best practice units. It is remarkable that all auction houses have at least one best practice event with the exception of the house "Other US".

The interpretation of the index numbers in each row is that the best practice performers have the value 1, while under-performers have values greater than 1. In the first row of Table 2 we see that Sotheby's New York is the best performer in 1988:I, while the number 1.71 for Sotheby's London means that this unit could have had sales 71% higher if it had obtained relatively the same auction results for its prints as Sotheby's New York did. The results for both units are measured as how the inputs - print surface for each technique - is transformed into outputs - sales values for each type of print technique - compared with the overall best transformation in an inter-temporal setting. The latter comparison is expressed by a common mark-up factor for all outputs. The house "France" is doing very badly in the first period, its sales could have been increased with 485%. "World" is also under- performing, while "Switzerland", Christie's New York and Christie's London are close to the performance of Sotheby's New York.

Table 2. The Contemporaneous performance Index

Period	Sotheby's New York	Sotheby's London	Christie's New York	Christie's London	France	Switzerland	Germany	Other EU	Other US	World
1988:I	1.00	1.71	1.03	1.15	5.85	1.01	-	-	-	2.69
1988:II	1.20	4.16	1.00	1.00	-	-	4.90	-	-	-
1989:I	1.32	2.96	3.31	1.00	1.00	4.63	2.34	1.54	-	2.98
1989:II	1.26	1.00	1.18	1.24	1.00	1.00	4.74	1.00	-	1.00
1990:I	2.41	1.00	2.59	1.00	3.09	1.00	1.00	1.41	4.34	1.00
1990:II	1.54	4.18	1.81	1.00	3.13	2.14	1.00	2.14	3.91	1.86
1991:I	2.98	5.69	1.00	2.66	4.30	1.16	1.00	-	8.24	1.00
1991:II	3.31	1.37	1.00	8.12	20.31	4.22	4.75	-	11.83	-
1992:I	2.49	-	3.94	-	-	2.48	1.22	-	5.89	1.00
1992:II	1.58	1.00	4.93	1.52	10.79	-	-	-	3.91	1.92
1993:I	2.92	1.82	4.01	-	5.25	1.00	2.61	1.65	6.09	4.37
1993:II	1.00	3.03	6.97	1.96	1.00	-	1.54	2.68	-	-
1994:I	3.40	3.14	3.74	-	1.00	2.14	6.32	13.69	3.59	8.81
1994:II	5.95	1.00	1.09	3.41	-	4.71	6.49	-	5.67	-
1995:I	2.88	3.09	3.21	1.00	4.41	-	3.82	2.74	1.79	-
1995:II	2.15	-	-	1.00	4.72	-	2.11	8.60	-	-

If the auction markets function efficiently (and provided we have not lost some significant quality differences between the prints) the contemporaneous index values should all be close to 1. Let us look for periods with smaller differences and periods with larger differences. The seven houses with sales in 1988:I are in two groups as already commented upon, while in 1988:II the six houses selling also divide in two with two best practice units. In 1989:I all but one house is selling, and the differences are becoming smaller. In 1989:II there are five of the nine houses selling as best practice, and it is only one house, “Germany”, that lags behind and should have increased sales with 374 %. The next period, 1990:I, shows greater differences, but still five of the 10 houses are best practice. Differences increase the next two periods, and 1991:II exhibits the maximal under-performance of the whole data set. “France” should have increased sales with 1931%. Such an almost catastrophic number for sellers should be investigated closer by inspecting the individual print sales. But also “Other EU” under-performs to the tune of 1083%, and Christie’ London with 712%. In 1992:I only six houses have sales, and four of them perform badly compared to best practice “World” and “Germany”. In 1992:II “France” is again under performing and should have increased with 979%, while the other houses are more even. The same pattern is repeated in the next period, while 1993:II has two best practice units and Christie’s New York showing its worst result with 597%. Differences increase in the next two periods, with Sotheby’s New York having its worst result with a mark-up of 495% in 1994:II. In 1995:I there is a more even performance but far behind the only best practice performer, Christie’s London. The Pattern is repeated in the last period, where only five houses participate.

The market for Picasso prints have had boom years and periods of sharp falls.[16] The impression is that the most equal performance is seen in the boom years around 1990, or 1990:I and 1990:II. When the bubble bursts the performance start to diverge quite markedly. Although the Picasso print market levels out, measured by average price for repeat sales, from 1993, the performance index varies quite a lot.

Of the 16 periods five of them are without best practice performers. The first period with prices still increasing, has no best practice performer. Then in 1991:II when the prices

[16] The boom period in the print market lasts until 1990 (Pesando (1993), Pesando and Shum , 1999).

start to collapse, there is only one best practice performer, and then none in the following period, only one in the period after, and then none again in 1993:I. But then there are two best practice units in 1993:II when the prices flattens out, and one best practice performer in each of the two successive periods. After the collapse of the market the prices seems to keep up somewhat better in Europe than in US. Interestingly, in the last year 1995 there are no best practice performers, and the performance is rather weak in an inter-temporal frame of reference.

4.2 The inter-temporal pattern of efficiency

distributions we see that Christie's London is the biggest house, followed by Sotheby's New York, Sotheby's London and Christie's New York. The four big houses have over ¾ of total sales over the 16 periods. Only one house, "Rest of US" does not have a best-performing unit. All the sales are quite small. This is also the case for "Germany". The four other small houses except "Switzerland" that as a small best practice unit, all have some medium-sized best performers. A general impression is that the index defined by (4) shows the auction house performance against the total inter- temporal mean.

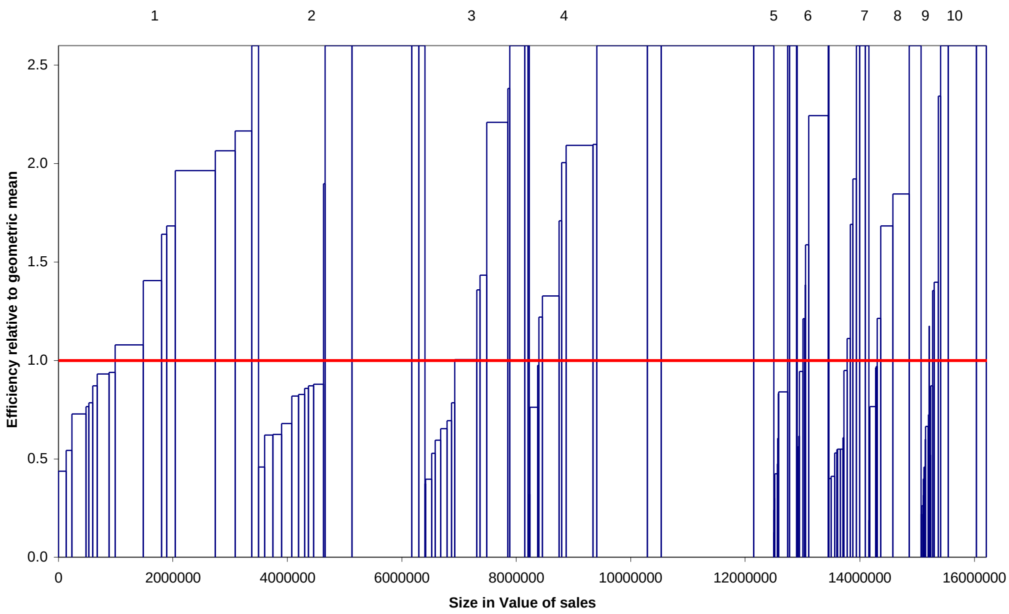

Figure 1. The inter temporal pattern of efficiency

The distribution of the index, sorted from the smallest values to the highest for each auction house, is presented in Figure 1. Each bar represents a unit. The size of each unit, measured in total period sales, is proportional to the width of each bar. The inter-temporal index is measured on the vertical axis and the sales values in 1990 dollars accumulated on the horizontal axis. The maximal value above the mean is 2.54, meaning that the best practice performers have sales that are 154% above the sales it would have had if the performance had been average. Inspecting the auction house distributions we see that Christie's London is the biggest house, followed by Sotheby's New York, Sotheby's London and Christie's New York. The four big houses have over ¾ of total sales over the 16 periods. Only one house, "Rest of US" does not have a best-performing unit. All the sales are quite small. This is also the case for "Germany". The four other small houses except "Switzerland" that as a small best practice unit, all have some medium-sized best performers. A general impression is that the small units are under performing compared with the mean performance, while the large units are over performing. This is especially evident for Christie's London, where the two largest sales are best performers, and also the same for Sotheby's London. The exception is Sotheby's New York, where a small unit is the only best practice performer. It is notable that the group of best practice performers, although dominated by medium- and the largest sized units, also comprises some small units.

4.3 The inter-temporal performance

The information in Figure 1 can be used to create an overall ranking of auction houses by computing the auction house overall performance index defined in (5). The results are set out in Table 3. We see that Christie's London is the overall best performer, with somewhat surprisingly "Switzerland" and "World" following next. Sotheby's New York and London come as No. 4 and 5, and then Christie's New York. The worst performers are "Other US" last, and "France" and "Germany" following, all three performing markedly below the average.

So far we have used performance information related to sales of all types of prints. To better asses the performance of an auction house for each type of print, based on all time

Table 3. The Overall Performance Index

Auction House	Index value
Sotheby's New York	1.1240
Sotheby's London	1.1052
Christie's New York	1.0653
Christie's London	1.5212
France	0.6876
Switzerland	1.3066
Germany	0.9101
Other EU	1.0162
Other US	0.4098
World	1.2992

periods, we developed an inter-temporal performance index (6) measuring the actual sales of each type of print as compared to the potential sales the auction house could have had in each period if it has been as efficient as the best performer. This index is then specific for each type of print. We construct hypothetical sales values for under-performing units by employing the mark-up scores from the solution of program (2). For each type of print we can compare the sales performance over all the auction periods for each auction house by forming the ratio of actual sales values over calculated efficient sales values[17]. The Overall Output- specific Performance Index, PI_{ma} for the auction houses is set out in Table 4. Note that not only the performance mark-ups, but also the volume of sales count when constructing the performance indices. An auction house may have high performance mark-ups for a single period, as for Sotheby's New York in 1994:II, Sotheby's London in 1991:I, Christie's New York 1993:II and Christie's London in 1991:II (see Table 2), but this may not influence the performance index much if the sales involved are small.

We observe some striking differences in performance between auction houses for the different print techniques. Linocuts are traded by all houses. Christie's London has the highest performance with an index value of 0.86, followed by "World" and "Other EU". The index value of 0.86 means that Christie's London obtained 14% lower sales values than if it had been as good as best practice for all its period sales. The worst performers are quite below best practice, "Other US" has only 19 % of best practice sales, and "Germany" and "France" 26%.

[17] Note that we compare a unit with best practice irrespective of period. A more conservative calculation would be to use the contemporaneous index (3) as basis.

Table 4. The Overall Output-specific performance Index

Auction house	Etching	Litho	Drypoint	Aquatint	Linocut
Sotheby's New York	0.4657	0.5331	0.4507	0.5961	0.3866
Sotheby's London	0.3408	0.4749	0.8090	0.5576	0.4944
Christie's New York	0.3470	0.4664	0.6959	0.3793	0.3855
Christie's London	0.7641	0.7349	0.9026	0.8633	0.8577
France	0.3110	0.2311	1	0.7708	0.2638
Switzerland	0.3539	0.7832	-	0.4659	0.4563
Germany	0.3418	0.3558	0.5969	0.4453	0.2631
Other EU	0.5615	0.5512	-	0.7099	0.5190
Other US	0.1764	0.1401	-	-	0.1930
World	0.3251	0.8386	-	0.7243	0.7997

Regarding aquatint “Other US” is not trading this technique. Christie's London is again the best performer with the index on the same level as for linocuts, with “France” following and then “World”. The lowest performers are not doing as badly as for linocuts, Christie’s New York under-performing by 38%, and “Germany” with 45%.

The technique drypoint is the least sold. It is only traded by six of the houses. “France” has the maximal index value of 1 because at the two occasions where it sold drypoint prints “France” became best practice. Christie’s London and Sotheby’s London come in the next places with relative high index values. The lowest performer Sotheby’s New York is 45% below best practice sales.

All houses trade lithographs. The house “World” is doing best, under performing 16%, followed by “Switzerland” and Christie’s London under performing with 22% and 27% respectively. The worst performer is “Other US”, under-performing substantially with 86% , the highest percentage recorded for all time periods.

For etchings Christie’s London is again the best performer, being 22% behind best practice, with “Other EU” and Sotheby’s New York coming next with quite higher under-performances of 44% and 53% respectively. The worst performer is again “Other US”, being 82% behind best practice.

Christie’s London has the most solid record overall, being in front for three techniques and second and third for the two others, supporting the classification shown in Table 3. As seen from Table 2 Christie's London had especially strong performance in the pre-boom and boom years. It is also making the strongest recovery in the last two periods. "Other US" has the worst record, being last for the three techniques it has traded in. This is also in accordance with the ranking in Table 3. The high ranking of "World" and "Switzerland" according to the overall index (5) in Table 3 may be somewhat surprising. The inter-temporal print type-specific index (6) provide more detailed information. We have already commented that the high placing of "World" for linocuts and aquatints are based on having only two periods with sales, and being best practice in one of each periods. For lithographs the performance is more solid with six periods with trade, and having three best practice occurrences and two of them when sales volume were quite large. "Switzerland has really only one strong line of prints performance, lithographs, where of the five trading periods one was best practice. Based on disaggregation of the overall results provided by the inter-temporal performance index we suggest to downplay the ranking of "World" and "Switzerland" shown by the overall performance index.

5. Concluding remarks

Although there is an increasing emphasis on performance of investment in prints, the role of auction houses has not been studied so much in the economic literature. It has been observed that similar prints can obtain quite different prices at different auctions within the same auction period, but no systematic exposition of differences have been offered. Previous works applying hedonic price technique have found no conclusive result about the most efficient auction house, but in these studies the object of art has been the unit, and influence of auction houses is analysed by testing whether auction house impact on price is significant or not within a framework of central tendencies.

In order to focus on auction houses as units we have applied a benchmarking technique, DEA, developed for efficiency studies. The analogy of a production process is a little special: the inputs are the physical characteristics, measured by surface area, of Picasso prints classified according to technique, and the outputs are the auction sales values within each technique. We cannot, of course, capture all relevant information about prints simply by type of technique and surface area of prints. However, these are variables found significant and used in studies of auction prices using hedonic regressions.

We have developed a model with mixed categorical and continuous variables most suitable for art objects markets not used before in the efficiency literature. New light is shed on the issue of categorical variables in DEA models by interpreting them as different types of inputs and/or outputs. The inter-linkages between categorical variables turned out to be important for the empirical findings.

A novel construct of the paper is various performance indexes giving an insight into auction house differences impossible to obtain using hedonic price regressions. The differences in auction prices for the same time pointed out in the literature (Pesando, 1993) has been structured and measured by a Contemporaneous Performance index. There are indeed huge differences between auction houses. There is a tendency for differences being smallest around the boom price period, and varying quite a lot during the bust years of the price boom. But also during the last years of the data set with stable average prices we see significant differences between auction houses.

There is no dominant auction house being successful in all periods. We have calculated an index to exhibit overall performance specific to each type of print technique. Christie's London comes out best. More surprisingly, Sotheby's New York and London are not doing so well, about average for the 10 auction houses. "Other US" is performing the worst. One explanation is that the big auctions for Christie's London are coming out as best practice, while this is not the case for Sotheby's. Christie's London was especially successful during the pre-boom and boom years. "Other US" is the worst performer, and has small volumes only. It is usually stated in the auction literature (Pesando, 1993) that large actions tend to increase the price. If this is the case it seems to be only Christie's London that manages to benefit from this effect.

What is the policy conclusion of the paper? If you plan to sell your Picasso print you would prefer the auction house with the best performance to handle your sales, but if you want to do a bargaining buying, you should go to the auction house with the lowest value of the performance index.

The type of model developed may also be applied to other institutions or markets, where the unit in question use physical assets of various types to produce a financial result, e.g. financial market units like stock broker firms, pension funds, etc.

Appendix

Sensitivity analysis

In the efficiency literature the point of departure for sensitivity analysis is calculations of several indicators of signs of influential outliers. Their role as peers can be shown by calculating the relative increase in auction prices for each inefficient unit having the efficient unit in question as a peer or referencing unit on the frontier. In the case of output orientation, the peer index, $r_p{}^m$, is calculated as the fraction of weighted total aggregated potential for increase in auction sales as function of the output type *m* (print technique) for which the peer, *p*, act as a referent (the unit index is *j*):[18]

$$r_p{}^m = \frac{\sum_{j=1}^{J} \frac{l_{jp}}{\sum_{p \in P^j} l_{jp}} (f_j y_{mj} - y_{mj})}{\sum_{j=1}^{J} (f_j y_{mj} - y_{mj})} \; , \; m = 1,..,M \qquad \text{(A.1)}$$

In the numerator we have the weighted increase in output of type *m* of the inefficient units having unit *p* as peer, normalised with the total sum of peer weights for each inefficient unit (the set P^j is the reference set of peers for unit *j*) in the case of CRS (for VRS the sum is 1) and in the denominator we have the total potential increase for output of type *m* if all inefficient units become efficient. The weights, l_{jp}, are zero for inefficient units not having unit p as a peer. (As a control, summing also over all the peers (index *p*) in the numerator, we get the index value of 1 for each type of output.)

Another measure of the importance of peers is provided by calculating the *super efficiency score* (Andersen and Petersen, 1993). It is defined by removing the peer in question from the data set forming the frontier, and then calculating the score of the peer against this new frontier. The mark-up score must necessarily be smaller than (or equal to) one. A third measure of the importance is a pure count of the number of times a peer is a referencing unit for inefficient units.

[18] See Torgersen et al. (1996) for the introduction and demonstration of the concept of Peer index.

Table A.1. The Peer Index; Super Efficiency; and Count

Auction houses	Unit	Etching	Litho	Drypoint	Aquatint	Linocut	Super Eff.	Count
Sotheby's New York	112	0.0074	0.0226	0.0000	0.0012	0.0092	0.8187	20
Sotheby's London	204	0.0009	0.0018	0.0105	0.0006	0.0013	0.7632	3
	205	0.0012	0.0007	0.0012	0.0025	0.0010	0.6258	8
	210	0.0011	0.0021	0.0161	0.0016	0.0015	0.4522	4
	214	0.0000	0.0000	0.0000	0.0000	0.0000	0.6747	0
Christie' New York	302	0.0000	0.0000	0.0000	0.0000	0.0000	0.9764	0
	307	0.0004	0.0013	0.0120	0.0023	0.0026	0.1603	3
	308	0.0000	0.0006	0.0000	0.0045	0.0000	0.9958	1
Christie's London	402	0.0017	0.0050	0.0003	0.0040	0.0013	0.7489	9
	403	0.0096	0.0079	0.0166	0.0125	0.0164	0.7912	12
	405	0.0010	0.0018	0.0145	0.0015	0.0034	0.4238	8
	406	0.0054	0.0095	0.0111	0.0010	0.0167	0.7896	16
France	503	0.0000	0.0000	0.0000	0.0000	0.0000	*	0
	504	0.0015	0.0023	0.0170	0.0042	0.0021	0.5318	4
	512	0.1771	0.1763	0.3106	0.5279	0.1589	*	25
Switzerland	513	0.0009	0.0007	0.0000	0.0044	0.0003	0.3635	4
	604	0.0492	0.2274	0.0024	0.0585	0.0797	0.7299	37
	605	0.6801	0.3753	0.3622	0.3074	0.4557	0.3198	68
Germany	705	0.0123	0.0264	0.1544	0.0311	0.0256	0.1316	12
	706	0.0004	0.0002	0.0000	0.0003	0.0000	0.8223	2
	707	0.0014	0.0010	0.0000	0.0019	0.0065	0.9844	4
Other EU	804	0.0237	0.0350	0.0569	0.0161	0.1511	0.7714	41
World	1004	0.0190	0.0800	0.0141	0.0113	0.0450	0.4855	36
	1005	0.0034	0.0062	0.0000	0.0002	0.0094	0.8516	10
	1007	0.0023	0.0063	0.0003	0.0049	0.0026	0.7065	6

- No feasible solution

Table A.1 sets out the peer index and also the super efficiency index and number of occurrences as referencing unit for a comparison. The indexing of the units by a three-digit number has the number for the auction house and the period number as indicated in Table 2. Table A.1 displays that three of the 25 efficient units (214, 302 and 503) are self-evaluators, i.e. they are not peers for any inefficient unit. Removing these units will consequently have no impact on the efficiency scores of any inefficient unit, their Peer index values are zero. Of the 22 remaining peers a few stands out as most influential in terms of the peer index value. We have five units with an index value of more than 0.10, and only two units with values above that for all techniques.

Inspecting the count number reveal that 15 units have below 10 efficient units in their referencing sets. The two with dominating peer index values have 68 and 25 respectively, the latter having rank 5.

Regarding etchings, the one dominating peer, unit 605, "Switzerland" for 1990:I, has an index value of 0.68, meaning that 2/3 of the total weighted potential improvement in auction values are due to the inefficient units having unit 605 as a peer. This is the maximal value for all types of prints. We see that the peer index values for the other techniques are almost half. This is due to the fact that unit 605 only trades in etchings. Nevertheless, unit 605 has the highest peer index value for also lithographs, drypoints and linocuts. The count index for unit 605 is the maximal, almost 50% higher than the peer with the second highest count, unit 804. This unit has the third highest peer index value for linocuts, but is ranked for the other print techniques. This is explained by the fact that unit 804 only trades in linocuts. For aquatints unit 512, "France" in 1993:II, has the highest peer index, considerably higher than unit 605. All other peer index values are quite low. The count index for unit 512 is not so high, ranking as No. 5. There seems in general to be a lack of discrimination using the count number as to type of technique. Unit 512 only trades in aquatints. There is a general pattern that units with high peer index values only trade in a single technique.

The super efficiency index may indicate the sensitivity of the local shape of the transformation surface by calculating the mark-up score for efficient units without including the unit in the set. We see from Table A.1 that only a few units stand out, unit 307, 605, and 705, with values of 0.16, 0.32 and 0.13 respectively. The number 0.13 is interpreted as the share of the outputs that the benchmark for unit 705 has of the observed outputs of unit 705. Five more units have super-efficiency score less than 0.5. For two units the program failed to find feasible solutions. Unfortunately this concerns unit 512 with a high peer index. There seems overall to be a poor correlation between the value of the super efficiency score and the importance of the peer in terms of a peer being a referent for many inefficient units. The super efficiency index seems to be of more value as a guide to a sensitivity check on the shape of the frontier itself. It measures how much outputs can be reduced and the unit still being on the frontier.

Although we have exposed some dominating units, there are no clear "red lights" as to outliers unduly influencing the results. It should be born in mind that any benchmarking study is based on outliers. Further sensitivity studies may be carried out studying the maximal changes in variables of key units in order to generate changes in the mark-up scores, as outlined in Charnes et al. (1994).

Table A.2. Auction house statistics

Auction house	Technique	No.Obs	Inputs (square centimetres)				Outputs (US dollars)			
			Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max
Sotheby's	etching	64	1573	3854	44	31520	5331	9223	884	75456
New York	litho	74	2852	1255	416	9506	19407	21685	1054	127332
	drypoint	12	1181	595	348	2200	3954	2159	2027	9615
	aquatint	25	1313	942	51	3922	9985	16519	1738	83462
	linocut	54	2929	989	364	3578	26594	28557	4181	130500
Sotheby's	etching	43	1272	588	146	2833	4097	2319	1296	13842
London	litho	50	2977	843	540	4640	16953	23806	2027	161919
	drypoint	6	2124	697	1451	3376	8470	6014	3670	19976
	aquatint	21	1515	966	72	4112	14977	31476	2426	147114
	linocut	49	3333	1175	968	4882	36581	45386	2830	242307
Christie's	etching	32	1151	730	92	3239	4584	4591	1178	23566
New York	litho	32	2663	947	591	4330	14610	14262	3244	72661
	drypoint	6	1061	318	707	1536	3425	2005	560	6467
	aquatint	10	2138	1417	106	3927	8212	4547	2160	15886
	linocut	37	3129	932	948	4631	29946	48547	3224	226368
Christie's	etching	27	994	709	107	2540	6435	5299	1697	20772
London	litho	42	3166	940	1215	7576	29798	38798	2910	214231
	drypoint	5	1955	1210	58	3927	17382	29000	3393	69228
	aquatint	12	1955	1210	58	3927	20944	29662	2198	92839
	linocut	42	2571	1154	367	3498	60382	73763	4741	311535
France	etching	21	1128	628	92	2489	4486	3779	920	18828
	litho	14	2778	1040	1026	4243	5747	5680	1379	23130
	drypoint	3	1000	189	782	1109	3490	343	3094	3688
	aquatint	4	1563	1857	63	3944	29048	45022	1533	95791
	linocut	8	2835	991	939	3673	14080	6846	4153	22109
Switzerland	etching	11	1237	773	241	2981	4889	1646	2901	7668
	litho	14	2829	1242	496	4336	26518	27762	3270	89815
	drypoint	0								
	aquatint	3	2513	1335	1237	3901	14479	15630	3928	32436
	linocut	5	2945	1448	973	4774	20805	8536	11976	30107
Germany	etching	10	1620	1157	301	3804	6702	3360	2600	13542
	litho	37	2698	798	567	3947	11415	10371	1935	51084
	drypoint	3	778	1131	122	2083	3050	396	2676	3465
	aquatint	6	2500	1346	1298	4019	9457	6088	3002	18243
	linocut	11	2874	1006	1002	3571	12895	7963	4820	30979
Other EU	etching	8	1522	673	451	2045	4651	2225	2660	8622
	litho	17	2857	689	852	3857	24076	26448	5480	101799
	drypoint	0								
	aquatint	2	1513	301	1300	1726	10391	9298	3816	16965
	linocut	12	3108	1101	945	4774	37241	44906	3973	160853
Other US	etching	10	1083	480	305	1804	2710	981	1216	4741
	litho	10	2317	1150	539	3531	5529	2702	1589	10273
	drypoint	0								
	aquatint	0								
	linocut	7	2284	1448	373	3495	8562	5496	3161	18000
World	etching	13	1049	358	482	1536	4400	4816	1320	19807
	litho	9	3136	1009	727	4453	42361	33443	6164	108289
	drypoint	0								
	aquatint	3	905	445	578	1411	4585	1727	2641	5941
	linocut	8	2999	1323	960	4677	68294	73043	9482	204543

References

Agnello, R. J., Pierce, R.K. (1999), Investment Returns and Risk for Art: Evidence from Auctions of American Paintings (1971-1996), Working Paper 99/03, University of Delaware.

Andersen, P., Petersen, N.C. (1993), A procedure for ranking efficient units in Data Envelopment Analysis, *Management Science* 39, 1261-1264.

Anderson, R. C. (1974), Paintings as Investment, *Economic Inquiry* 12,13-26.

Banker, R. D., Morey, R.C. (1986), The use of categorical variables in Data Envelopment Analysis, *Management Science* 32(12), 1613-1627.

Buelens, N., Ginsurgh, V. (1993), Revisiting Baumol's 'art as floating crap game', *European Economic Review* 37, 1351-1371.

Candela, G., Scorcu, A.E. (1997), A Price Index for Art Market Auctions. An application to the Italian Market of Modern and Contemporary Oil Paintings, *Journal of Cultural Economics* 21(3), 175-196.

Caves, D.W., Christensen, L.R., Diewert, E. (1982), The economic theory of index numbers and the measurement of input, output, and productivity, *Econometrica* 50, 1393-1414.

Chanel, O., Gérard-Varet, L.A., Ginsurgh, V. (1996), The Relevance of Hedonic Price Indices, *Journal of Cultural Economics* 20, 1-24.

Charnes, A., Cooper, W.W., Lewin, A.Y., Seiford, L.M. (eds.) (1994), *Data Envelopment Analysis: Theory, Methodology, and Applications*, Boston/Dordrecht/ London: Kluwer Academic Publishers, Section 3.3 Categorical inputs and outputs, 52-54.

Coelli, T., Rao, D.S.P., Battese, G.E. (1998), *An introduction to efficiency and productivity analysis*, Boston/Dordrecht/London: Kluwer Academic Publishers.

Czujack, C. (1997), Picasso paintings at auction, 1963-1994, *Journal of Cultural Economics* 21, 229-247.

Farrell, M.J. (1957), The measurement of productive efficiency, *Journal of the Royal Statistical Society*, Series A, 120 (III), 253-281.

Frey, B. S., Pommerehene, W.W. (1989), *Muses and Markets; Explorations in the Economics of the Arts*, Oxford: Basil Blackwell.

Førsund, F. R. (2002), Categorical variables in DEA, *International Journal of Business and Economics* 1(1), 31-41.

Førsund, F.R., Zanola, R. (2002), Selling Picasso paintings: the efficiency of auction houses, *Working Paper* 7/01, International Centre for Economic Research (ICER).

Kamakura, W.A. (1988), A note on the use of categorical variables in Data Envelopment Analysis, *Management Science* 34(10), 1273-1276.

Locatelli-Biey, M., Zanola, R. (2002), The market for sculptures: an adjacent year regression index, *Journal of Cultural Economics* 1,

Locatelli-Biey, M., Zanola, R. (2002), The Market for Paintings: An Hybrid Price Index, WP, University of Eastern Piedmont.

Pesando, J.E. (1993), Art as an investment: The market for modern prints, *American Economic Review* 83, 1075-1089.

Pesando, J.E., Shum, P.M. (1999), The returns to Picasso's prints and to traditional financial assets, 1977 to 1996", *Journal of Cultural Economics* 23, 183-192.

Picci, L. and Scorcu, A.E. (2002): Bidders' and sellers' strategies in sequential auctions. New evidence about the afternoon effect, *Economica* (forthcoming).

Renneboog, L., Van Houtte, T. (2002), The monetary appreciation of paintings: from realism to Magritte, *Cambridge Journal of Economics* 26, 331-357.

Torgersen, A.M., Førsund, F.R., Kittelsen, S.A.C. (1996), Slack-adjusted efficiency measures and ranking of efficient units, *Journal of Productivity Analysis* 7(4), 379-398.