

# Association of CCR and BCC Efficiencies to Market Variables in a Retrospective Two Stage Data Envelope Analysis

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**Abstract.** The analysis compares constant returns to scale (CRS) and varying returns to scale (VRS) measures, by modeling the performance of internet companies using a two-stage DEA process. In the DEA literature, process efficiency is widely measured by a CRS measure, CCR, and a VRS measure, BCC, which were proposed by Charnes et al. (1978) and Banker et al. (1984), respectively. Measuring the performance of Internet companies using two-stage DEA was also presented by Cao and Yang (2011). The results of the analysis reported in this paper suggest that both forms of DEA efficiency scores are relevant to measure the performance of Internet companies.

**Keywords:** Decision support systems, E-commerce, Evaluating information, Internet companies, Investment analysis.

## 1 Introduction

Previous work on the study of association between company specific indicators has been made considering national aggregate data (e.g. concerning manufacturing strategy, see Coelho, 2011). In evaluating Internet companies, the common approach is to focus primarily on a single variable or a small collection of financial ratios such as return on investment (ROI), return on equity (ROE) while ignoring the non-financial information in Internet industry (Cao and Yang, 2011). Although the ratio analysis provides useful information, it only portrays one facet of performance. Without the help of supporting non-financial information, financial information might be insufficient for judging an online business. Moreover, there are many factors related to an Internet company's performance such as assets, expense, number of employees and visitors, etc. Therefore, it is necessary to assess the performance of Internet companies in a multidimensional systems perspective. A small number of studies (Barua et al. 2004, Serrano-Cinca et al. 2005, Ho et al. 2011, Cao and Yang, 2011) have been conducted to evaluate Internet companies using data envelopment analysis (DEA).

Data envelopment analysis (DEA) is a nonparametric method in operations research and economics for the estimation of production frontiers (empirical heuristics standing for impractical or unattainable analytical optimization). It is used to

empirically measure productive efficiency of decision making units (or DMUs). Non-parametric approaches have the benefit of not assuming a particular functional form or shape for the frontier, but do not provide a general relationship (equation) relating output and input. DEA is a linear programming technique used to evaluate the efficiency of decision making units (DMUs) on the basis of their multiple inputs and outputs (Charnes, Cooper and Rhodes, 1978; Banker, Charnes and Cooper, 1984; Butler and Li, 2005).

In the DEA methodology, formally developed by Charnes, Cooper and Rhodes (1978), efficiency is defined as a ratio of weighted sum of outputs to a weighted sum of inputs, where the weights structure is calculated by means of mathematical programming and constant returns to scale (CRS) are assumed. In 1984, Banker, Charnes and Cooper developed a model with variable returns to scale (VRS). Tone (1995) proposed a simple method for deciding the local returns-to-scale characteristics of DMUs (Decision Making Units) in Data Envelopment Analysis. This method proceeds as follows: first, the BCC (Banker-Charnes-Cooper) model is solved to find the returns-to-scale of BCC-efficient DMUs and a reference set for each BCC-inefficient DMU. Then the local returns-to-scale characteristics of each BCC-inefficient DMU is apprehended by observing only the returns-to-scale characteristics of DMUs in their respective reference sets.

An important decision in DEA modelling is the selection of inputs and outputs that are included in the specification, as different inputs/outputs combinations will produce different efficiency rankings of firms. A particular DMU may or may not be efficient depending on the selection of inputs and outputs. Decision makers may be reluctant to use a technique that is so sensitive to decisions taken at the modelling stage. Serrano-Cinca et al. (2005) suggest a new approach to the problem of deciding which inputs and outputs the model should contain. A series of DEA specifications are contemplated, and the resulting efficiency scores are analyzed using multivariate statistical techniques. There is a further problem with DEA: efficiency is a mere score between 0 and 1 (or between 0% and 100%). Two different DMUs may achieve the same DEA score while, at the same time, being very different: they just take a different route to the achievement of efficiency (Serrano-Cinca et al., 2005). By considering the series relationship of sub-processes within an entire production process, a relational two-stage DEA can overcome the disadvantages of a traditional DEA model (Cao and Yang, 2011). This is achieved by segmenting internal DMU processes and obtaining efficiency scores in two steps.

The aim of this study is to explore the effect on relational dual-stage DEA efficiency scores and extrapolative power of the latter of alternative modalities for returns to scale. To this end, data was used in hindsight, to apprehend which modality of relational dual-stage DEA measure of efficiency of DMUs (CCR or BCC) yielded efficiency measures with better predictive power.

## **2 Data**

Data was obtained by matching the sample of Internet companies used by Serrano-Cinca (2005), which originated from the end of 2000 and comprised 40 companies,

with the sample used by Ho et al. (2011), comprising 52 companies and dated from the end of 2005. The complete data set used is shown in Appendix, comprising 9 companies that resulted from the matching of the two afore-mentioned data sets.

The inputs and outputs considered by Serrano-Cinca et al. (2005) were:

- Input A: Number of employees
- Input B: Total operating expenses (\$000)
- Input C: Total assets (\$000)
- Output 1: Unique visitors
- Output 2: Revenues (\$000).

A requirement of the DEA model is homogeneity. For this reason, all financial data in the Serrano-Cinca sample relates to end of 2000 year accounts. “Unique visitors” was taken at the end of March 2000 in order to avoid any distortion that might be introduced by the Christmas period.

On the other hand, the inputs and outputs considered by Ho et al. (2011) were:

- Input A: Total assets (\$000)
- Input B: Operating expenses (\$000)
- Output 1: Reach (average)
- Output 2: Page views (average)
- Output 3: Gross margin (\$000)
- Output 4: Accumulative cash flow (\$000)

All input and output data of the companies in Ho et al.’s sample is from 2005. The fiscal year of all financial data ends on 31 December 2005.

Total assets and operating expenses are featured in the two datasets, while number of employees is only featured in the first. Outputs are somewhat similar between both datasets, unique visitors from the first data set finds correspondence in reach and page views of the second dataset. Revenues, featured in the first data set, finds a correspondence in gross margin and accumulative cash flow in the second data set. In this way the dual-stage DEA modelling for the two times (2000 and 2005) is fairly similar, enabling a comparison of efficiency measures obtained for each point in time.

Additionally, end of 2000 fiscal year market capital and market price as well as 2012 data for end of 2012 year stock price, assets and equity was sought for the 9 companies. This was only successfully obtained for 5 companies, as four out of nine had been acquired by other companies and as hence were no longer publicly traded (details in the appendix). The models compared in this study were the input-oriented, constant returns to scale (CRS), envelopment form of the DEA (Charnes et al., 1978; Cooper et al., 2000) and the input-oriented, varying returns to scale (VRS), envelopment form of DEA (Banker et al., 1984).

### **3 DMU Process Modelling**

With the data obtained as described in the previous section of this paper, the next step was to apply the models to analyse the data. One decision had to be made whether the

analysis aimed to minimise inputs or maximise outputs for the processes under consideration. Both constant and variable returns to scale were used for comparison. The data from all decision making units (DMUs) in this study were subject to the calculation of the Frontier Analyst software based on the input minimizing-oriented CCR and BCC models, in order to obtain the dual-stage DEA efficiency values. According to Hussain and Jones (2010), Frontier Analyst uses the most tried and tested models in DEA, which, in academic literature, have proven to be the most robust. The two models used were the BCC model for variable returns to scale and the CCR model for constant returns to scale. Statistical analysis was developed with the support of STATA IC 12 software.

### 3.1 DEA Efficiency Model Choice

In DEA, the efficiency model can address one of two questions:

1. Given the level of outputs that a unit produces, by how much might the inputs be reduced while maintaining the current level of outputs? This is input minimisation, seeking to minimize inputs to produce the same outputs.
2. Given the current level of inputs used by a unit, what level of outputs should it be possible to achieve? This is output maximisation, seeking to maximize outputs given the current inputs.

Under the assumption of constant returns to scale (CRS), the efficiency results obtained from both the input minimisation and output maximisation options are identical. Hence, for the VRS modality the use of input minimisation or output maximisation depends on the situation being analysed (Hussain and Jones, 2010). In the case of the output maximisation model, an appreciation of whether it is actually possible to achieve the target outputs generated by the analysis is needed, e.g. if the output targets are considered to be unattainable because of external factors then this model is likely to be inappropriate. Alternatively, it may be that the inputs a unit uses are relatively inflexible in which case the output maximisation project might be best. Given the competitive nature of the domain of the sample data (Internet companies) in rather closely contained sectors (e-tailers, content, search), input minimization was chosen for the efficiency models of the BCC runs of the study.

### 3.2 Returns to Scale Alternatives

Data Envelope Analysis allows assessing the relative efficiency of units under a system of either constant or variable returns to scale. The efficiency results obtained from using the different scale assumptions are likely to be different. In the constant returns modality (CCR mode) outputs directly reflect input levels (i.e. doubling input produces exactly double outputs). In the varying returns modality (BCC mode) outputs fall off as input levels rise (i.e. doubling input produces less than double outputs). Using the variable returns to scale option allows the analysis more room to find optimal solutions (Hussain and Jones, 2010). The choice of model, constant (CCR) or

variable (BCC), depends on the process being analysed. If any increase in input (resources) used yields a proportionate increase in outputs (results), then this indicates there is a linear relationship between inputs and outputs, so a constant returns to scale model should be used. If however, an increase in inputs does not yield the same increase in outputs, then the variable returns to scale model ought to be used, as a non-linear relationship between results and resources would have been identified. This is the fundamental issue this study tackles, with both alternatives tested on the data. The hypothesis is that variable returns to scale are more adequate to Internet companies than constant returns to scale.

### 3.3 Dual-stage DEA Process Modelling

The DEA model for the 2000 data retrieved from Serrano-Cinca (2005) was established in a dual-stage process. Controlled inputs for stage 1 (marketability) were number of employees, total operating expenses and total assets, with output of stage 1 modelled as unique visitors. For stage 2 (profitability), and the same data, unique visitors were modelled as controlled inputs, with revenues modelled as output (additionally stage 1 controlled inputs were considered as uncontrolled inputs for stage 2). The efficiency scores obtained for the two stages of each DMU were multiplied resulting in the overall dual-stage efficiency score. This process was developed twice, considering for the minimising input DEA efficiency approach, both the CCR modality and the BCC modality.

For the 2005 data retrieved from Ho et al. (2011), controlled inputs considered for stage 1 (marketability) of the dual-stage process modelling were total assets and operating expenses. For stage 1 process modelling, outputs considered were reach and page views. The latter stage 1 outputs became stage 2 controlled inputs, with outputs modelled as accumulative cash flow and gross margin, while for stage 2 (profitability) operating expenses and total assets were modelled as uncontrolled inputs. For this data, both the CCR modality and the BCC modality were implemented, based on a minimising input DEA efficiency approach.

## 4 Analysis of Results

As expected, no unit received a lower efficiency score using variable returns to scale, than they did with the constant returns to scale model. Any units which were operating with minimum input or maximum output levels were also found to be efficient using variable returns to scale (BCC), and so the total number of 100% efficient units is higher in this modality than in the CCR modality. Table 1 presents the dual-stage efficiency scores for the 2000 data obtained from Serrano-Cinca et al. (2005). Table 2 presents the same kind of scores for the same Internet companies, but considering 2005 data obtained from Ho et al. (2011). In both cases the dual-stage efficiency scores are obtained from the Data Analysis Envelope (DEA) approach described by Cao and Yang (2011), where stage 1 refers to marketability and stage 2 refers to profitability of Internet companies. For both time periods, there are more efficient DMUs in the BCC modality than in the CCR modality.

**Table 1.** Relational dual-stage efficiency scores (Cao and Yang, 2011) for 2000 data, obtained for both CCR and BCC modalities, considering input minimisation

Unit name	2000 data						ratio BCC Ek / CCR Ek
	CCR			BCC			
	Ek1	Ek2	Ek	Ek1	Ek2	Ek	
ADBL	17,4%	7,9%	1,37%	95,20%	91,5%	87,11%	63,4
AMZN	19,3%	100,0%	19,3%	19,50%	100,0%	19,5%	1,0
CNET	93,7%	9,6%	9,0%	97,20%	10,8%	10,5%	1,2
EBAY	91,6%	14,5%	13,28%	94,00%	15,3%	14,38%	1,1
EDGR	24,8%	23,5%	5,83%	100,0%	100,0%	100,0%	17,2
INSW	44,8%	9,1%	4,08%	57,10%	15,4%	8,79%	2,2
LOOK	100,0%	5,2%	5,2%	100,0%	6,8%	6,8%	1,3
TSCM	24,9%	13,4%	3,34%	39,60%	27,8%	11,01%	3,3
YHOO	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	1,0

**Table 2.** Relational dual-stage efficiency scores (Cao and Yang, 2011) for 2005 data, obtained for both CCR and BCC modalities, considering input minimisation

Unit name	2005 data						ratio BCC Ek / CCR Ek
	CCR			BCC			
	Ek1	Ek2	Ek	Ek1	Ek2	Ek	
ADBL	23,8%	36,3%	8,64%	45,7%	41,5%	18,97%	2,2
AMZN	36,1%	100,0%	36,1%	36,3%	100,0%	36,3%	1,0
CNET	41,9%	9,6%	4,02%	43,7%	100,0%	43,7%	10,9
EBAY	12,3%	100,0%	12,3%	12,6%	100,0%	12,6%	1,0
EDGR	21,3%	35,6%	7,58%	100,0%	100,0%	100,0%	13,2
INSW	17,1%	100,0%	17,1%	100,0%	100,0%	100,0%	5,8
LOOK	19,9%	100,0%	19,9%	48,5%	100,0%	48,5%	2,4
TSCM	81,1%	100,0%	81,1%	100,0%	100,0%	100,0%	1,2
YHOO	100%	13,2%	13,2%	100,0%	100,0%	100,0%	7,6

Moreover, for 2005 CRS (or CCR) efficiency scores compared to the 2000 ones, Yahoo kept its marketability maximum efficiency, losing its profitability maximum efficiency, resulting in the loss of its maximum relational dual-stage efficiency. Amazon improved marketability efficiency while keeping its maximum profitability efficiency. Four other DMUs attained maximum profitability efficiencies, with improvement in dual-stage efficiency over the 5 year period for all, except for Ebay, which dropped in marketability over the period.

In what concerns the evolution of VRS or BCC efficiency scores over the same 5 year time period, the number of DMUs with maximum relational dual-stage efficiency doubled. Audible.com suffered a very steep drop in both marketability and

profitability efficiency, while CNet lost marketability efficiency while improving profitability efficiency, quadrupling overall dual-stage efficiency.

The last column in both Tables 1 and 2 shows the ratio of BCC over CCR relational dual-stage efficiency. The biggest decrease in the ratios for the 5 year time period concerns Audible.com as its BCC overall efficiency dropped steeply with a slight increase in its CCR overall efficiency.

Table 3 presents the results of analysis of market capital increase and stock price increase over the period 2000-2005, and up to 2012 for market price only. Differences between market price and capital changes in the 2000 to 2005 period indicate that either public-offerings occurred in the meantime with capital increase, or stock options were exercised, or insider stock acquisition took place.

**Table 3.** Market capital and market price change

Unit Name	2000-2005 Market Capital increase	2000-2005 Market Price change	2005-2012 Market Price change	2000-2012 Market Price change
ADBL	1180%	1429%	-	-
AMZN	119%	240%	463%	1813%
CNET	201%	82%	-	-
EBAY	1136%	472%	30%	641%
EDGR	306%	96%	-	-
INSW	18%	175%	-	-
LOOK	82%	-70%	-76%	-93%
TSCM	404%	229%	-77%	-26%
YHOO	431%	178%	-50%	39%

Analysis of association was carried out over the whole data set, including original data and the results presented in Tables 1, 2 and 3. Statistically significant Pearson correlation coefficients are shown in Table 4. Moreover, a linear regression analysis was carried out for market price change over the period 2000 to 2005 based on the beginning of period data and the relational dual-stage efficiency analysis results for the same time (Table 5). Due to very small numbers (n=5) of surviving independent companies by the end of 2012, regression analysis was not possible for market price change over the period 2005 to 2012.

The results of analysis of association shown in Table 4 reveal the importance of the constant returns to scale dual-stage efficiency in predicting market capital in 2005. These results also shed light on the high strength of association between market price change in the period from 2000 to 2005 and ratio between VRS and CCR dual-stage DEA efficiency based on 2000 data. The Linear regression analysis results performed on the former, shown in Table 5, obtained a very high determination of 94,70%, significant at  $p < 0.05$ . Significance of regression coefficients and standardized coefficient values corroborate the importance of the aforementioned ratio.

**Table 4.** Pearson correlation coefficients attaining statistical significance

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
(1)	1			0,683*							
(2)		1							0,897◇		
(3)			1			0,747*	0,886◇	0,754◇		0,741*	
(4)	0,683*			1			0,832◇				
(5)					1				0,807◇		
(6)			0,747*			1					
(7)			0,886◇	0,832◇			1				
(8)			0,754◇					1		1,000	0,983◇
(9)		0,897◇			0,807◇				1		
(10)			0,741*					1,000◇		1	0,982◇
(11)								0,983◇		0,982◇	1

\* -  $p < 0.05$ , ◇ -  $p < 0.01$ , r – ratio, incr. – increase, ch. – change, n=9 for 2000 and 2005 data, n=5 for 2012 data; (1) - 2000 Ek CCR; (2) - 2000 r. Ek BCC / CCR; (3) - 2000 market capital; (4) - 2005 market capital; (5) - 2000-2005 market capital incr.; (6) - 2000 market price ; (7) - 2005 market price ; (8) - 2012 market price; (9) - 2000-2005 market price change; (10) - 2005-2012 market price change; (11) - 2000-2012 market price change.

**Table 5.** Linear regression analysis of Market price change over the period from 2000 to 2005, based on CRS and VRS relational dual-stage DEA measures of efficiency and market data

Variable	Coefficient	Std. Error	t	P> t	[95% Conf. Interval]		Std. Coeff.s
2000 Ek CRS	6.275	3.946	1.59	0.21	-6.28	18.83	0.444
2000 Ek VRS	-6.670	2.798	-2.38	0.09	-15.58	2.23	-0.637
2000 r .Ek	0.276	0.047	5.84	0.01	0.12	0.42	1.284
2000 mark. pr.	-0.269	0.190	-1.42	0.25	-0.87	0.33	-0.347
Regr. Const.	2.745	1.397	1.96	0.14	-1.70	7.19	-

r. – ratio BCC / CCR, Ek – relational dual-stage efficiency of DMU, n=9.

## 5 Discussion

The question whether variable returns to scale are more adequate to dual-stage DEA efficiency measures of Internet companies than constant returns to scale, remains to be answered. The results, from hindsight of the period from 2000 to 2005, suggest that both CRS and VRS modalities should be considered in DMU efficiency assessment of Internet companies, considering a relational dual-stage DEA analysis.

The CCR efficiency and the ratio of BCC efficiency over CCR, were found in the sample considered to be moderately to strongly associated with end of period market capital ( $r=0.683$ ,  $p<0.05$ ) and stock price increase in the period ( $r=0.897$ ,  $p<0.01$ ), respectively.

While the Dual-Stage efficiency obtained from the CCR modality of DEA showed predictive power (considering the correlation between this efficiency score obtained from 2000 data and the market capital of the units in 2005), it was the ratio between the dual-stage efficiencies (BCC over CCR) that exhibited the highest correlation with market price increase of the units in the five year period. The small sample and the particular characteristics of the 5 year period encompassed (dot com bubble burst in the collapse of the Internet sector in the year 2000) do not enable generalising the results. This notwithstanding, the results suggest that both forms of dual-stage DEA efficiency score modality may be relevant for judging investment alternatives for Internet companies. Future research, on a wider empirical basis is needed to confirm these findings.

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