Chapter 3

Measure-specific DEA Models

3.1 Measure-specific Models

Although DEA does not need *a priori* information on the underlying functional forms and weights among various input and output measures, it assumes proportional improvements of inputs or outputs. This assumption becomes invalid when a preference structure over the improvement of different inputs (outputs) is present in evaluating (inefficient) DMUs (see Chapter 4). We need models where a particular set of performance measures is given pre-emptive priority to improve.

Let $I \subseteq \{1,2, \ldots, m\}$ and $O \subseteq \{1,2, \ldots,s\}$ represent the sets of specific inputs and outputs of interest, respectively. Based upon the envelopment models, we can obtain a set of measure-specific models where only the inputs associated with I or the outputs associated with O are optimized (see Table 3.1).

The measure-specific models can be used to model uncontrollable inputs and outputs (see Banker and Morey (1986)). The controllable measures are related to set I or set O.

A DMU is efficient under envelopment models if and only if it is efficient under measure-specific models. i.e., both the measure-specific models and the envelopment models yield the same frontier. However, for inefficient DMUs, envelopment and measure-specific models yield different efficient targets.

Consider Figure 1.1. If the response time input is of interest, then the measure-specific model will yield the efficient target of S1 for inefficient S. If the cost input is of interest, S3 will be the target for S. The envelopment model projects S to S2 by reducing the two inputs proportionally.

Table 3.1. Measure-specific Models

Frontier Type	Input-Oriented	Output-Oriented
CRS	$\min \theta - \varepsilon(\sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+)$ subject to $\sum_{j=1}^{n} \lambda_j x_{ij} + s_i^- = \theta x_{io} \quad i \in I;$ $\sum_{j=1}^{n} \lambda_j x_{ij} + s_i^- = x_{io} \quad i \notin I;$ $\sum_{j=1}^{n} \lambda_j y_{rj} - s_r^+ = y_{ro} \quad r = 1,2,...,s;$ $\lambda_j \geq 0 \quad j = 1,2,...,n.$	$\max \phi - \varepsilon(\sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+)$ subject to $\sum_{j=1}^{n} \lambda_j x_{ij} + s_i^- = x_{io} \quad i = 1,2,...,m;$ $\sum_{j=1}^{n} \lambda_j y_{rj} - s_r^+ = \phi y_{ro} \quad r \in O;$ $\sum_{j=1}^{n} \lambda_j y_{rj} - s_r^+ = y_{ro} \quad r \notin O;$ $\lambda_j \geq 0 \quad j = 1,2,...,n.$
VRS	Add $\sum_{j=1}^{n} \lambda_j = 1$	
NIRS	Add $\sum_{j=1}^{n} \lambda_j \leq 1$	
NDRS	Add $\sum_{j=1}^{n} \lambda_j \geq 1$	
Efficient Target	$\begin{cases} \hat{x}_{io} = \theta^* x_{io} - s_i^{-*} & i \in I \\ \hat{x}_{io} = x_{io} - s_i^{-*} & i \notin I \\ \hat{y}_{ro} = y_{ro} + s_r^{+*} & r = 1,2,...,s \end{cases}$	$\begin{cases} \hat{x}_{io} = x_{io} - s_i^{-*} & i = 1,2,...,m \\ \hat{y}_{ro} = \phi^* y_{ro} + s_r^{+*} & r \in O \\ \hat{y}_{ro} = y_{ro} + s_r^{+*} & r \notin O \end{cases}$

3.2 Measure-specific Models in Spreadsheets

Since the measure-specific models are closely related to the envelopment models, the spreadsheet models can be modified from the envelopment spreadsheet models.

Figure 3.1 shows an input-oriented VRS measure-specific spreadsheet model where the Assets input is of interest. We only need to change the formulas in cells D21:D22 (representing Equity and Employee for the DMU under evaluation) in the input-oriented VRS envelopment spreadsheet model shown in Figure 1.8 to

Cell D21 =INDEX(C2:C16,E18,1)
Cell D22 =INDEX(C2:C16,E18,1)

The Solver parameters remain the same, as shown in Figure 1.15. All the VBA procedures developed for the envelopment models can be used. In Figure 3.1, the VBA procedure "DEA1" is assigned to the button "Measure-Specific".

If we apply the same formula changes in the Second-stage Slack Spreadsheet Model shown in Figure 1.23, with the same Solver parameters shown in Figure 1.24 and with the macro "DEASlack", we can optimize the slacks for the spreadsheet model shown in Figure 3.1 after we obtain the efficiency scores. Figure 3.2 shows the results (see Excel file measure-specific spreadsheet.xls in the CD).

	A	B	C	D	E	F	G	H	I	J
1	Company	Assets	Equity	Employees		Revenue	Profit		λ	Efficiency
2	Mitsubishi	91920.6	10950	36000		184365.2	346.2		0	1
3	Mitsui	68770.9	5553.9	80000		181518.7	314.8		0	1
4	Itochu	65708.9	4271.1	7182		169164.6	121.2		0	1
5	General Motors	217123.4	23345.5	709000		168828.6	6880.7		0	1
6	Sumitomo	50268.9	6681	6193		167530.7	210.5		0.56	1
7	Marubeni	71439.3	5239.1	6702		161057.4	156.6		0	1
8	Ford Motor	243283	24547	346990		137137	4139		0	0.377606
9	Toyota Motor	106004.2	49691.6	146855		111052	2662.4		0	0.578288
10	Exxon	91296	40436	82000		110009	6470		0	1
11	Royal Dutch/Shell Group	118011.6	58986.4	104000		109833.7	6904.6		0	1
12	Wal-Mart	37871	14762	675000		93627	2740		0.44	1
13	Hitachi	91620.9	29907.2	331852		84167.1	1468.8		0	0.484837
14	Nippon Life Insurance	364762.5	2241.9	89690		83206.7	2426.6		0	1
15	Nippon Telegraph & Telephone	127077.3	42240.1	231400		81937.2	2209.1		0	0.42684
16	AT&T	88884	17274	299300		79609	139		0	0.504427
17										
18		Reference		DMU under	15	Efficiency				
19	**Constraints**	set		Evaluation		0.504427				
20	Assets	44835.477	≤	44835.477						
21	Equity	10222.526	≤	17274						
22	Employees	299300	≤	299300				Measure-Specific		
23	Revenue	135142.15	≥	79609						
24	Profit	1319.0622	≥	139						
25	Σλ	1	=	1						

Figure 3.1. Input-oriented VRS Measure-specific Spreadsheet Model

	E	F	G	H	I	J	K	L	M	N	O	P
1		Revenue	Profit		λ	Efficiency		Assets	Equity	Employees	Revenue	Profit
2		184365.2	346.2		0	1		0	0	0	0	0
3		181518.7	314.8		0	1		0	0	0	0	0
4		169164.6	121.2		0	1		0	0	0	0	0
5		168828.6	6880.7		0	1		0	0	0	0	0
6		167530.7	210.5		0.7705	1		0	0	0	0	0
7		161057.4	156.6		0	1		0	0	0	0	0
8		137137	4139		0	0.737556		75728.26	0	220277.5	0	0
9		111052	2662.4		0	0.603245		0	30247.6	58265.4	29763.39	0
10		110009	6470		0	1		0	0	0	0	0
11		109833.7	6904.6		0	1		0	0	0	0	0
12		93627	2740		0.2295	1		0	0	0	0	0
13		84167.1	1468.8		0	0.557596		0	17865.99	146812.7	58813.12	0
14		83206.7	2426.6		0	1		0	0	0	0	0
15		81937.2	2209.1		0	0.470611		0	25465.33	122500.6	60995.79	0
16		79609	139		0	0.533544		0	8738.346	139610.4	70960.21	652.0406
17												
18	15											
19		**Slack**										
20		0										
21		8738.346										
22		139610.4		Slack								
23		70960.21										
24		652.0406										
25		219961										

Figure 3.2. Second-stage Slacks for Input-oriented VRS Measure-specific Model

3.3 Performance Evaluation of Fortune 500 Companies

Fortune magazine analyzes the financial performance of companies by eight measures: revenue, profit, assets, number of employees (employees), stockholders' equity (equity), market value (MV), earnings per share (EPS) and total return to investors (TRI).

In order to obtain an overall performance index, Zhu (2000) employs DEA to reconcile these eight measures via a two-stage transformation process described in Figure 3.3. Each stage is defined by a group of "inputs (x)" and "outputs (y)".

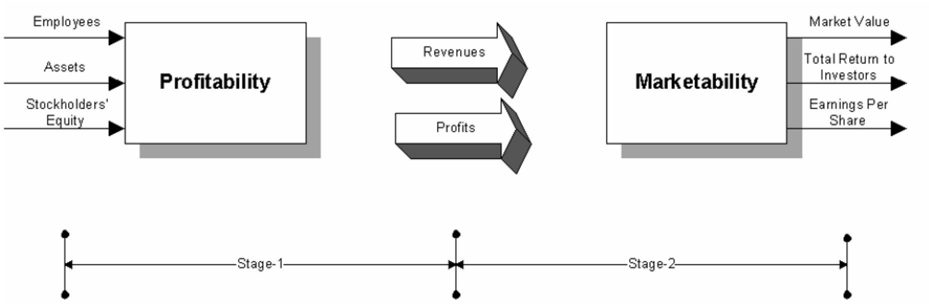

Figure 3.3. Input-output System for Fortune 500 Companies

The performance in the first stage (stage-1) may be viewed as profitability, i.e., a company's ability to generate the revenue and profit in terms of its current labor, assets and capital stock. The performance in the second stage (stage-2) may be viewed as (stock) marketability, i.e., a company's performance in stock market by its revenue and profit generated.

The data of 1995 is used. The DMU numbers correspond to the ranks by the magnitude of revenues. Because some data on MV, profit and equity are not available for some companies, we exclude these companies, and analyze the performance of the 364 companies.

2.3.1 Identification of Best Practice Frontier

Because the Fortune 500 list consists of a variety of companies representing different industries, we assume that the best-practice frontier exhibits VRS. We use the input-oriented VRS envelopment model to identify the best-practice.

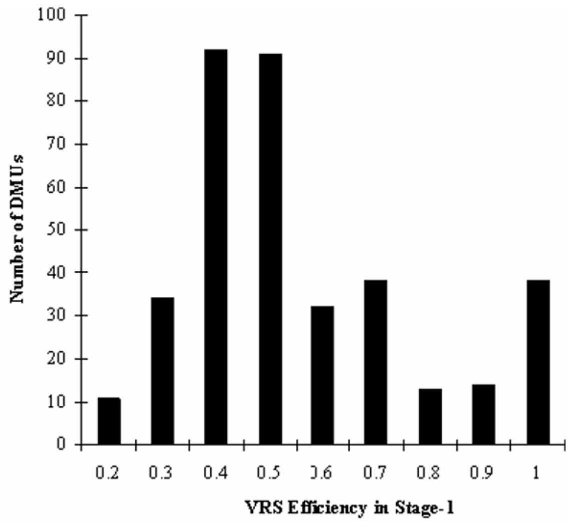

Figure 3.4. Profitability VRS Efficiency Distribution

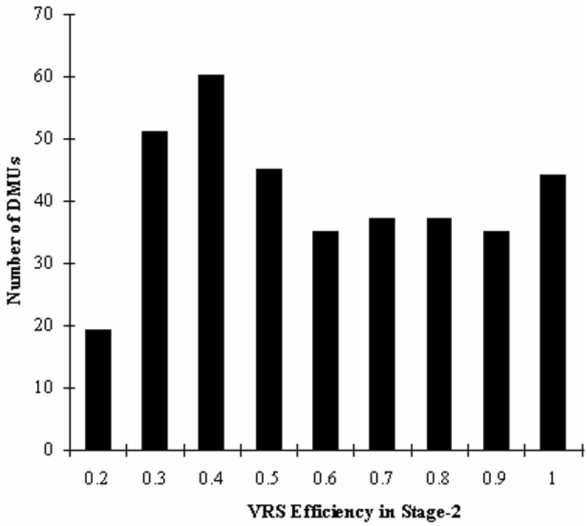

Figure 3.5. Marketability VRS Efficiency Distribution

Figures 3.4 and 3.5 report the distributions of VRS efficiency scores. 30 and 16 DMUs are VRS-efficient in profitability (stage-1) and marketability (stage-2), respectively. In stage-1, most VRS scores are distributed over [0.27, 0.51]. In stage-2, the VRS scores are almost evenly distributed over [0.16, 1]. Only four companies, namely, General Electric (DMU7), Coca-

Cola (DMU48), Nash Finch (DMU437), and CompUSA (DMU451) are on the best-practice frontiers of stage-1 and stage-2.

2.3.2 Measure-specific Performance[1]

Proportional reductions of all inputs are used to determine the best practice frontier for the Fortune 500 companies. However, in an evaluation of inefficient DMUs, non-proportional input (output) improvement may be more appropriate. Therefore, we seek an alternative way to further characterize the performance of inefficient companies by measure-specific models.

Because we have already obtained the VRS best-practice frontier and the measure-specific models yield the same frontier, we modify the VRS measure-specific models for a particular inefficient DMU_d,

$$\begin{aligned}
&\theta_d^{k*} = \min \theta_d^k \quad d \in \mathbf{N}\\
&\text{subject to}\\
&\sum_{j\in\mathbf{E}} \lambda_j^d x_{kj} = \theta_d^k x_{kd} \qquad k \in \{1,\ldots,m\}\\
&\sum_{j\in\mathbf{E}} \lambda_j^d x_{ij} \le x_{id} \qquad i \ne k\\
&\sum_{j\in\mathbf{E}} \lambda_j^d y_{rj} \ge y_{rd} \qquad r = 1,\ldots,s\\
&\sum_{j\in\mathbf{E}} \lambda_j^d = 1\\
&\lambda_j^d \ge 0,\ j \in \mathbf{E}.
\end{aligned} \tag{3.1}$$

$$\begin{aligned}
&\phi_d^{q*} = \max \phi_d^q \quad d \in \mathbf{N}\\
&\text{subject to}\\
&\sum_{j\in\mathbf{E}} \lambda_j^d y_{qj} = \phi_d^q y_{qd} \qquad q \in \{1,\ldots,s\}\\
&\sum_{j\in\mathbf{E}} \lambda_j^d y_{rj} \ge y_{rd} \qquad r \ne q\\
&\sum_{j\in\mathbf{E}} \lambda_j^d x_{ij} \le x_{id} \qquad i = 1,\ldots,m\\
&\sum_{j\in\mathbf{E}} \lambda_j^d = 1\\
&\lambda_j^d \ge 0,\ j \in \mathbf{E}.
\end{aligned} \tag{3.2}$$

where **E** and **N** represent the index sets for the efficient and inefficient companies, respectively, identified by the VRS envelopment DEA model.

[1] The material in this section is adapted from European Journal of Operational Research, Vol 123, Zhu, J., Multi-factor Performance Measure Model with An Application to Fortune 500 Companies, 105-124, 2000, with permission from Elsevier Science.

Table 3.2. Profitability Measure-specific Efficiency

DMU No.	Company Name	Profitability employees	assets	equity	revenue	profit
1	General Motors	1.000	1.000	1.000	1.000	1.000
2	Ford Motors	1.000	1.000	1.000	1.000	1.000
3	Exxon	1.000	1.000	1.000	1.000	1.000
4	Wal-Mart Stores	1.000	1.000	1.000	1.000	1.000
5	AT&T	0.479	0.503	0.653	1.172	41.670
6	IBM	0.304	0.598	0.573	1.307	1.397
7	General Electric	1.000	1.000	1.000	1.000	1.000
8	Mobil	1.000	1.000	1.000	1.000	1.000
9	Chrysler	0.805	0.735	0.906	1.060	1.381
10	Philip Morris	1.000	1.000	1.000	1.000	1.000
13	Du Pont De Nemours	0.933	0.950	0.976	1.015	1.039
14	Texaco	0.933	0.862	0.936	1.046	2.475
15	Sears Roebuck	1.000	1.000	1.000	1.000	1.000
17	Procter & Gamble	0.325	0.743	0.654	1.291	1.413
18	Chevron	0.493	0.469	0.444	1.716	4.100
19	Citicorp	0.285	0.096	0.385	2.237	1.415
20	Hewlett-Packard	0.286	0.772	0.535	1.287	1.443
Average		0.755	0.808	0.827	1.184	3.784

Table 3.3. Marketability Measure-specific Efficiency

DMU No.	Company Name	Marketability Revenue	Profit	MV	TRI	EPS
1	General Motors	0.025	0.010	3.207	9.258	84.743
2	Ford Motors	0.028	0.013	3.314	33.754	170.670
3	Exxon	0.155	0.088	1.284	3.022	41.071
4	Wal-Mart Stores	0.058	0.029	2.011	43.768	447.912
5	AT&T	1.000	1.000	1.000	1.000	1.000
6	IBM	0.114	0.032	1.690	7.235	59.740
7	General Electric	1.000	1.000	1.000	1.000	1.000
8	Mobil	0.068	0.052	2.401	6.494	103.697
9	Chrysler	0.057	0.020	4.388	17.559	115.283
10	Philip Morris	0.239	0.095	1.408	2.465	47.335
13	Du Pont De Nemours	0.122	0.023	2.342	8.748	107.288
14	Texaco	0.080	0.059	3.202	7.863	243.004
15	Sears Roebuck	0.079	0.020	4.737	9.926	135.778
17	Procter & Gamble	0.168	0.127	1.789	5.644	138.595
18	Chevron	0.122	0.059	2.035	11.386	427.273
19	Citicorp	0.118	0.017	3.000	4.154	82.197
20	Hewlett-Packard	0.172	0.111	1.839	3.268	111.866
Average		0.212	0.162	2.391	10.385	136.379

Models (3.1) and (3.2) determine the maximum potential decrease of an input and increase of an output while keeping other inputs and outputs at current levels.

Tables 3.2 and 3.3 report the results for the top-20 companies. Recall that revenue and profit are two factors served as the two outputs in stage-1 and the two inputs in stage-2. Therefore, we have two measure-specific efficiency scores for each revenue and each profit.

Table 3.4. Profitability Measure-specific Industry Efficiency

Industries	Employees	Assets	Equity	Revenue	Profit
Aerospace	0.12 (0.11)	0.30 (0.35)	0.24 (0.23)	1.98 (2.26)	3.85 (4.16)
Airlines	0.12 (0.12)	0.24 (0.29)	0.24 (0.27)	1.95 (2.37)	4.54 (5.36)
Beverages	0.34 (0.33)	0.56 (0.46)	0.56 (0.39)	1.71 (2.17)	1.72 (4.96)
Chemicals	0.46 (0.32)	0.56 (0.46)	0.46 (0.31)	1.91 (2.54)	1.83 (2.46)
Commercial Banks	0.13 (0.13)	0.06 (0.05)	0.31 (0.24)	3.66 (4.26)	2.62 (3.24)
Computer and Data Services	0.20 (0.30)	0.57 (0.54)	0.36 (0.31)	2.93 (3.12)	1.69 (2.39)
Computers, Office Equipment	0.25 (0.26)	0.60 (0.59)	0.48 (0.38)	1.51 (2.00)	1.77 (3.33)
Diversified Financials	0.15 (0.38)	0.62 (0.39)	0.39 (0.43)	2.46 (3.09)	2.08 (2.40)
Electric & Gas Utilities	0.30 (0.32)	0.18 (0.18)	0.16 (0.15)	3.73 (3.85)	2.69 (4.03)
Electronics, Electrical Equipment	0.41 (0.30)	0.86 (0.53)	0.69 (0.38)	1.68 (2.35)	1.57 (3.12)
Entertainment	0.12 (0.16)	0.20 (0.24)	0.15 (0.25)	3.24 (3.06)	4.33 (7.86)
Food	0.29 (0.35)	0.45 (0.55)	0.32 (0.43)	1.84 (2.01)	2.49 (6.26)
Food & Drug Stores	0.35 (0.23)	0.70 (0.64)	0.44 (0.41)	1.49 (1.83)	2.39 (3.34)
Forest & Paper Products	0.16 (0.17)	0.30 (0.36)	0.21 (0.18)	2.47 (2.83)	3.44 (7.88)
General Merchandisers	0.65 (0.32)	0.85 (0.65)	0.65 (0.43)	1.35 (2.16)	1.95 (3.52)
Health Care	0.07 (0.30)	0.34 (0.47)	0.23 (0.32)	2.69 (2.75)	3.61 (4.94)
Industrial & Farm Equipment	0.14 (0.13)	0.33 (0.36)	0.24 (0.18)	2.43 (2.89)	2.78 (3.59)
Insurance: Life & Health (stock)	0.15 (0.25)	0.06 (0.07)	0.19 (0.22)	2.57 (2.97)	4.72 (5.23)
Insurance: Property & Causality (stock)	0.29 (0.37)	0.29 (0.27)	0.47 (0.35)	2.26 (2.76)	1.84 (2.64)
Metal Products	0.12 (0.11)	0.43 (0.42)	0.19 (0.17)	3.04 (3.28)	2.82 (4.83)
Motor Vehicles & Parts	0.77 (0.32)	0.92 (0.51)	0.84 (0.39)	1.19 (2.11)	1.36 (2.67)
Petroleum Refining	0.64 (0.51)	0.71 (0.50)	0.73 (0.44)	1.29 (1.72)	1.85 (6.28)
Pharmaceuticals	0.38 (0.41)	0.63 (0.64)	0.52 (0.54)	2.02 (2.14)	1.44 (1.59)
Pipelines	0.63 (0.57)	0.51 (0.44)	0.59 (0.50)	1.76 (1.91)	1.40 (2.64)
Publishing, Printing	0.13 (0.20)	0.39 (0.43)	0.16 (0.21)	3.35 (3.44)	2.77 (2.84)
Soaps, Cosmetics	0.40 (0.47)	0.64 (0.64)	0.58 (0.58)	1.40 (1.45)	1.67 (3.00)
Special Retailers	0.24 (0.27)	0.69 (0.66)	0.35 (0.40)	1.72 (2.11)	2.39 (4.28)
Telecommunications	0.36 (0.25)	0.41 (0.34)	0.42 (0.33)	1.70 (2.45)	3.72 (10.19)
Temporary Help	0.50 (0.56)	0.84 (0.87)	0.68 (0.68)	1.30 (1.31)	1.39 (1.31)
Wholesalers	0.54 (0.58)	0.69 (0.74)	0.38 (0.55)	1.34 (1.46)	2.37 (2.08)

* The number in parenthesis represents the arithmetic average.

We may use the average measure-specific efficiency scores (optimal values to (3.1) or (3.2)) within each industry to characterize the measure-specific industry efficiency. However, different companies with different sizes may exist in each industry. Therefore arithmetic averages may not be a good way to characterize the industry efficiency. Usually, one expects large input and output levels, e.g., assets and revenue, form relatively big companies.

Table 3.5. Marketability Measure-specific Industry Efficiency

Industries	Revenue	Profit	MV	TRI	EPS
Aerospace	0.21 (0.29)	0.06 (0.06)	3.44 (4.51)	5.88 (6.39)	102.60 (131.24)
Airlines	0.35 (0.55)	0.34 (0.38)	4.73 (4.10)	2.66 (5.80)	35.65 (54.23)
Beverages	0.64 (0.61)	0.80 (0.37)	1.37 (2.67)	4.57 (4.94)	102.55 (95.84)
Chemicals	0.32 (0.52)	0.06 (0.11)	3.55 (4.16)	9.63 (13.37)	84.31 (100.13)
Commercial Banks	0.34 (0.51)	0.07 (0.13)	3.94 (4.05)	6.40 (5.98)	85.39 (104.16)
Computer and Data Services	0.82 (0.85)	0.83 (0.66)	1.20 (1.52)	4.01 (5.68)	38.83 (38.77)
Computers, Office Equipment	0.24 (0.50)	0.09 (0.02)	2.37 (3.90)	4.28 (8.59)	84.83 (86.03)
Diversified Financials	0.33 (0.47)	0.13 (0.17)	2.82 (3.79)	5.24 (7.31)	6.88 (117.12)
Electric & Gas Utilities	0.56 (0.65)	0.08 (0.14)	4.99 (5.00)	10.34 (11.68)	128.75 (126.03)
Electronics, Electrical Equipment	0.63 (0.54)	0.47 (0.19)	2.14 (3.54)	6.34 (14.22)	86.56 (87.05)
Entertainment	0.40 (0.50)	0.41 (0.39)	1.49 (1.56)	6.96 (10.07)	248.91 (285.42)
Food	0.30 (0.42)	0.09 (0.20)	3.42 (3.28)	8.83 (16.35)	145.47 (143.31)
Food & Drug Stores	0.28 (0.44)	0.10 (0.21)	5.52 (5.31)	6.24 (25.35)	83.66 (86.30)
Forest & Paper Products	0.49 (0.59)	0.06 (0.16)	4.24 (5.14)	11.63 (26.57)	67.17 (66.03)
General Merchandisers	0.12 (0.32)	0.04 (0.08)	3.48 (4.33)	17.41 (24.60)	129.62 (152.9)
Health Care	0.50 (0.66)	0.16 (0.28)	2.68 (2.91)	8.95 (13.56)	98.43 (95.67)
Industrial & Farm Equipment	0.39 (0.52)	0.08 (0.15)	4.19 (4.20)	7.56 (13.39)	98.35 (103.26)
Insurance: Life & Health (stock)	0.37 (0.53)	0.10 (0.14)	4.86 (5.16)	6.25 (6.58)	57.71 (65.72)
Insurance: Property & Causality (stock)	0.28 (0.47)	0.05 (0.08)	4.09 (5.55)	6.42 (8.49)	71.85 (80.33)
Metal Products	0.63 (0.70)	0.30 (0.36)	2.22 (2.12)	7.47 (8.89)	103.54 (96.76)
Motor Vehicles & Parts	0.07 (0.32)	0.02 (0.08)	41.19 (5.72)	13.26 (30.38)	77.53 (77.95)
Petroleum Refining	0.17 (0.36)	0.07 (0.16)	2.41 (4.21)	9.94 (18.53)	102.81 (122.06)
Pharmaceuticals	0.44 (0.44)	0.33 (0.29)	1.75 (2.00)	4.77 (5.65)	163.58 (193.30)
Pipelines	0.51 (0.65)	0.07 (0.13)	4.38 (4.22)	5.22 (6.47)	46.10 (103.94)
Publishing, Printing	0.67 (0.73)	0.21 (0.22)	3.23 (3.19)	14.35 (19.16)	69.09 (73.99)
Soaps, Cosmetics	0.25 (0.37)	0.13 (0.12)	1.89 (2.23)	10.04 (11.98)	101.42 (109.16)
Special Retailers	0.40 (0.60)	0.15 (0.30)	3.19 (3.90)	6.79 (20.26)	103.34 (98.36)
Telecommunications	0.68 (0.44)	0.12 (0.25)	1.85 (2.53)	7.19 (61.16)	188.16 (214.68)
Temporary Help	0.69 (0.78)	0.32 (0.36)	3.68 (3.52)	18.87 (93.62)	30.83 (30.48)
Wholesalers	0.37 (0.47)	0.18 (0.30)	3.95 (4.61)	6.64 (8.83)	49.55 (49.33)

* The number in parenthesis represents the arithmetic average.

Thus, we define weighted measure-specific scores within each industry by considering the sizes of the companies.

*(size-adjusted) k*th input-specific industry efficiency measure for industry **F**

$$I_k^{\mathbf{F}} = \sum_{d\in\mathbf{F}} \theta_d^{k*} \cdot \frac{x_{kd}}{\sum_{d\in\mathbf{F}} x_{kd}} = \frac{\sum_{d\in\mathbf{F}} \hat{x}_{kd}}{\sum_{d\in\mathbf{F}} x_{kd}} \tag{3.3}$$

*(size-adjusted) q*th output-specific industry efficiency measure for industry **F**

$$O_q^{\mathbf{F}} = \sum_{d\in\mathbf{F}} \phi_d^{q*} \cdot \frac{y_{qd}}{\sum_{d\in\mathbf{F}} y_{qd}} = \frac{\sum_{d\in\mathbf{F}} \hat{y}_{qd}}{\sum_{d\in\mathbf{F}} y_{qd}} \tag{3.4}$$

where $\hat{x}_{kd}$ (= $\theta_d^{k*} x_{kd}$) and $\hat{y}_{qd}$ (= $\phi_d^{q*} y_{qd}$) are, respectively, the projected (potentially efficient) levels for *k*th input and *q*th output of DMU_d, $d\in$ **F**.

The weights in (3.3) ($\frac{x_{kd}}{\sum_{d\in\mathbf{F}} x_{kd}}$, $d\in$ **F**) and (2.4) ($\frac{y_{qd}}{\sum_{d\in\mathbf{F}} y_{qd}}$, $d\in$ **F**) are normalized, therefore a specific industry F achieves 100% efficiency, i.e., $I_k^{\mathbf{F}}$ = 1 and $O_q^{\mathbf{F}}$ = 1, if and only if, all of its companies are located on the best-practice frontier.

Tables 3.4 and 3.5 report the industry efficiency scores for the 30 selected industries where the number in parenthesis represents the corresponding arithmetic mean of measure-specific efficiency scores.

A relatively large discrepancy between weighted and arithmetic average scores is detected for six industries – General Merchandiser, Health Care, Motor Vehicles & Parts, Petroleum Refining, Pipelines, and Telecommunications. Since (3.3) and (3.4) determine the industry efficiency by considering the size of each company, this may imply that efficiency may highly correlate with size in these industries.

2.3.3 Benchmark Share

Non-zero λ_j^* indicates that DMU$_j$ is used as a benchmark. As an efficient company, the role it plays in evaluating inefficiency companies is to be of interest. One wants to know the importance of each efficient DMU in measuring the inefficiencies of inefficient DMUs. Based upon the non-zero λ_j^*, we develop benchmark-share measures for each efficient company via (3.1) and (3.2).

We define the *k*th input-specific benchmark-share for each efficient DMU_j, $j \in \mathbf{E}$,

$$\Delta_j^k = \frac{\sum_{d \in \mathbf{N}} \lambda_j^{d*}(1-\theta_d^{k*})x_{kd}}{\sum_{d \in \mathbf{N}} (1-\theta_d^{k*})x_{kd}} \tag{3.5}$$

where λ_j^{d*} and θ_d^{k*} are optimal values in (3.1).

We define the qth output-specific benchmark-share for each efficient DMU_j, $j \in \mathbf{E}$,

$$\Pi_j^q = \frac{\sum_{d \in \mathbf{N}} \lambda_j^{d*}(\phi_d^{q*}-1)y_{qd}}{\sum_{d \in \mathbf{N}} (\phi_d^{q*}-1)y_{qd}} \tag{3.6}$$

where λ_j^{d*} and ϕ_d^{q*} are optimal values in (3.2).

The benchmark-share Δ_j^k (or Π_j^q) depends on the values of λ_j^{d*} and θ_d^{k*} (or λ_j^{d*} and ϕ_d^{q*}). Note that $(1-\theta_d^{k*})x_{kd}$ and $(\phi_d^{q*}-1)y_{qd}$ characterize the potential decrease on kth input and increase on qth output, respectively.

Δ_j^k and Π_j^q are weighted λ_j^* across all inefficient DMUs. The weights, $\frac{(1-\theta_d^{k*})x_{kd}}{\sum_{d \in \mathbf{N}} (1-\theta_d^{k*})x_{kd}}$ in (3.5) and $\frac{(\phi_d^{q*}-1)y_{qd}}{\sum_{d \in \mathbf{N}} (\phi_d^{q*}-1)y_{qd}}$ in (3.6) are normalized. Therefore, we have $\sum_{j \in \mathbf{E}} \Delta_j^k = 1$ and $\sum_{j \in \mathbf{E}} \Pi_j^q = 1$. (Note that $\sum_{j \in \mathbf{E}} \lambda_j^{d*} = 1$ in (3.1) and (3.2).)

It is very clear form (3.5) and (3.6) that an efficient company which does not act as a referent DMU for any inefficient DMU will have zero benchmark-share. The bigger the benchmark-share, the more important an efficient company is in benchmarking.

Table 3.6 reports the benchmark-shares for 12 selected VRS-efficient companies. The benchmark-shares for the remaining VRS-efficient companies are less than 0.01%. Of the total 60 benchmark-shares, 12 are greater than 10%. Particularly, DMU48 (Coca-Cola), DMU156 (General Mills) and DMU281 (Bindley Western) have the biggest benchmark-share with respect to employees, equity and profit, respectively. This means that, e.g., General Mills plays a leading role in setting a benchmark with respect to equity input given the current levels of employees and assets. Note that General Mills had the highest returns on equity in 1995.

In Table 2.7, DMU226 (Continental Airlines) and DMU292 (Berkshire Hathaway) are two important companies in TRI and EPS benchmarking, respectively. (Note that Continental Airlines and Berkshire Hathaway had the highest TRI and EPS in 1995.) Although Berkshire Hathaway was ranked 18 in terms of MV levels by the Fortune magazine, the benchmark-share of 39.99% indicates that it had an outstanding performance in terms of

MV given other measures at their current levels. This indicates that single financial performance alone is not sufficient to characterize a company's performance.

Finally, note that, e.g., DMU292 and DMU474 both acted as a referent DMU in 63% of the inefficient DMUs when measuring the revenue-specific efficiency. However, the benchmark-share indicates that DMU474 is more important.

Table 3.6. Benchmark-share for Profitability

DMU No.	Company Name	Employees	Assets	Equity	Revenue	Profit
8	Mobil	3.07%	1.51%	0.76%	**16.00%**	0.15%
32	Fed. Natl. Mortgage	2.78%	0	2.76%	0.89%	0.10%
44	Loews	7.17%	0.14%	0	0.95%	1.41%
48	Coca-Cola	2.58%	**12.54%**	**10.65%**	2.88%	**40.65%**
94	IBP	0	**22.51%**	0.07%	**13.16%**	0.80%
153	Bergen Brunswig	0.60%	0	0.16%	5.91%	0.17%
156	General Mills	1.86%	0.01%	**60.91%**	**17.19%**	7.85%
168	Cardinal Health	3.12%	2.82%	0.01%	**10.89%**	0
281	Bindley Western	**52.91%**	4.79%	2.93%	5.97%	2.86%
419	Micron Technology	0.17%	**28.37%**	0.24%	0.29%	**11.04%**
437	Nash Finch	0	**10.16%**	0.02%	0.24%	0.27%
447	Williams	8.68%	0	0	0.02%	8.62%
Total		82.94%	82.85%	78.51%	74.39%	73.92%

Table 3.7. Benchmark-share for Marketability

DMU No.	Company Name	Revenue	Profit	MV	TRI	EPS
5	AT&T	0	**12.33%**	6.95%	2.22%	0
7	IBM	0	0.20%	3.83%	6.39%	0.79%
48	Coca-Cola	5.44%	0.80%	**11.37%**	0.13%	0.11%
78	Kimberly-Clark	0.04%	**36.66%**	6.96%	0	0.10%
210	Burlington Northern Santa FE	0.05%	4.29%	6.39%	0	0
219	Microsoft	8.46%	0	9.97%	0	0
226	Continental Airlines	0.44%	0.69%	1.30%	**81.91%**	0.87%
292	Berkshire Hathaway	**23.56%**	8.37%	**39.99%**	0.18%	**73.96%**
312	Chiquita Brands International	0.00%	**15.49%**	0.07%	0.17%	**11.41%**
376	Consolidated Natural Gas	0.99%	**11.29%**	4.89%	0.05%	0.00%
417	Oracle	0.00%	0.00%	1.37%	0	0
437	Nash Finch	0.09%	0.51%	0	0	3.56%
451	CompUSA	1.43%	7.22%	0.88%	8.85%	4.11%
474	Computer Associates	**29.90%**	0.04%	1.69%	0.00%	0.00%
494	Foundation Health	5.21%	2.07%	4.25%	0.07%	2.58%
495	State Street Boston Corp.	**24.39%**	0.04%	0.09%	0.03%	2.51%
Total		100%	100%	100%	100%	100%

We here explore the multidimensional financial performance of the Fortune 500 companies. Revenue-top-ranked companies do not necessarily have top-ranked performance in terms of profitability and (stock) marketability. Most companies exhibited serious inefficiencies. The measure-specific models enable us to study the performance based upon a specific measure while keeping the current levels of other measures. See Zhu (2000) for more discussion on measuring the performance of Fortune 500 companies.

3.4 Solving DEA Using DEAFrontier Software

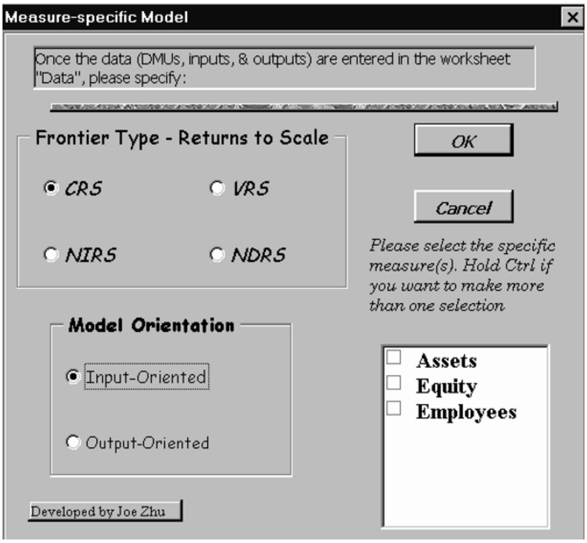

Figure 3.6. Measure-specific Models

To run the measure-specific models, select the "Measure Specific Model" menu item. You will be prompted with a form for selecting the models presented in Table 3.1, as shown in Figure 3.6.

Select the measures that are of interest. If you select all the input or all the output measures, then you have the envelopment models.

The results are reported in the "Efficiency", "Slack" and "Target" sheets.

REFERENCES

1. Banker, ,R.D. and R.C. Morey (1986), Efficiency analysis for exogenously fixed inputs and outputs, *Operations Research*, 34, 513-521.
2. Zhu, J. (2000), Multi-factor performance measure model with an application to Fortune 500 companies, *European Journal of Operational Research*, 123, No. 1, 105-124.