Measuring Technical Efficiency of Cars: A Field Investigation in the Italian Domestic Market

Corrado lo Storto
DIEG, School of Engineering, University of Naples Federico II, Naples, Italy
corrado.lostorto@unina.it

Abstract - This paper implemented Data Envelopment Analysis to develop a measure of technical efficiency (TE) for a car. The measurement of TE uses published technical data and judgements by industry experts. It is assumed that the technical value of a car is a function of a functional feature performance set of the product delivered to users when bearing some usage and ownership costs. TE is calculated for a sample of 216 cars sold in the Italian market from the 1970s to the early 1990s.

Index Terms - Data Envelopment Analysis, car, technical efficiency, product technical value, benchmarking.

1. Background

Since the 1960s the car industry all over the world has gone through an intense transformation to meet the challenges coming from the market - both as customer preferences and competition, environmental regulations, greater concern for safety and pressure and opportunities offered by new technologies. Innovation in the auto industry has consequently assumed major significance. Measuring the technical efficiency that a car is delivering to consumers is henceforth of paramount importance in order to indentify trajectories for improving the product and make it more competitive and appealing in the market.

Literature provides several conceptualization of a product as a: set of physical actions and objects[1], satisfaction generating system[2], psychosocial symbol[3], set of causal concepts[4], experience[5], offering[6], set of features[7], technology[8]. While in the economic and marketing-strategy literature there was a terrific proliferation of contributions as to most of the proposed conceptualizations with a rich dissemination of insights from one perspective to the other and from the theory to the practice, there was a relative scarce attention of scholars to the two latter ideas of product as a technology embodiment system capable of delivering a set of functionalities to users and a parallel indifference of practitioners for this. A major concern of scholars to this latter perspective of product analysis could help managers to make sound decisions and plans. The identification of the technical value, and in particular, the technical efficiency of a product as a measure of its capability to provide the user with benefits associated to a set of functionalities suffering some ownership and usage costs, could be useful to disclose uncertainty and ambiguity relatively to several management matters, i.e. the correct product positioning in order to understand better the nature of competition relative to certain types of product features, the relative assessment of the whole set of product performance, the way to increasing product performance by improving specific technological and functional features. Particularly, this comparative evaluation may provide insights as to how products might be developed to fit more closely with markets needs and to give the firm a competitive edge. Moreover, measuring technical efficiency and positioning of the product allows to identify gaps, segments or niches within some segment of the market. If such a gap is found, it represents a market opportunity that might be an opportunity for the firm. Product positioning based on a sound benchmarking of technological and functional features might be used to display competitive relationships and temporal changes in a manner that is similar in appearance to a perceptual map. Naturally, these analyses support rather than substitute for the perceptual data that can be provided by customers. The measurement of technical efficiency and mapping of product features can contribute insights into current and prospective product offering, and help to find opportunities for product improvement and new product development. The state of technology does not remain static either in the short or the long run. In the short run for instance, one way that products compete is by leapfrogging each other in terms of performance - whether measured in speed, quality, power, etc. When used as an average measure relative to certain periods of time, the product technical efficiency can be useful either to provide a picture of the technology state in that product market, or to trace the evolution of the technical value of the product in a given market segment over time, thus making it possible to analyse the output-input causal relationships between performance, technology, and costs.

This paper implements Data Envelopment Analysis (DEA) to get a measure of car technical efficiency. This measure is calculated for a sample of 216 cars sold in the Italian domestic market from the 1970s to the 1990s.

2. A Measure of a Car Technical Efficiency

In order to measure the technical efficiency of a car, it is preliminarily necessary to assess the technological capability of that car to deliver functionalities to the user. The problem of measuring the technological capability of a product can be approached from two different perspectives. The first one is to consider several similar products sold in the market in different times, to analyze each product as a system and evaluate the technological capability of every component or part included in the product and the way it interacts with the others. This approach is typical of value engineering analysis. In most cases, this is a difficult and burdensome way to compare products in terms of their technical value. That is evident for those products incorporating thousands of parts and components like a plane or a car. A second perspective is to consider a product as a "black box" and characterize its embodied technology set by the performance of the yielded output associated to a cluster of functionalities F_i delivered to users relevant for that product[9-12]. It considers a product as a bundle of different features[7,13]. Different approaches have been proposed: scoring models[14], trade-off between technological parameters surfaces[15], objective sector functions[16]. This perspective is known in the literature as "functional perspective"[17,18].

In this study, the second perspective was adopted. A car is considered as a system incorporating several technologies, i.e. the technology of metal working, alloys moulding, engine combustion, electronic control, safety, comfort, etc., and the integration of all them deliver functionalities to the user. The rationale behind this conceptualization of a car as a bundle of technologies and functional features finds its justification in the following reasoning. When a consumer buys a car, he/she buys some benefits, i.e. mobility, quality, comfort, safety, etc., but bearing some costs for the use and ownership of the product. Car technologies are generally hidden to most of its users. Indeed, they have only a rough idea of them from their effects, measured by the performance set associated to functional features, i.e. the engine power, the engine torque, the maximum speed, the level of comfort, and so on. Measurements for these parameters or features give a quantitative indication of the benefits offered to consumers and, at the same time, of the nature of technology embodied in a car. The technical value of a car (CTV) is henceforth assumed to be a function of the performance set (FP_i) associated to functional features $F_1, F_2, ..., F_n$:

$$CTV = f(FP_1, FP_2, ..., FP_n) = \Sigma w_i FP_i$$

The CTV is a measure of the *overall benefit* a car deliver to users. The technical efficiency of a car can purposefully be measured as the ratio of the CTV measure to the amount of costs $C_1, C_2, \dots, C_m$ that the users have to bear to benefit functional features $F_1, F_2, \dots, F_n$:

$$TE = \frac{CTV}{\sum v_i C_i}$$

Thus, technical efficiency measures the *relative benefit* the users gain when using a car.

3. Measuring Technical Efficiency Through Data Envelopment Analysis

Data Envelopment Analysis (DEA) is extensively used by scholars to identify the production frontier and measure efficiency rates in several industries. Like other methods, i.e. the stochastic production frontiers, DEA estimates the maximum potential output for a given set of inputs. However, DEA provides efficiency relative measurements of a specific unit by estimating an empirical production function frontier from multiple inputs and outputs relative to a sample of homogeneous units implementing a linear programming technique[19]. The production frontier is generated solving a sequence of linear programming (LP) problems, one for each unit included in the sample, while the relative efficiency score of a unit is measured by the distance between the actual observation and the frontier obtained from all the units under examination, adopting the Farrell measure of technical efficiency (TE) as a measure for the unit efficiency score. Efficiency is thus evaluated as the classical engineering ratio of outputs to inputs. Given the set of units, the model determines for each unit the optimal set of input weights and output weights that maximize its efficiency score. DEA does neither require any explicit assumption about the underlying relation between inputs and outputs nor the a priori knowledge of weights to be assigned to assess efficiency.

In this study, technical efficiency is measured by implementing an input-oriented DEA model constructing the production function by searching for the maximum possible proportional reduction in input usage, while output levels are held fixed. As the Italian market includes cars classified into 9 market segments for their extremely different characteristics, technical efficiency was calculated assuming variable returns to scale (VRS) (BCC model).[20] An input-oriented BCC LP model is defined as:

$$\text{Min } \Theta + \varepsilon\left[\sum_{i=1}^{m} S_i^- + \sum_{r=1}^{s} S_r^+\right]$$

$$\text{s.t.} \quad \sum_{j=1}^{n} \lambda_j y_{rj} - S_r^+ = y_{rj}, \quad r = 1,...,s$$

$$\sum_{j=1}^{n} \lambda_j x_{ij} + S_i^- = \Theta x_{ij}, \quad i = 1,...,m$$

$$\sum_{j=1}^{n} \lambda_j = 1$$

$$\lambda_j \geq 0 \qquad j = 1,...,n$$

$$S_r^+,\ S_i^- \geq 0 \qquad r = 1,...,s,\ i=1,...,m$$

where $\sum \lambda_j=1$ is the convexity constraint added to the CCR model[21] that assumes constant returns to scale. As the standard development of the DEA model produces an efficiency measure which is between 0 and 1, and does not generate a ranking of units, the original CCR model was modified introducing the concept of super-technical efficiency (STE)[22] that makes the efficiency analysis more discerning and provides a full not censored ranking of units efficiency (AP DEA model). An efficiency score of a car k greater than 100% may thus be measured[23,24].

4. The Implementation Of DEA In The Italian Car Market

The technical efficiency model includes 4 outputs (car performance features) and 2 inputs (costs) that were obtained as functions of car technical data and expert subjective judgments (Table 1):

Table A.1 in Appendix displays details about input and output measurement. Car prices were adjusted having as reference the 1993 consumer price index. All selected cars were identified in the specialized trade literature. Cars are ordinary passenger cars that have been equipped with conventional spark ignition petrol engines or turbocharged spark ignition engines. The need to assess and compare subjectively features required the researcher to consult an expert of the automotive field. Three sub-samples of petrol cars sold in the Italian market were considered (37 cars present in the market between 1970 and 1972, 82 in the years 1980-82, 97 between 1990 and 1993). Sub-sample were selected with the aim of having a good mix of all cars sold in Italy in that period. The data were collected from technical and trade literature[25,26].

Table. 1. DEA input and output variables

VARIABLES	DATA/JUDGMENTS RELATIVE TO:
Outputs	
ENGINE	engine power, torque, capacity, car mass
MOBILITY	max speed, acceleration, pick up
SAFETY	braking space and quality, safety equipment
QUALITY	noise, comfort, internal fittings, space, ventilation, equipment, driving
Inputs	
PPC	car price (1993 consumer price index)
PUC	average fuel consumption

5. Results

Table 2 reports the outcome of DEA. Both the average TE and STE decreased from the 1970s to 1980s, but increased moving to 1990s. The standard deviation regularly decreases from 1970s to 1990s, showing a lower variation of technical efficiency scores across cars in the 1990s and a polarization of car efficiencies around higher values in comparison to previous two decades. Table 2 displays the number and ratio of efficient cars (TE=1.0) to total number of cars in sub-samples, too. These latter data confirm previous statistical data showing a considerable increase of 100% efficient cars in the 1990s.

Table. 2. Technical efficiency and super-efficiency scores

	1970s		1980s		1990s	
	mean	st.dev	mean	st.dev	mean	st.dev
TE	0.847	0.105	0.82	0.083	0.929	0.066
STE	0.855	0.120	0.84	0.180	1.013	0.281
efficient	4		4		29	
%efficient	10.8		4.9%		29.9	

Table 3 reports the results of a forward stepwise regression analysis performed with the aim to identify more critical variable influencing efficiency. The STE score for all 216 cars was considered as the dependent variable, while the input and output variables were included in the regression model as independent variables.

Table. 3. Stepwise regression analysis (all sample)

		coefficient	t	prob.
INTERCEPT		0.619	6.582	0.000
ENGINE		-1.200	-5.073	0.000
PERFORMANCE		1.376	3.783	0.000
SAFETY		0.810	5.010	0.000
QUALITY	pooled			
PPC	pooled			
PUC		-0.624	-2.901	0.004
F: 18.945, prob: 0.000				
r-squared: 0.411				

Four variables are mostly influencing the efficiency score of cars in sample: ENGINE, MOBILITY, SAFETY, and PUC. The examination of coefficient signs reveals that, as expected, MOBILITY and SAFETY positively affect the efficiency score, PUC has a negative effect on efficiency, but – not expected - ENGINE is negatively correlated to efficiency. Furthermore, MOBILITY has a greater effect than SAFETY, and PUC, even though negatively influences efficiency, has a less critical impact.

Tables 4-5 show the outcome of the forward stepwise linear regression analyses performed relative to specific sub-samples in the years 1990s and 1980s only. Due to the small number of cases for the 1970s sub-sample, regression was not performed.

Table. 4. Stepwise regression analysis (years 1990s)

		coefficient	t	prob.
Intercept		0.027	0.091	0.928
ENGINE	pooled			
MOBILITY	pooled			
SAFETY	pooled			
QUALITY		1.253	3.317	0.001
PPC	pooled			
PUC	pooled			
F: 10.999, prob: 0.001				
r-squared: 0.106				

Table. 5. Stepwise regression analysis (years 1980s)

		coefficient	t	prob.
Intercept		1.541	9.041	0.000
ENGINE		-2.491	-8.894	0.000
MOBILITY		2.896	7.494	0.000
SAFETY	pooled			
QUALITY		-0.729	-3.401	0.001
PPC		0.885	3.035	0.003
PUC		-1.089	-3.911	0.000
F: 18.843, prob: 0.000				
r-squared: 0.553				

The great differences between the two regression analyses as to the behavior of the coefficients (size and sign) reveals that the car market characteristics substantially changed from the 1980s to the 1990s. While in the 1980s factors affecting technical efficiency were easily identifiable, in the 1990s the market structure became more variegated, internationally exposed, and the great number of niches makes it difficult to extrapolate average trends and cause-effect linkages. In the 1990s only the QUALITY performance feature is statistically significative, positively associated to STE. In the 1980s, as expected, the ownership cost (PPC) positively affects STE, while this latter diminishes when fuel consumption (PUC) increases. Vice versa, QUALITY, and much more, ENGINE are unexpectadly negatively associated to STE.

6. Conclusions

A method for measuring the technical efficiency of a car has been proposed. The method is based on the implementation of Data Envelopment Analysis and uses factors that are objectively measurable in terms of the technical features of the engine, the performance features of the car, and factors subjectively measurable in terms of the quality and safety level of the car. This approach has the advantage of simplicity, and can be usefully adopted for several purposes: to identify benchmarks in the market; to keep trace of technology and technology advance in the market; to identify the features which the car manufacturers should mostly focus on.

Even though the primary aim of this paper was to illustrate the method and its implications, the implementation of the method on a sample of 216 cars sold in the Italian market between the early 70s and the early 90s shows some interesting insights. In particular, the method has identified those car features that might purposefully improve car efficiency and the technical efficiency trend from the 1970s to the 1990s.

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Appendix

Table. A.1 Input and output variables measurement

$$ENGINE^i = \left(\frac{POW^i_{ENG}}{CAP^i_{ENG}} \cdot \frac{TOR^i_{ENG}}{MASS^i} \right)^{\frac{1}{2}}$$

$POW^i_{ENG} =$ max engine power of car i, $TOR^i_{ENG} =$ max engine torque of car i, $CAP^i_{ENG} =$ engine capacity of car i, $MASS^i =$ mass of car i

All measurements are objective and available in trade technical literature. $ENGINE^i$ was further normalized in the range [0, 1] by dividing its measurement by the maximum ENGINE value in sample.

$$MOBILITY^i = \left[\left(AC^i_1 \cdot AC^i_2 \cdot AC^i_3 \cdot AC^i_4 \cdot AC^i_5 \cdot AC^i_6 \right)^{\frac{1}{6}} \cdot \left(U^i_1 \cdot U^i_2 \cdot U^i_3 \cdot U^i_4 \right)^{\frac{1}{4}} \cdot V^i_{MAX} \right]^{\frac{1}{3}}$$

$AC^i_1 =$ acceleration of car i in the space [0 - 1 km], $AC^i_2 =$ acceleration of car i after 400 m,

$AC^i_3 =$ acceleration of car i to increase speed from 0 to 60 kmh, $AC^i_4 =$ acceleration of car i to increase speed from 0 to 80 kmh,

$AC^i_5 =$ acceleration of car i to increase speed from 0 to 100 kmh, $AC^i_6 =$ acceleration of car i to increase speed from 0 to 120 kmh,

$U^i_1 =$ pick up of car i to increase speed from 40 kmh, $U^i_2 =$ pick up of car i to increase speed from 70 to 80 kmh,

$U^i_3 =$ pick up of car i to increase speed from 70 to 100 kmh, $U^i_4 =$ pick up of car i to increase speed from 70 to 120 kmh,

$U^i_4 =$ pick up of car i to increase speed from 70 to 120 kmh, $V_{MAX} =$ max speed of car i

All measurements are objective and available in trade technical literature. $MOBILITY^i$ was further normalized in the range [0, 1] by dividing its measurement by the maximum MOBILITY value in sample.

$$SAFETY^i = \left[\left(BRAS^i \cdot BQ^i \right)^{\frac{1}{2}} \cdot \left(S^i_1 \cdot S^i_2 \cdot S^i_3 \cdot S^i_4 \right)^{\frac{1}{4}} \right]^{\frac{1}{2}}$$

$$BRAS^i = \frac{\dfrac{MASS^i}{MASS^{MAX}}}{\dfrac{\left(BS^i_1 \cdot BS^i_2 \cdot BS^i_3 \right)^{\frac{1}{3}}}{BS^{MIN}}}$$

$BQ^i =$ subjective measure of the braking quality of car i, $BRAS^i =$ braking space of car i, $MASS^i =$ mass of car i,

$MASS^{MAX} =$ maximum car mass in sample, $BS^i_1 =$ braking space of car i at speed of 60 kmh, $BS^i_2 =$ braking space of car i at speed of 80 kmh,

$BS^i_3 =$ braking space of car i at speed of 100 kmh, $BS^i_3 =$ braking space of car i at speed of 100 kmh,

$BS^{MIN} =$ minimum $\left(BS^i_1 \cdot BS^i_2 \cdot BS^i_3 \right)^{\frac{1}{3}}$ in sample, $S^i_1 =$ subjective measure of the steering quality of car i,

$S^i_2 =$ subjective measure of the visibility quality of car i, $S^i_3 =$ subjective measure of the road holding quality of car i,

$S^i_4 =$ subjective measure of the safety equipment quality of car i

All subjective measurements were provided by expert judgment by means of a 5 levels Likert type scale in the range [0, 1]. Objective were available in trade technical literature. $SAFETY^i$ was further normalized in the range [0, 1] by dividing its measurement by the maximum SAFETY value in sample.

$$QUALITY^i = \left[\left(NO^i_1 \cdot NO^i_2 \cdot NO^i_3 \cdot NO^i_4 \right)^{\frac{1}{4}} \cdot \left(IQ^i_1 \cdot IQ^i_2 \cdot IQ^i_3 \cdot IQ^i_4 \cdot IQ^i_5 \right)^{\frac{1}{5}} \cdot CO^i \right]^{\frac{1}{3}}$$

$NO^i_1 =$ internal noise level of car i at speed of 60 kmh, $NO^i_2 =$ internal noise level of car i at speed of 80 kmh,

$NO^i_3 =$ internal noise level of car i at speed of 100 kmh, $NO^i_4 =$ internal noise level of car i at speed of 120 kmh,

$IQ^i_1 =$ subjective measure of the car i internal fittings quality, $IQ^i_2 =$ subjective measure of the car i internal ventilation and climate quality,

$IQ^i_3 =$ subjective measure of the car i internal equipment quality, $IQ^i_4 =$ subjective measure of the car i internal space quality,

$IQ^i_5 =$ subjective measure of the car i driving seat quality, $CO^i =$ subjective measure of the car i travel comfort quality

All subjective measurements were provided by expert judgment by means of a 5 levels Likert type scale in the range [0, 1]. Objective were available in trade technical literature. $QUALITY^i$ was further normalized in the range [0, 1] by dividing its measurement by the maximum QUALITY value in sample.

$$PUC^i = \left(FU^i_1 \cdot FU^i_2 \cdot FU^i_3 \right)^{\frac{1}{3}}$$

$FU^i_1 =$ fuel consumption of car i in city driving, $FU^i_2 =$ fuel consumption of car i at speed of 90 kmh,

$FU^i_3 =$ fuel consumption of car i at speed of 120 kmh

$$PPC^i_{1993} = \frac{CPI(1993)}{100} \cdot PPC^i_t$$

, $PPC^i_{1993} =$ purchasing price of car i at year 1993, $PPC^i_t =$ purchasing price of car i sold at year t