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Technology Forecasting of Digital Single-Lens Reflex Camera Market: The Impact of Segmentation in TFDEA

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***Abstract*--With the advancement of digital image technology, the big change in the camera market is that digital single-lens reflex cameras (DSLRs) have replaced film type single-lens reflex cameras, which have seen very little development lately. This advancement is reflected in some core technologies of DSLRs such as digital image sensors and electronic shutter mechanisms, which have allowed taking photographs even in the toughest conditions. Therefore, as a disruptive technology, the developments in DSLR technologies are worthy of notice.**

This paper utilizes technology forecast using data envelopment analysis (TFDEA), which is a quantitative forecasting method. In the study, we use input and output data collected from about a hundred DSLRs of the top five currently dominant brands such as Canon, Nikon, Sony, Pentax and Olympus. Final results show future DSLRs' capabilities and provide insight that TFDEA, as a forecasting method, can be applicable to determine market trends of consumer electronics as well as technologies. Furthermore, the results showed that market segmentation provided more reliable and accurate results with lower mean absolute deviation (MAD) value while all camera market approach provided less accurate results with a high standard deviation or MAD value.

I. INTRODUCTION

With the advancement of digital image technology, the big change in the camera market is that digital single-lens reflex cameras (DSLRs) have replaced film type single-lens reflex cameras, which have seen very little development lately. This advancement is reflected in some core technologies of DSLRs such as digital image sensors and electronic shutter mechanisms, which have allowed taking photographs even in the toughest conditions. Today, DSLR cameras are becoming more popular among photographers and enthusiasts. There are a lot of advantages of DSLRs compared with the compact point and shoot cameras, for example; the bigger sensor size, several choices of lens, high image quality, higher level of camera control and versatility for shooting in any light condition, which makes a DSLR a good choice for most of professional photographers as well as amateurs [1]. As of 2012, there are seven manufactures dominating the DSLRS' market for a generation or more. These manufacturers are; Canon Inc., Nikon Corp, Sony Corp, Olympus Corp, Pentax, Fuji and Panasonic Corp. They all have their own representative products of DSLRs.

The data from Camera & Imaging Products Association (CIPA) is a good proxy for discovering trend in the camera industry. Based on CIPA's data, revenue from DSLR cameras is growing slowly and the unit shipments are growing albeit at a much slower pace. Fig. 1 shows the total unit shipped of DSLR cameras and basic cameras[2]. The forecast for total shipment (the cumulative total of shipments from January to December) of DSLR cameras in 2010 is 109.9 million units, a year-on-year increase of 3.8% [3].

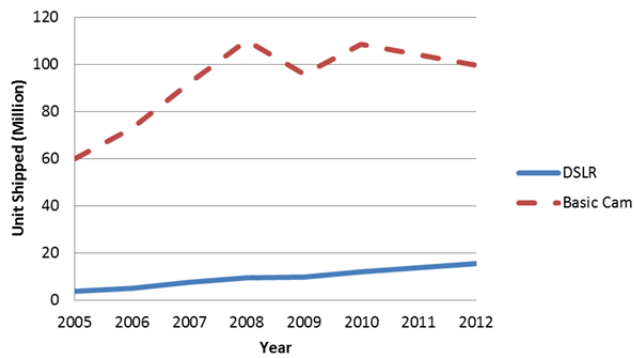

Fig. 1 Total unit shipped of DSLR cameras and basic cameras from CIPA [2]

Trends in the DSLRs camera market have implications on other technologies. For example, higher resolution of digital camera sensors results in bigger file size which requires improvement of memory card technology to be able to handle larger files in terms of the capacity and writing speed, the improvement of in-camera image processor chip to be able to process image quickly, and the improvement of computer hardware to be able to support massive image file processing. The potential benefit of the result would assist all the manufacturers to get ready to promote their competitive products and other industries to get ready to adapt to the change in technology.

II. LITERATURE REVIEW

A. Technology Forecasting

Technological forecasting is aimed at predicting future technological capabilities, attributes, and parameters. That is, a technological capability or attribute can be forecast to be available at some time in the future [4].

Methods for technology forecasting are broadly classified into two main categories: exploratory forecasting and normative forecasting. Exploratory forecasting means forecasting the future based on past data and present conditions. A good choice of a technology forecasting method in a particular situation could affect the usefulness and accuracy of the forecast [5].

B. DEA – Data Envelopment Analysis

The DEA model was introduced in the 1970s, and for many years, it got recognized relatively quickly. Their work

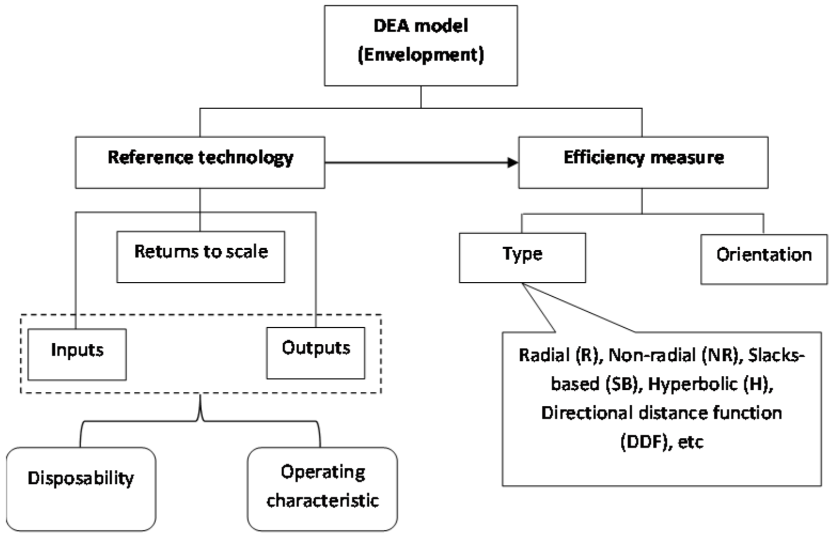

Fig. 2 The general structure of a DEA model (envelopment form) [7]

extended the theory underlying DEA, made progress enhancing the computational aspects of the analysis, and reported on selected applications. As application catches up with theory, the DEA model promises to find more significant use in the future [6].

The purpose of DEA is to determine which of the DMUs make efficient use of their inputs and which do not. For the inefficient units, the analysis can actually quantify what levels of improved performance should be attainable. In addition, the analysis indicates where an inefficient DMU might look for benchmarking help as it searches for ways to improve [6]. Fig. 2 shows the general structure of a DEA model.

C. TFDEA – Technology Forecasting using Data Envelopment Analysis

"Technology Forecasting Using Data Envelopment Analysis" (TFDEA) was introduced in 2001 [8]. TFDEA is an extension of "Data Envelopment Analysis" (DEA) as an operation research method. After its introduction, TFDEA has been a favorable approach to obtain technological predictions [9]. One fundamental concept for TFDEA is being "state-of-the-art (SOA)" technology, which indicates a technology's superiority over the others for the time being that the analysis is performed. If a technology is SOA, its efficiency score is assigned as 1, by considering the historical levels of performance. TFDEA assigns the subsequent efficiency scores for each of the remaining technologies based on the preceding SOA technology [9].

In TFDEA, we need an efficiency score at the time of release and against what is assumed to be the current time (or the period at which the frontier is considered frozen). These are denoted by an R or C respectively [10]. Technology Forecasting with Data Envelopment Analysis (TFDEA) offers an effective means to determine technological capability over time without the burden of fixed a-priori weighting schemes [10]. TFDEA explains advancement of technology by capturing dynamics of efficiencies over time. Hence, it requires series of efficiency measurement based on DEA (Data Envelopment Analysis) [11].

III. MODEL AND DATA

A. Model

Many variables have been considering in the project for forecasting the DSLR camera technology. However, not all the characteristics that use in marketing can be used in forecast this technology such as megapixel and ISO. The technical characteristics would be constructed into structural variables; MSRP and weight of the DSLR cameras (used to achieve better performance) and functional variables; resolution, focus point, and max FPS as shown in Fig. 3 below. A clear explanation of the characteristics is given in the paper for a better understanding.

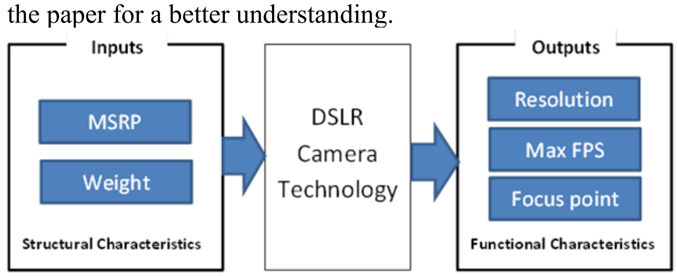

Fig. 3 Basic input-output model of DSLR cameras

The method used is the forecasting of technology using data envelopment analysis first proposed in PICMET 2001 by Anderson et al [12]. Lim and Anderson succeeded in developing the add-in program for running TFDEA in Microsoft Excel [11]. The program comes with some specific options needed to be set before running the program as followed.

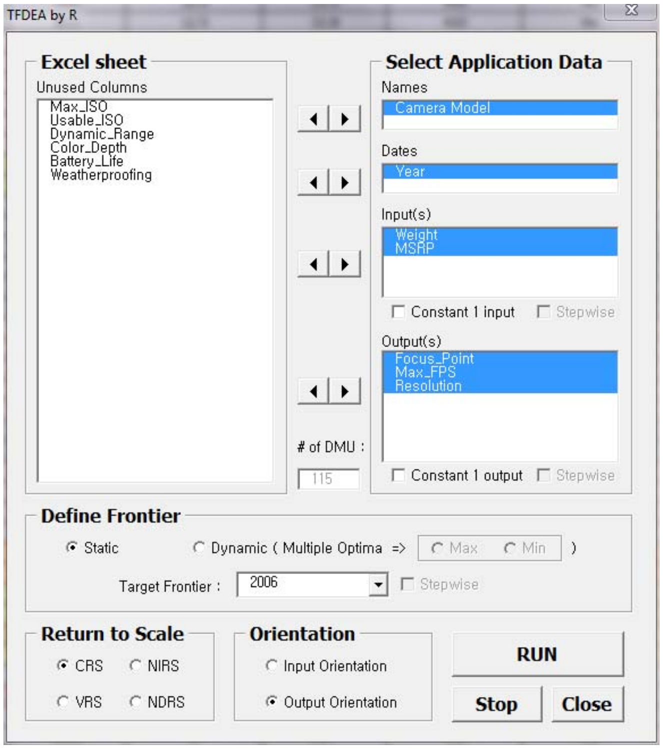

Fig. 4 Application Programing Interface (API) dialogue box

B. Frontier

There are two options that need to consider under the define frontier, Static and Dynamic frontier. However, when choosing the target frontier, it should be based on the nature of technology itself. Some of them are developed every year same as the DSLR technology, and the other might be for every three to five years. Moreover, after choosing frontier type, the target frontier has to decide which data set will be the forecasting period, and which set will be the learning period [10].

C. Return to Scale

Under the return to scale option, there are four types of return to scale: constant return to scale (CRS), increasing return to scale (IRS), decreasing return to scale (DRS) and variable return to scale (VRS). The state-of-art of technology and the change of efficiency will depend upon the return to scale. Therefore, it is important to choose the right option. In this study, to consider economy of scale which exists in this industry, CRS is deployed [13].

D. Orientation

Lastly, orientation has to be chosen to running the program between input orientation and output orientation. There is no specific methodology to choose because it depends on the nature of technology and the purpose of the decision makers. For the input-oriented model, the objective function is minimizing the investment or the input while the function variable level remains the same. In another word, using less input while getting the same output. However, the output-oriented model will increase the efficiency by maximizing the output while using the same level of input. That means producing more output while not paying more money for the input [14]. For forecasting the DSLR cameras technology in this paper, Dynamic frontier year with output-orientation and CRS will be selected to observe the result. However, more explanation will be described in the result section.

E. Data Collection

TABLE 1 SAMPLE OF SEMI-PROFESSIONAL DSLR CAMERA DATA

Camera Model	Year	MSRP	Weight (lb.)	Resolution (Mega pixel)	Max FPS	Focus Point
Nikon D200	2005	$1,699	1.8	10.2	5	11
Canon EOS 5D	2005	$3,299	1.79	12.8	3	9
Pentax K10D	2006	$900	1.75	10.2	3	11
Nikon D300	2007	$1,799	1.8	12.3	6	51
Olympus E3	2007	$1,300	1.96	10.1	5	11
Sony Alpha DSLR A700	2007	$1,399	1.5	12.5	5	11
Nikon D700	2008	$2,999	2.19	12.1	5	51
Canon EOS 5D Mark II	2008	$2,700	1.79	21.1	3.9	9
Sony Alpha DSLR A900	2008	$2,999	1.9	24.6	5	9
Olympus E30	2008	$1,689	1.53	12.3	5	11
Pentax K20D	2008	$1,300	1.76	14.6	3	11
Nikon D300s	2009	$1,699	1.9	12.3	7	51
Canon EOS 7D	2009	$1,699	1.81	18.0	8	19
Sony Alpha DSLR A850	2009	$1,999	1.9	24.6	3	9
Pentax K-7	2009	$1,150	1.65	14.6	5.2	11
Olympus E5	2010	$1,699	1.76	12.3	5	11
Pentax K-5	2010	$1,600	1.63	16.3	7	11
Nikon D800	2012	$2,999	1.98	36.3	4	51
Canon EOS 5D Mark III	2012	$3,499	1.9	22.3	6	61

This study focuses exclusively on DSLR cameras excluding lens range from cropped sensor cameras such as Micro four-third, APS-C, and APS-H, to 35mm Full Frame cameras in the U.S. market. It does not include other types of digital cameras such as point and shoot, super zoom, mirror-less, and medium format cameras. The data is collected from several sources such as the manufacturer's official websites, digital photography reviews from www.dpreview.com, www.imaging-resource.com, and from www.dxomark.com. In total, 115 DSLR cameras from 5 manufactures from 1999 to 2012 were used. Table 1 below represents a sample of DSLR cameras data in semi-professional category sorted by year.

F. MSRP

There are two kinds of prices in DSLR camera market: the manufacturer's suggested retail price (MSRP) and the street price. The MSRP is the price of a DSLR camera when it is officially announced by its manufacturer. This study focuses on the MSRP of DSLR camera body only excluding lens in U.S dollar. From our observation, the trend of MSRP is different depending on the type of DSLR cameras. Fig. 5 illustrates the trend of MSRP of DSLR cameras of five manufacturers with respect to time.

G. Weight

Weight is used as one of the structural characteristics for a DSLR camera to deliver functions. In this study, we focus on the weight of DSLR camera body only excluding lens, battery, and memory cards, and it is measured in pound (lb). Weights of DSLR cameras are different depending on the types of cameras. In general, the weights increase from entry to professional DSLR cameras. From our observation, the weight trend of each DSLR camera type is likely to be slowly decreasing. The Fig. 6 illustrates the trend of DSLR camera body weight with respect to time.

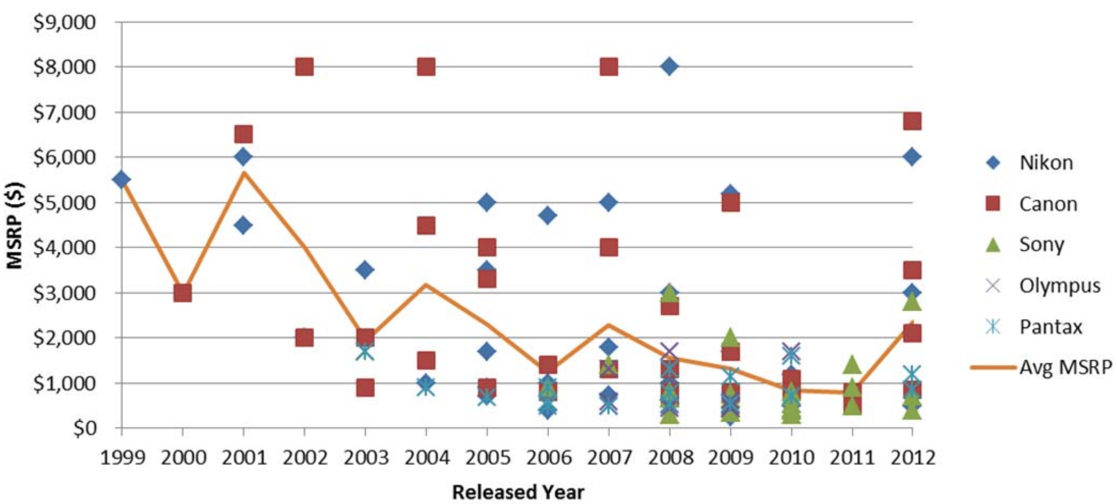

Fig. 5 MSRP ($) with respect to time

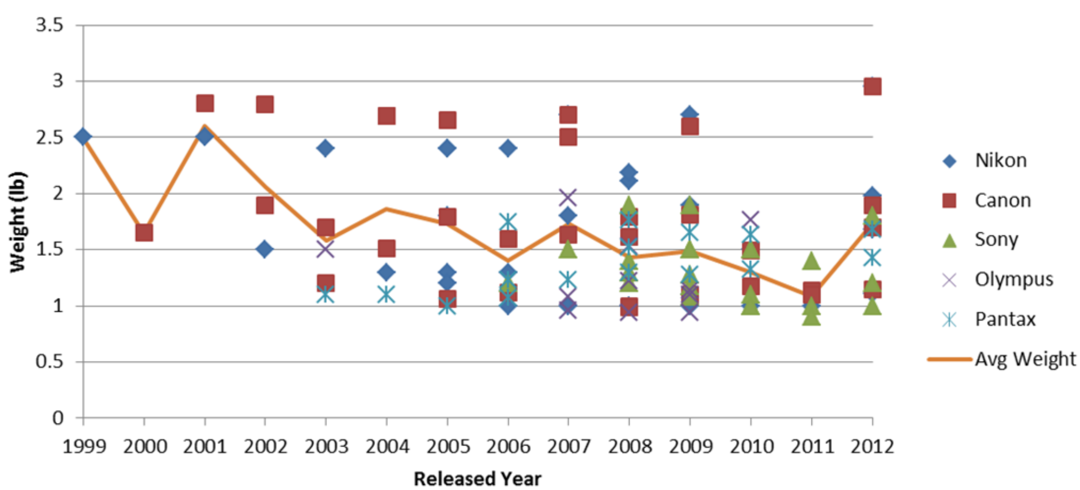

Fig. 6 Weight of DSLR camera body with respect to time

H. Resolution

Resolution is one of the most important characteristics of DSLR cameras and the first criteria that highly effects buyer's decision. Effective resolution represents the amount of details that a camera sensor can capture and it is measured in pixels. DSLR cameras with higher effective resolution can capture more details which results in better image quality and makes it suitable for those landscape and studio photographers who need extremely high resolution for very large prints. In general, professional DSLR cameras especially the high-end flagship DSLR cameras, such as EOS 1Ds Mark III series from Canon and Nikon D3X, offer the highest pixel count than any type of the cameras in the same generation. From 1999 to 2012, the DSLR camera's resolutions have been increasing as the sensor technology developed. The Fig. 7 illustrates the improvement of effective resolution of DSLR cameras with respect to time.

I. Max FPS

Max FPS stands for the maximum of frames per second that a DSLR camera can shoot in high continues or burst mode. Max FPS is referred as the speed of DSLR cameras and it is a very important tool for sport photographers. DSLR cameras regularly provide different FPS depending on the type of the cameras.

J. Focus point

Number of focus points is also one of the most important characteristics of DSLR cameras, which determines the wideness of area coverage in a frame that a DSLR camera can focus. The larger the number of focus points, the better and wider coverage that a camera can track and focus within a frame. Each type of DSLR cameras provides different metering and focusing systems which result in different numbers of focus points. Generally, number of focus points also distinguishes the type of DLSR cameras and the market.

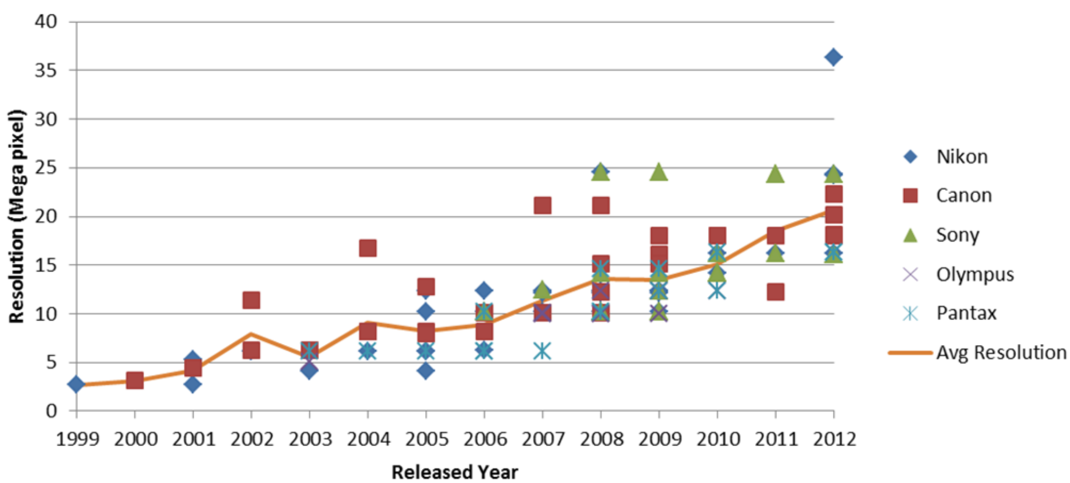

Fig. 7 Effective resolution with respect to time

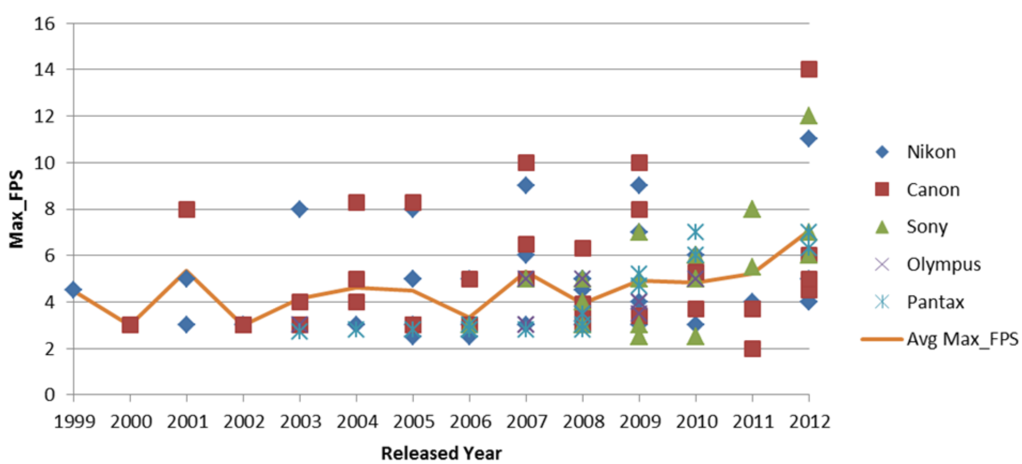

Fig. 8 Frames per second (FPS) of DSLR camera with respect to time

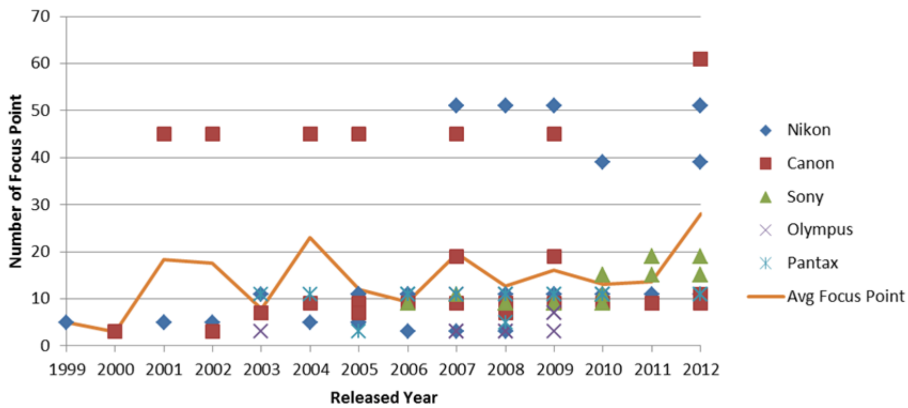

Fig. 9 Number of Focus Points with Respect to Time

IV. METHODOLOGY

A. TFDEA Procedure

To use TFDEA for technology foresight, we must first determine the time period of analysis; identify the main indicators of SOA (State Of Art) that characterize the products. Then, based on indicators, we should determine a TFDEA model type, collect data, and solve TFDEA model with optimization software. Last, we need to analyze the results, validate the model, and draw forecasting chart for conclusions. This is done for each time period presented in the data set following the procedure.

B. Identify indicators

The output-oriented TFDEA model is illustrated in the flow chart presented as:

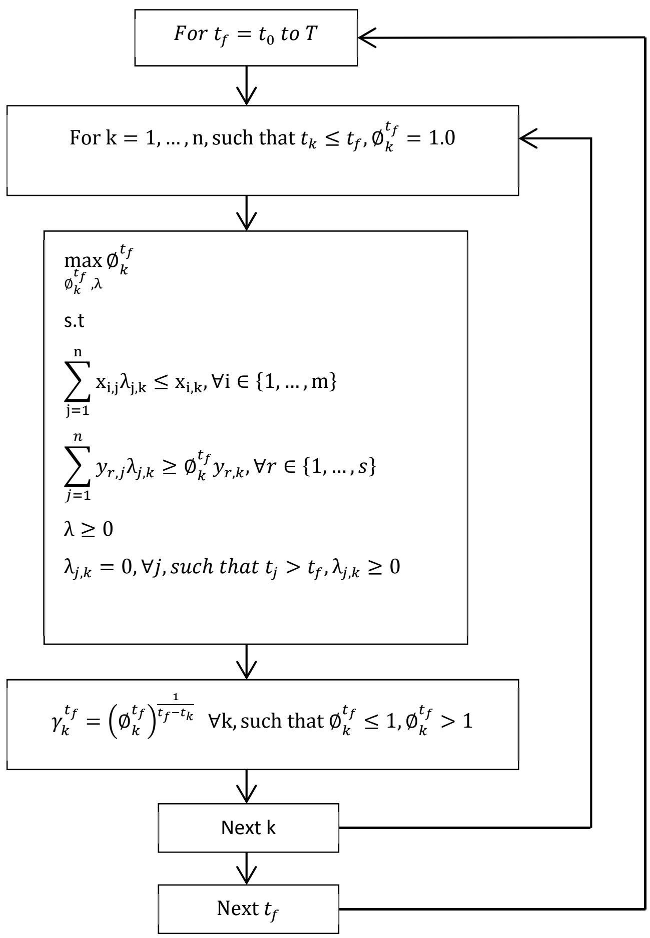

Fig. 10 Flow chart of TFDEA [14]

In the data, we included year, MSRP, weight, resolution, max FPS, and Focus Points as our main indicators. We choose output-oriented TFDEA model to calculate base on our project objective. The basic structural properties of DSLR camera are price, weight and size, which are selected as structural indicators. Resolution, max FPS, and Focus Point are selected as functional indicators.

Conceptually, TFDEA calls for testing each technology. The technological rate of change, γ, for product k at any time, t, is represented by γ_k^t [11]. Briefly, $x_{i,j}$ represents the i^{th} input and $y_{r,j}$ represents the rth output of technology k. The variable $\emptyset_k^{t_f}$ also serves as the objective function and represents the amount of additional output which should be achievable by technology k at time period t_f if k were state-of-art at that time. The variables $\lambda_{j,k}$ describe how much of technology j is used in setting a target of performance for technology k. According to TFDEA method, the algorithm is shown as above in Fig. 10.

To predict the characteristics of DSLR camera technology in 2012 and beyond, we need the past technical characteristics of comparable DSLR camera. Thus we examined indicators for the data collected from the more than 100 DSLR to obtain the ideal result by trying on different types of inputs and outputs combination.

V. RESULTS

Table 2 illustrates the best-fit result of the model. Dynamic frontier year is selected to use the effective date to define the second goal as maximum value. Output orientation model is used because DSLR trend tends to improve resolution and frame per second (FPS) more than weight and price. Therefore, finding how the output of the DSLR technology is increased at the same level of input is our goal. CRS imply that outputs are increased in the same proportion inputs. The Average Rate of Change is shown at 1.244200, which means DSLR efficiency is improved around 24 percent every year. Frontier year at 2006 means the dataset is divided into before 2006, at 2006 and after 2006. MAD (Mean Absolute Deviation) is 1.767841, which means it could be 21 months error when this forecasting model is applied to the DSLR model. The second portion of the table illustrates that the model uses 2 inputs, MSRP and weight, and 3 outputs, resolution, Max FPS and FP, for forecasting DSLR technology. There are 50 cameras of the 115 analyzed that are State of Art (SOA) when they are released to the market and 10 cameras are still the SOA in 2006. 12 out of 50 state-of-art cameras are used to calculate the rate of change. 7 technologies are released before forecasted date, and 67 cameras are released after forecasted date.

TABLE 2 MODEL RESULT

Frontier Type	Orientation	2nd Goal	Return to Scale	Avg RoC	Frontier Year	MAD
Dynamic	OO	Max	CRS	1.244200	2006	1.767841
Input(s)	**Output(s)**	**SOA products at Release**	**SOA products on Frontier**	**RoC contributors**	**Release before forecast**	**Release after forecast**
2	3	50	10	12	7	67

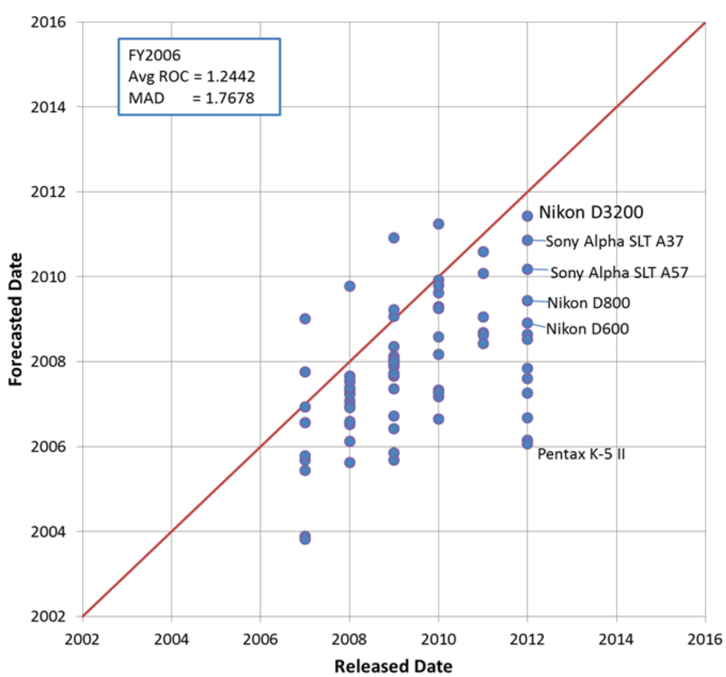

Fig. 11 Forecasting result at frontier year 2006

The Fig. 11 shows the result chart of DSLR technology at frontier year 2006 with 2 inputs and 3 outputs. From the chart, there are some technologies that are located on the diagonal line, which means it is perfect forecasting. However, most of the forecasted camera technologies are not located on the SOA line, which can be the mean absolute deviation error of 21 months.

VI. DISCUSSION

A. Effect of Market Segmentation

In the model and data section, the DSLR market can be divided into several market segmentations; professional, semi-professional, mid-range and entry market. And, in general, each market requires different characteristics. For example, in the professional DSLR market, photographers prefer higher performance and ruggedness, while entry level photographers want affordable price of cameras. Therefore, when a particular segment of dataset used in this research is analyzed with TFDEA, the result might show distinguishable characteristics of the market segments. The Fig. 12 and 13 show forecasting results of two ranges of datasets, professional and semi-professional markets. In here, in case of semi-professional cameras, the learning period is relatively shorter than the professional market. Therefore, considering enough the learning period, the frontier year is set to 2008 because the first camera in semi-professional market was released in 2002 while the first professional camera was released in 1999.

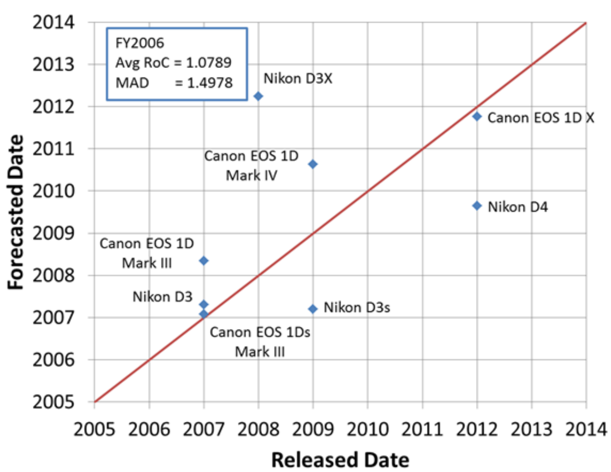

Fig. 12 Forecasting results of the professional market

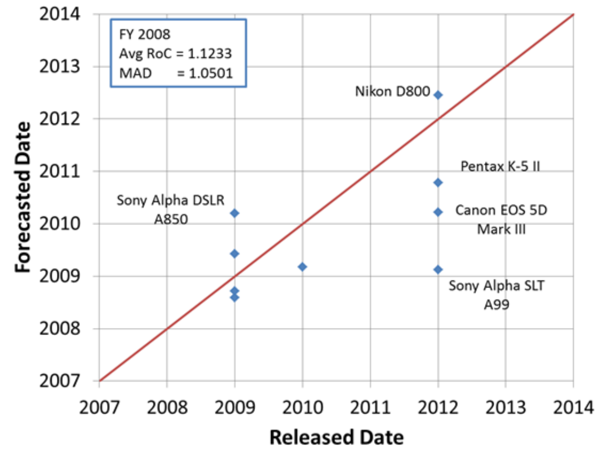

Fig. 13 Forecasting results of the semi-professional market

In these two results, MAD is lower than the forecasting results of all dataset without considering segmentation. This means smaller forecasting error and more accurate forecasting results. In addition, compared with all range market, the results in which market range is reflected have smaller differences between released date and forecasted date like the table 3.

As a result, considering market segmentation in TFDEA is reasonable to get more credible forecasting results. In other words, if distinct market segmentation exists such as this research, we need to use different inputs and outputs according to the circumstances.

VII. CONCLUSION

A. Limitation

An analysis of validation of previous camera data to forecast the camera technology in the future by including all the cameras in the market from professional to low-end cameras to the model seemed to be inapplicable with the result of high in standard deviation (MAD) since different camera market ranges result in different levels of camera technology. In case of the professional cameras which are considered to be the most versatile cameras to capture image in any light conditions, the lack of the usable ISO data as a functional characteristic to some of cameras is the missing measurement of camera efficiency and the result could be biased. The maximum ISO could be considered as an alternative output but it is left unused since it is not an accurate indicator of cameras to be considered high-ISO performers.

TABLE 3 COMPARISON OF MARKET SEGMENTATION

Model	Market segment	Released date	Without segmentation		With segmentation	
			Forecasted Date	Difference	Forecasted Date	Difference
Canon Eos 1D X	Professional	2012	2004.83	-7.17	2011.76	-0.24
Nikon D800	Semi-professional	2012	2009.68	-2.32	2012.45	+0.45

There are other several outputs that are interesting and should be included in the model since DSLR cameras are compelling than other types of camera but with the limitation of the model, only a maximum of 3 outputs can be applied.

With the time constraint, the DLSR cameras in mid-range and entry markets were left to be forecasted in this report. Additionally, some MSRP in entry DSLR camera market can be considered invalid since they are sold with lens kit and there is no accurate MSRP of entry DSLR camera bodies only available which the result could be potentially inaccurate.

B. Future Work

Since DSLR cameras in mid-range and low-end markets were left and these two markets are considerably larger than semi-profession and professional camera markets, forecasting technology changes in these markets is interesting and should be considered to be a future work.

Different DSLR cameras markets have different technology priorities. For example, professional cameras are designed for those professional photographers who demand speed and versatility to capture images in any light conditions rather than resolution. Therefore, considering prioritizing the outputs with weights for each camera market can be a future work to improve the result.

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APPENDIX 1– RESULTS (ALL DSLRS)

Results

Run by TFDEA add-in ver 2.1

Frontier Type	Orientation	2nd Goal	Return to Scale	Avg RoC	Frontier Year	MAD
Dynamic	OO	Max	CRS	1.244200	2006	1.767841
Input(s)	**Output(s)**	**SOA products at Release**	**SOA products on Frontier**	**RoC contributors**	**Release before forecast**	**Release after forecast**
2	3	50	10	12	7	67

DMU	Name	Date	Efficiency_R	Efficiency_F	Effective Date	Rate of Change	Forecasted Date
1	Nikon D1	1999	1	1.85185185	2003.000000	1.166545	-
2	Canon EOS D30	2000	1	1.833333333	2003.000000	1.223903	-
3	Nikon D1H	2001	1.107446154	1.666666667	2003.000000	-	-
4	Nikon D1X	2001	1	2.712382708	2004.233129	1.361553	-
5	Canon EOS 1D	2001	1	1.056603774	2005.000000	1.013860	-
6	Canon EOS 1Ds	2002	1	1.046881208	2004.623529	1.017617	-
7	Nikon D100	2002	1	1.571093497	2004.659218	1.185173	-
8	Canon EOS D60	2002	1	1.972977307	2004.754098	1.279845	-
9	Nikon D2H	2003	1	1	2003.000000	-	-
10	Olympus E1	2003	1.564352244	1.642150647	2004.113208	-	-
11	Pentax *ist D	2003	1	1.172096007	2005.736912	1.059735	-
12	Canon EOS 10D	2003	1.459390238	1.752638581	2004.842432	-	-
13	Canon EOS 300D	2003	1	1	2003.000000	-	-
14	Canon EOS 1D Mark II	2004	1	1.01509434	2005.000000	1.015094	-
15	Canon EOS 1Ds Mark II	2004	1	1	2004.000000	-	-
16	Nikon D70	2004	1.136691041	1.359799811	2004.047261	-	-
17	Canon EOS 20D	2004	1	1	2004.000000	-	-
18	Pentax *ist DS	2004	1	1.100377059	2005.718845	1.057227	-
19	Nikon D2X	2005	1.395348837	1.425589982	2005.224490	-	-
20	Nikon D2Hs	2005	1	1	2003.000000	-	-
21	Canon EOS 1D Mark II N	2005	1	1	2005.000000	-	-
22	Nikon D200	2005	1.109514923	1.125531225	2004.719891	-	-
23	Canon EOS 5D	2005	1.055424528	1.26109096	2006.000000	-	-
24	Nikon D70s	2005	1.200312433	1.329167884	2004.183861	-	-
25	Nikon D50	2005	1	1.329278838	2005.312419	2.486989	-
26	Canon EOS 350D XT	2005	1	1.025895893	2005.419355	1.062862	-
27	Pentax *ist DL	2005	1	1.076212166	2004.432074	-	-
28	Nikon D2Xs	2006	1.425589982	1.425589982	2005.224490	-	-
29	Pentax K10D	2006	1.171059283	1.171059283	2006.000000	-	-
30	Nikon D80	2006	1.05819707	1.05819707	2005.960938	-	-
31	Canon EOS 30D	2006	1.058398842	1.058398842	2003.536727	-	-
32	Sony Alpha DSLR A100	2006	1.06092437	1.06092437	2006.000000	-	-
33	Pentax K100D	2006	1.154424571	1.154424571	2005.985717	-	-
34	Nikon D40	2006	1	1	2006.000000	-	-

35	Canon EOS 400D Xti	2006	1	1	2006.000000	-	-
36	Pentax K110D	2006	1	1	2006.000000	-	-
37	Nikon D3	2007	1.077062557	0.866569609	2005.023116	-	2005.678573
38	Canon EOS 1D Mark III	2007	1	0.831151475	2003.040228	-	2003.886677
39	Canon EOS 1Ds Mark III	2007	1.066469298	0.879817982	2004.856031	-	2005.442046
40	Nikon D300	2007	1	0.484672793	2005.699771	-	2009.014664
41	Sony Alpha DSLR A700	2007	1.028082813	0.888812629	2005.246377	-	2005.785839
42	Olympus E3	2007	1.344924502	1.18424032	2004.389871	-	-
43	Canon EOS 40D	2007	1	0.835897436	2003.000000	-	2003.820389
44	Pentax K100D Super	2007	1	1	2006.000000	-	-
45	Nikon D40X	2007	1.02124183	0.884103641	2006.000000	-	2006.563775
46	Olympus E410	2007	1	0.682103828	2006.000000	-	2007.750963
47	Olympus E510	2007	1.125	0.814869931	2006.000000	-	2006.936994
48	Nikon D3X	2008	1	0.597987646	2004.919692	-	2007.273017
49	Nikon D700	2008	1.216666667	0.678084595	2005.302025	-	2007.080036
50	Canon EOS 5D Mark II	2008	1.091751769	0.765022004	2006.000000	-	2007.225900
51	Sony Alpha DSLR A900	2008	1	0.696501161	2006.000000	-	2007.655365
52	Olympus E30	2008	1.377	0.911049292	2005.202346	-	2005.628713
53	Pentax K20D	2008	1.41932192	1.087084149	2006.000000	-	-
54	Nikon D90	2008	1	0.640098857	2005.484163	-	2007.526024
55	Canon EOS 50D	2008	1.064451505	0.766487295	2004.906030	-	2006.123172
56	Sony Alpha DSLR A300	2008	1.334813296	0.892509317	2006.000000	-	2006.520466
57	Sony Alpha DSLR A350	2008	1.008656388	0.744527314	2006.000000	-	2007.350183
58	Pentax K200D	2008	1.41189182	1.005848467	2006.000000	-	-
59	Nikon D60	2008	1.096618922	0.809946698	2006.000000	-	2006.964730
60	Canon EOS 450D XSi	2008	1	0.739168618	2006.000000	-	2007.383244
61	Canon EOS 1000D XS	2008	1.133634791	0.877486917	2006.000000	-	2006.598157
62	Sony Alpha DSLR A200	2008	1	0.437909499	2006.000000	-	2009.779264
63	Olympus E420	2008	1	0.700404524	2005.915394	-	2007.545181
64	Olympus E520	2008	1.032020148	0.69924812	2006.000000	-	2007.637350
65	Pentax K-m	2008	1.183023668	0.817699737	2006.000000	-	2006.921128
66	Nikon D3s	2009	1.176596657	0.866569609	2005.023116	-	2005.678573
67	Canon EOS 1D Mark IV	2009	1.06945381	0.78720185	2005.329720	-	2006.424815
68	Nikon D300s	2009	1	0.486606321	2005.777303	-	2009.073974
69	Canon EOS 7D	2009	1.019227725	0.68802478	2005.013404	-	2006.724810
70	Sony Alpha DSLR A850	2009	1.060236511	0.696501161	2006.000000	-	2007.655365
71	Pentax K-7	2009	1.322992269	0.894171702	2005.339438	-	2005.851388
72	Sony Alpha DSLR A380	2009	1.06124805	0.64615376	2006.000000	-	2007.998772
73	Sony Alpha DSLR A500	2009	1.115808171	0.662668176	2006.000000	-	2007.883267
74	Sony Alpha DSLR A550	2009	1	0.586880397	2005.247751	-	2007.686886
75	Olympus E600	2009	1	0.597599185	2006.000000	-	2008.356299
76	Olympus E620	2009	1.024511816	0.684979437	2006.000000	-	2007.731709

77	Pentax K-x	2009	1.012391834	0.627282522	2006.000000	-	2008.134430
78	Nikon D3000	2009	1	0.341171754	2006.000000	-	2010.921754
79	Nikon D5000	2009	1	0.691829691	2005.668382	-	2007.354548
80	Canon EOS 500D	2009	1	0.656929991	2006.000000	-	2007.923071
81	Sony Alpha DSLR A330	2009	1.224484362	0.636315097	2006.000000	-	2008.068996
82	Sony Alpha DSLR A230	2009	1.073116513	0.494596813	2006.000000	-	2009.222126
83	Olympus E450	2009	1.007551849	0.643693627	2006.000000	-	2008.016230
84	Olympus E5	2010	2.112	1.048004414	2005.202346	-	-
85	Pentax K-5	2010	1.397142857	0.704673677	2005.050109	-	2006.652084
86	Nikon D7000	2010	1	0.470529715	2005.845475	-	2009.295910
87	Canon EOS 60D	2010	1.341	0.746478175	2006.000000	-	2007.338207
88	Sony Alpha DSLR A560	2010	1.697464789	0.772506417	2006.000000	-	2007.181342
89	Sony Alpha DSLR A580	2010	1.438518519	0.622313403	2006.000000	-	2008.170830
90	Sony Alpha SLT A55	2010	1	0.439276469	2005.861388	-	2009.626387
91	Pentax K-r	2010	1.32	0.61754976	2005.072610	-	2007.278609
92	Nikon D3100	2010	1.112676056	0.490655257	2006.000000	-	2009.258746
93	Canon EOS 550D	2010	1.053	0.568399504	2006.000000	-	2008.585577
94	Sony Alpha DSLR A290	2010	1	0.31821604	2006.000000	-	2011.240554
95	Sony Alpha DSLR A390	2010	1.139492958	0.424642809	2006.000000	-	2009.920064
96	Sony Alpha SLT A33	2010	1	0.42998689	2005.935419	-	2009.798244
97	Sony Alpha SLT A65	2011	1	0.347478434	2005.752351	-	2010.590274
98	Sony Alpha SLT A77	2011	1.4	0.486469807	2005.752351	-	2009.050306
99	Nikon D5100	2011	1.5	0.556657848	2006.000000	-	2008.681112
100	Canon EOS 600D	2011	1.413468222	0.564026468	2006.000000	-	2008.620925
101	Canon EOS 1100D	2011	1.538312061	0.589329858	2006.000000	-	2008.420073
102	Sony Alpha SLT A35	2011	1	0.409776941	2006.000000	-	2010.083160
103	Nikon D4	2012	1.484726147	0.81980827	2005.236149	-	2006.145491
104	Canon EOS 1D X	2012	1.212684106	0.66257516	2004.793939	-	2006.677849
105	Nikon D800	2012	1	0.434342209	2005.623735	-	2009.440434
106	Canon EOS 5D Mark III	2012	1	0.46542068	2005.135921	-	2008.636323
107	Sony Alpha SLT A99	2012	1.8	0.667989418	2006.000000	-	2007.846662
108	Pentax K-5 II	2012	2.086833283	0.719029951	2004.561731	-	2006.071400
109	Nikon D600	2012	1.121529576	0.495680265	2005.704216	-	2008.916328
110	Canon EOS 6D	2012	2.045049505	0.758928571	2006.000000	-	2007.262500
111	Sony Alpha SLT A57	2012	1	0.293669681	2004.564537	-	2010.172493
112	Pentax K-30	2012	1.731317346	0.622488819	2005.437633	-	2007.607173
113	Nikon D3200	2012	1	0.305161393	2006.000000	-	2011.432275
114	Canon EOS 650D	2012	1.524758165	0.576140873	2006.000000	-	2008.523664
115	Sony Alpha SLT A37	2012	1	0.345619048	2006.000000	-	2010.862479

APPENDIX 2– RESULTS (PROFESSIONAL DSLRS)

Results

Run by TFDEA add-in ver 2.1

Frontier Type	Orientation	2nd Goal	Return to Scale	Avg RoC	Frontier Year	MAD
Dynamic	OO	Max	CRS	1.078884	2006	1.497766

Input(s)	Output(s)	SOA products at Release	SOA products on Frontier	RoC contributors	Release before forecast	Release after forecast
2	3	17	6	5	5	3

DMU	Name	Date	Efficiency_R	Efficiency_F	Effective Date	Rate of Change	Forecasted Date
1	Nikon D1	1999	1	1.83020859	2003.357143	1.148804	-
2	Nikon D1H	2001	1.107446154	1.660495256	2003.111732	-	-
3	Nikon D1X	2001	1	2.067004046	2005.000000	1.199045	-
4	Canon EOS 1D	2001	1	1.056603774	2005.000000	1.013860	-
5	Canon EOS 1Ds	2002	1	1.046881208	2004.623529	1.017617	-
6	Nikon D2H	2003	1	1	2003.000000	-	-
7	Canon EOS 1D Mark II	2004	1	1.01509434	2005.000000	1.015094	-
8	Canon EOS 1Ds Mark II	2004	1	1	2004.000000	-	-
9	Nikon D2X	2005	1	1	2006.000000	-	-
10	Nikon D2Hs	2005	1	1	2003.000000	-	-
11	Canon EOS 1D Mark II N	2005	1	1	2005.000000	-	-
12	Nikon D2Xs	2006	1	1	2006.000000	-	-
13	Nikon D3	2007	1	0.836890172	2004.953905	-	2007.299079
14	Canon EOS 1D Mark III	2007	1	0.777237193	2005.024293	-	2008.343391
15	Canon EOS 1Ds Mark III	2007	1	0.792966338	2004.024275	-	2007.079499
16	Nikon D3X	2008	1	0.534663531	2004.000000	-	2012.246293
17	Nikon D3s	2009	1.00278093	0.836890172	2004.853520	-	2007.198694
18	Canon EOS 1D Mark IV	2009	1	0.672507645	2005.400046	-	2010.625341
19	Nikon D4	2012	1.077081414	0.721499001	2005.350903	-	2009.650079
20	Canon EOS 1D X	2012	1	0.598413744	2005.000000	-	2011.762703

APPENDIX 3– RESULTS (SEMI-PROFESSIONAL DSLRS)

Results

Run by TFDEA add-in ver 2.1

Frontier Type	Orientation	2nd Goal	Return to Scale	Avg RoC	Frontier Year	MAD
Dynamic	OO	Max	CRS	1.124802	2008	1.394531

Input(s)	Output(s)	SOA products at Release	SOA products on Frontier	RoC contributors	Release before forecast	Release after forecast
2	2	16	6	5	2	7

DMU	Name	Date	Efficiency_R	Efficiency_F	Effective Date	Rate of Change	Forecasted Date
1	Nikon D100	2002	1	1.66666667	2007.000000	1.107566	-
2	Olympus E1	2003	1	1.666666667	2007.000000	1.136219	-
3	Pentax *ist D	2003	1	1.358024691	2007.000000	1.079511	-
4	Nikon D200	2005	1	1.2	2007.000000	1.095445	-
5	Canon EOS 5D	2005	1	1.664796311	2007.730028	1.205269	-
6	Pentax K10D	2006	1	1	2006.000000	-	-
7	Nikon D300	2007	1	1	2007.000000	-	-
8	Olympus E3	2007	1	1	2007.000000	-	-
9	Sony Alpha DSLR A700	2007	1	1	2007.000000	-	-
10	Nikon D700	2008	1.46	1.46	2007.000000	-	-
11	Canon EOS 5D Mark II	2008	1.065464119	1.065464119	2008.000000	-	-
12	Sony Alpha DSLR A900	2008	1	1	2008.000000	-	-
13	Olympus E30	2008	1.02	1.02	2007.000000	-	-
14	Pentax K20D	2008	1	1	2008.000000	-	-
15	Nikon D300s	2009	1.142857143	0.874450785	2007.000000	-	2008.140742
16	Canon EOS 7D	2009	1	0.754166667	2007.000000	-	2009.399022
17	Sony Alpha DSLR A850	2009	1	0.774820627	2008.000000	-	2010.169290
18	Pentax K-7	2009	1	0.772738276	2006.503130	-	2008.695302
19	Olympus E5	2010	1.466133763	1.173333333	2007.000000	-	-
20	Pentax K-5	2010	1.009024674	0.776190476	2007.000000	-	2009.154270
21	Nikon D800	2012	1	0.686950618	2008.000000	-	2011.192776
22	Canon EOS 5D Mark III	2012	1.115010291	0.930769231	2007.502755	-	2008.112786
23	Pentax K-5 II	2012	1	0.632075669	2006.839705	-	2010.740375
24	Sony Alpha SLT A99	2012	1.009662059	0.854117647	2007.640496	-	2008.981286