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Determining the Efficiency of Disposable Baby Diapers through Data Envelopment Analysis

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Abstract

Following the patent of the disposable diaper in the late 1940s, the popularity of the disposable diaper drastically increased. Various companies, including Johnson & Johnson and Proctor & Gamble, continuously compete with each other to create the "best" disposable diaper product. This project compares 12 of the most popular brands of disposable diapers to determine the efficiency of each diaper and what changes could be made to increase efficiency, when applicable.

Introduction

Parenting involves countless decisions and challenges. What type of clothing? What type of bottle? What type of pacifier? Should I use cloth or disposable diapers? Once the basic decisions are made, the parent still must choose between specific brands. Valerie Hunter Gordon invented the first disposable diaper in 1949 (Gordon, 1951; Paddi Patents, n.d.). Johnson & Johnson then introduced disposable diapers, commercially, in the US around 1949. Soon other companies entered the market, including the popular Pampers brand in 1961 (Butler & Gilson, 2007). Since then, the use of disposable diapers has increased drastically. It is estimated that 90-95% of diapers used in developed countries are disposable (Odio and Friedlander, 2000). Data from Europe indicates diapers are changed on average 4-5 times a day (UK Environment Agency 2005). The design of the disposable diaper has also changed over the years, as companies try to improve upon various aspects, such as super absorbency and comfort.

The average baby will go through an estimated 6,930 diapers in his or her life (Trustyz, n.d.). In the US alone, it is estimated that 27.4 billion disposable diapers are consumed every year (Real Diaper Association 2014). This raises the question of which diaper provides the most value to consumers. The purpose of this project is to compare 12 of the most popular diaper brands by assigning weighted measurements to each category and determining the efficiency of each disposable diaper. What can be improved and which brand should consumers purchase to best meet their needs? Are store brands any better or worse, or are they the same as name brands? This will all be revealed through the Data Envelopment Analysis. Lab testing and feedback from parents during trial periods of 3+ months concentrating on the variables of price per diaper, absorption, leakage, comfort, health, and durability were used as the primary focus.

Literature Review

With the exception of a report done by Consumer Reports in 1975 comparing different disposable diaper brands (O'Mara, 2014), there has been almost no recent comparative analysis, regarding disposable diapers, to allow consumers to assess which brand is best. The original 1975 report not only compared diaper effectiveness, but also focused on the cutting down of trees required for the manufacture of disposable diapers. The study included the risk and association of viruses that had been found in feces contained within disposable diapers found in "sanitary" landfills (Mothering, 2014). A result of this study was that the majority of published papers focused on the environmental impact of disposable diapers. In 1979, Dr. F. Weiner, a pediatrician, published a case study that indicated how disposable diaper use causes more severe and frequent diaper rash (Weiner, 1979). These findings and publications set the tone for the majority of papers published on diapers from that point on. Studies

have been done to optimize diaper design to ensure overall child safety and comfort (Lane, Rehder, & Helm, 1990; Zimmer, Lawson, & Calvert, 1986). Even more recent studies have continued to focus on the diaper design (Satsumoto & Havenith, 2010), safety (Evans, Helmes, Kirsch, & Ruble, 2014; Kosemund et al., 2009), health impact on the child (Akin et al., 2008; Mirabella, Castellani, & Sala, 2013), and impact on adolescent development (Cole, Lingeman, & Adolph, 2012).

There have been a select few studies and articles regarding diaper comparison that are from valid sources, such as Consumer Reports (Consumer Reports 2016; Consumer Reports 2004) and one scientific study involving an in depth diaper comparison (Davis, Leyden, Grove, and Raynor, 1989). There are also many websites that allow parents to leave comments on diapers and their efficiency; however, these comments and remarks are subjective and not scientific in nature (e.g. amazon). To our knowledge, there have been no academic or research publications that have examined the value and efficiency of baby diapers in an objective manner. The DEA model has been used to assist with consumer selection of products, but no such analysis has been done on disposable diaper brands.

Methodology

This study used Data Envelopment Analysis (DEA), a non-parametric approach proposed by Charnes, Cooper, and Rhodes (1978). This model has been used to help consumers compare and select products. The application of the DEA model has been used for smartphones (Mustafa and Peaw, 2005), automobiles (Papahristoudoulou, 1997), and computers (McMullen and Tarasewich, 2000). Despite the popular use of the DEA model for assistance with consumer selection, to our knowledge there are no academic or research publications using this model to assist in selecting baby diapers.

DEA is used to measure efficiency of decision-making units (DMUs) in situations with multiple input and output variables. The DMUs used for this study were 12 popular disposable baby diaper brands. We used the price per diaper as the input variable, and output variables were 5 diaper qualities important to consumers and ranked on a scale of 1-10, 10 being the highest rated. These qualities were: absorption, leakage, comfort, health, and durability. The outcome of DEA is an efficiency ratio, which indicates the quality with respect to the cost of each diaper brand and compared to the other brands. The measure of efficiency of a DMU is defined as the ratio of a weighted sum of outputs to a weighted sum of inputs. The DEA model through linear programming reveals the areas in which brands can improve to increase their efficiency. This study focused on maximizing efficiency using the following formulas (Charnes et al. 1978):

Objective Function:

$$E_r = \frac{\sum_{i-1}^{M} u_i o_{ir}}{\sum_{j=1}^{N} v_j I_{jr}} = \frac{u_1 O_{1r} + u_2 O_{2r} + .. + u_M O_{Mr}}{v_1 I_{1r} + v_2 I_{2r} + .. + v_N I_{Nr}}$$

Subject To:

$$\frac{\sum_{m=1}^{M} u_m o_{mg}}{\sum_{n=1}^{N} v_n I_{ng}} = \frac{u_1 O_{1g} + u_2 O_{2g} + .. + u_M O_M}{v_1 I_{1g} + v_2 I_{2g} + .. + v_N I_{Ng}}$$

Symbol	Representing
E_r	Efficiency of the rth DMU
O_{ir}	The ith output dimention for the rth DMU
ui	The weight for the ith output dimension
I_{jr}	The jth input dimention for the rth DMU
V_j	The weight for the jth input dimension
O_{ig}	The ith output dimension for the gth DMU
I_{jg}	The jth input dimension for the gth DMU
i	The index for output dimension
j	The index for input dimension
r	The target DMU
g	The gth DMU, =1…G

The above formulas need to be changed to linear functions when using standard linear programming software. To achieve this, the weighted inputs for the DMU need to be scaled to a sum of 1.

Objective Function:

$$\text{Max } E_r = u_1 O_{1r} + u_2 O_{2r} + \ldots + u_M O_{Mr}$$

Subject to:

$$v_1 I_{1r} + v_2 I_{2r} + \ldots v_N I_{Nr} = 1$$

DMU Constraints Reformulated:

$$(u_1 O_{1g} + u_2 O_{2g} + \ldots u_M O_{Mg}) - (v_1 I_{1g} + v_2 I_{2g} + \ldots v_N I_{Ng}) <= 0$$

$$g = 1, 2, \ldots, G$$

Where: $u_j >= 0$ $j = 1, 2, \ldots, M$

$v_i >= 0$ $i = 1, 2, \ldots, N$

The linear formulation of the problems would be:

Input and Output Analysis

Input Variable

Price: Diapers were purchased in bulk at common retail stores and cost was broken down into price per diaper.

Output Variables

Absorption: Testing was done through parental observations and lab testing. The total weight of liquid that could be absorbed into the inner core of the diaper, while keeping the inner surface of the diaper dry was used as a measure of absorbency. The inner surface is defined as the portion of the diaper closest to the baby's skin. The inner core is the portion of the diaper below the inner surface where moisture is drawn away from the baby's skin (Spurrier, 2015b).

Leakage: Leakage was tested by using both parental feedback as well as laboratory testing, to determine at what point liquid leaked from the diaper (Spurrier, 2015b).

Comfort: The placement of the diaper tabs was used as a measurement of potential comfort. In addition, parents provided feedback regarding marks on the skin that were attributed to diaper usage (Spurrier, 2015b).

Health: Ratings were based on the materials and added chemicals used to make up the diaper, and the potential effects on the baby's health. The lab focused on diaper construction based on dye, chlorine, latex, and perfume. In addition, biodegradability was considered for eco-friendly disposability (Spurrier, 2015b).

Durability: Leg and back elastic quality were assessed to determine durability rating, along with overall construction. Lab testing was done through stretching and the addition of liquids to evaluate diaper durability (Spurrier, 2015b).

DMUs

Twelve different diapers were used as the decision-making units (DMUs): (1) Pampers: Swaddlers Sensitive, (2) Pampers: Swaddlers, (3) Cuties, (4) Huggies: Little Snugglers, (5) Huggies: Snug & Dry, (6) Huggies: Pure & Natural, (7) Target Brand: Up & Up, (8) Fisher-Price: Happy Days, (9) Luvs: Ultra Leakguards, (10) Walmart Brand: White Cloud, (11) Walmart Brand: Parent's Choice, and (12) Babies R Us: Supreme.

Data

Data was provided by BabyGearLab, which claims to be the "world's best source of baby product comparison information," (Spurrier, 2015a). BabyGearLab was founded by Juliet Spurrier, MD, a board certified pediatrician with a medical degree from Georgetown University. The intended purpose of the lab is to perform side-by-side comparisons of baby products to help consumers choose the best brand, according to their needs. The lab is not affiliated with any particular corporation or brand, which gives them a non-biased view. The website states "We pride ourselves on simply reporting our findings in an accurate and objective manner without bias," (Spurrier, 2015b).

The testing process began with selection of the top disposable baby diapers for each category. Diapers were purchased

at a retail store and tested across a variety of categories both in lab and in field-testing. Field-testing was done by volunteer parents who used the products and provided feedback over a 3+ month period. In addition, rigorous lab testing was performed across the following categories: absorbency, leakage, comfort, health, durability, and price. Results were then rated on a scale of 1-10, with 10 being the best possible score. All the data are recorded in the Table 1.

Results

According to our results in Table 2, DMUs receiving an efficiency ratio of "1" are considered efficient; while an efficiency ratio less than "1" indicates DMU's that are not efficient. Therefore, Cuties, Huggies Snug & Dry, Up & Up, White Cloud, Parents Choice, and Babies R Us Supreme can be considered efficient while Pampers Swaddlers Sensitive, Pampers Swaddlers, Huggies Little Snugglers, Huggies Pure & Natural, Fisher-Price Happy Days, and Luvs Ultra Leakguards are not efficient. These results indicate that customers should choose from product with an efficient rating. This research can help consumers narrow down their selections in accordance with their budgets and preferences.

Shadow price from DEA analysis can indicate the best way to improve the efficiency of inefficient DMUs by referring to the efficient ones. Using the results from the Table 2, manufacturers of diaper can improve the design of the diapers correspondingly.

By comparing the input/output variables in Table 1 to the Efficiency Recommendations in Table 3, it can be seen where each brand can improve. For example, to become efficient, Pampers Swaddlers Sensitive would need to drop the price per diaper to $0.32 (from $0.35 as indicated in Table 1). This brand would also need to increase ratings in comfort, health, and durability to the following values 8.4, 4.3, 6.6 respectively. Pampers Swaddlers need to drop the price to $0.31, increase comfort to receive a rating of at least 6.4, and increase health at least 1.8. To become efficient, Huggies Little Snugglers needs to lower the cost (to $0.20), while increasing absorption (4.1), leakage (6.0), and health (4.3). To increase efficiency, Huggies Pure and Natural needs to drop the price to $0.21, as well as increase leakage and durability (4.3 and 6.7 respectively). Fisher Price Happy Days would need to drop the price per diaper to $0.20, and increase ratings of comfort (5.5), health (2.9), and durability (4.3). Luvs Ultra Leakguards needs to increase leakage (3.0) and comfort (4.2) ratings, while decreasing the price to $0.17. Efficiency of each brand is summarized in Table 4.

Conclusions

For parents with newborn children, the task of choosing which products are best for their babies, but are also cost effective, can be daunting. Baby diapers are no exception. The amount of money spent on diapers in a baby's lifetime can be substantial, for example 7000 diapers at 20 cents per diaper equals $1,400. Consumers want to make sure they are getting the best product for their money. Through this study, consumers can see which products to choose in accordance with what is most important to them. From a manufacturing point of view, the DEA model can prove helpful when figuring out where to concentrate efforts for improvement regarding product efficiency.

Based on the results, the following six disposable diaper brands have the best qualities in respect to their price: Cuties, Huggies Snug & Dry, Up & Up, White Cloud, Parents Choice, Babies R Us Supreme. An important observation is that four of the six brands are store brands. However, just because a brand is efficient at its current price, does not mean it has the best ranking in the quality most important to the consumer.

There are a number of limitations to this study. Comfort was assessed based on tab placement, which is not a direct reflection of how the diaper feels to a child. Children of diaper wearing age are unable to verbalize their level of comfort, and therefore the measure of this variable will never be truly objective. Furthermore, lab testing was done by only one lab; while the lab claims to not have any bias, increasing data to incorporate testing from more labs would base the results more robust and unbiased. Lastly, there are other categories that this study did not include, but may be important for a consumer. With current focus on the environment, sustainability and eco-friendly options are increasing. Future studies should be done either

to focus solely on "green" diaper products; sustainability should be incorporated as an output variable.

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About the Authors

Joseph Baker and Jenna Bernasconi are both graduating seniors majoring in Business Management. Their collaborative research project was completed in the Fall 2015 semester under the mentorship of Dr. Xiangrong Liu (Management). Joseph plans to pursue a career in business management, Jenna in human resources or administration.

Table 1: Input/Output Variables

		v1	u1	u2	u3	u4	u5
		Input (in dollars)	**Outputs (out of possible 10)**				
DMU		Price per Diaper	Absorption	Leakage	Comfort	Health	Durability
1	Pampers Swaddlers Sensitive	0.35	8	6	4	1	6
2	Pampers Swaddlers	0.33	8	4	4	1	7
3	Cuties	0.24	6	4	6	1	8
4	Huggies Little Snugglers	0.3	4	5	7	1	7
5	Huggies Snug & Dry	0.26	7	2	4	1	4
6	Huggies Pure & Natural	0.36	5	3	6	2	3
7	Up & Up (Target)	0.14	3	5	6	4	4
8	Fisher-Price Happy Days	0.24	5	4	4	2	4
9	Luvs Ultra Leakguards	0.2	4	3	4	1	6
10	White Cloud (Walmart)	0.17	3	2	8	2	3
11	Parent's Choice (Walmart)	0.17	3	3	3	1	8
12	Babies R Us Supreme	0.19	1	2	4	3	8

Table 2: Linear Programming Results

	DMU1	DMU2	DMU3	DMU4	DMU5	DMU6	DMU7	DMU8	DMU9	DMU10	DMU11	DMU12
Obj	0.922167488	0.938131313	1	0.674074074	1	0.574074074	1	0.847701149	0.848809524	1	1	1
v1	2.857142857	3.03030303	4.166666667	3.333333333	3.846153846	2.777777778	7.142857143	4.166666667	5	5.882352941	5.882352941	5.263157895
u1	0.100492611	0.106060606	0.145833333	0	0.142857143	0.092592593	0	0.146551724	0.116666667	0	0	0
u2	0.019704433	0.02020202	0	0	0	0	0	0.028735632	0	0	0	0
u3	0	0	0	0.040740741	0	0.018518519	0	0	0	0.125	0	0
u4	0	0	0	0	0	0	0.25	0	0.028571429	0	0	0.052631579
u5	0	0.001262626	0.015625	0.055555556	0	0	0	0	0.058928571	0	0.125	0.105263158
const0	0.922167488	0.938131313	1	0.674074074	1	0.574074074	1	0.847701149	0.848809524	1	1	1
const1	0	0	0	0	0	0	0	0	0	0	0	0
const2	0	0	0	0	0	0	0	0	0	0	0	0
const3	0	0.447916667	1	0	0	0.666666667	0	0	0.547619048	0	0	0
const4	0	0	0	0	0	0	0	0	0	0	0	0
const5	0.75862069	0.6875	0	0	1	0	0	0.448275862	0	0	0	0
const6	0	0	0	0	0	0	0	0	0	0	0	0
const7	0.896551724	0.166666667	0	0.972222222	0	0.333333333	1	0.620689655	0.071428571	0	0	0
const8	0	0	0	0	0	0	0	0	0	0	0	0
const9	0	0	0	0	0	0	0	0	0	0	0	0
const10	0	0	0	0	0	0	0	0	0	1	0	0
const11	0	0	0	0.388888889	0	0	0	0	0.166666667	0	1	0
const12	0	0	0	0	0	0	0	0	0	0	0	1

Table 3: Efficiency and Recommendations

		Price per Diaper (in dollars)	Absorption	Leakage	Comfort	Health	Durability
DMU1	Pampers Swaddlers Sensitive	0.32	8.0	6.0	8.4	4.3	6.6
DMU2	Pampers Swaddlers	0.31	8.0	4.0	6.4	1.8	7.0
DMU3	Cuties	0.24	6.0	4.0	6.0	1.0	8.0
DMU4	Huggies Little Snugglers	0.20	4.1	6.0	7.0	4.3	7.0
DMU5	Huggies Snug & Dry	0.26	7.0	2.0	4.0	1.0	4.0
DMU6	Huggies Pure & Natural	0.21	5.0	4.3	6.0	2.0	6.7
DMU7	Up & Up (Target)	0.14	3.0	5.0	6.0	4.0	4.0
DMU8	Fisher-Price Happy Days	0.20	5.0	4.0	5.5	2.9	4.3
DMU9	Luvs Ultra Leakguards	0.17	4.0	3.0	4.2	1.0	6.0
DMU10	White Cloud (Walmart)	0.17	3.0	2.0	8.0	2.0	3.0
DMU11	Parent's Choice (Walmart)	0.17	3.0	3.0	3.0	1.0	8.0
DMU12	Babies R Us Supreme	0.19	1.0	2.0	4.0	3.0	8.0

Efficient: DMU3 (Cuties), DMU5 (Huggies Snug & Dry), DMU7 (Up & Up), DMU10 (White Cloud), DMU11 (Parents Choice), DMU12 (Babies R Us Supreme)
Not Efficient: DMU1 (Pampers Swaddlers Sensitive), DMU2 (Pampers Swaddlers), DMU4 (Huggies Little Snugglers), DMU6 (Huggies Pure & Natural), DMU8 (Fisher-Price Happy Days), DMU9 (Luvs Ultra Leakguards)

Pampers Swaddlers Sensitive refer to: Huggies Snug & Dry (0.758620689655172) and Up &Up (0.896551724137931)
Pampers Swaddlers refer to: Cuties (0.447916666666666), Huggies Snug & Dry (0.758620689655172), and Up &Up (0.896551724137931)
Huggies Little Snugglers refer to: Up &Up (0.896551724137931) and Parents Choice (0.388888888888889)
Huggies Pure & Natural refer to: Cuties (0.447916666666666) and Up &Up (0.896551724137931)
Fisher-Price Happy Days refer to: Huggies Snug & Dry (0.758620689655172) and Up &Up (0.896551724137931)
Luvs Ultra Leakage refer to: Cuties (0.447916666666666), Up &Up (0.896551724137931), and Parents Choice (0.388888888888889)

Table 4: Efficiency Summary

Brand	Price per Diaper	Absorption	Leakage	Comfort	Health	Durability
Pampers Swaddlers Sensitive	🌎	🌍	🌍	🌎	🌎	🌎
Pampers Swaddlers	🌎	🌍	🌍	🌎	🌎	🌍
Cuties	🌍	🌍	🌍	🌍	🌍	🌍
Huggies Little Snugglers	🌎	🌎	🌎	🌍	🌎	🌍
Huggies Snug & Dry	🌍	🌍	🌍	🌍	🌍	🌍
Huggies Pure & Natural	🌎	🌍	🌎	🌍	🌍	🌎
Up & Up (Target)	🌍	🌍	🌍	🌍	🌍	🌍
Fisher-Price Happy Days	🌎	🌍	🌍	🌎	🌎	🌎
Luvs Ultra Leakguards	🌎	🌍	🌎	🌎	🌍	🌍
White Cloud (Walmart)	🌍	🌍	🌍	🌍	🌍	🌍
Parent's Choice (Walmart)	🌍	🌍	🌍	🌍	🌍	🌍
Babies R Us Supreme	🌍	🌍	🌍	🌍	🌍	🌍

🌍= efficient as is
🌎= needs improvement