

Modeling Consumer Preferences over the Smartphone Attributes: A Choice Experiment Analysis

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Abstract

This paper measures the consumers' willingness to pay for hypothetical graphene-based smartphones (GBSs). The hypothetical smartphones contain desirable graphene-based attributes (GBAs) such as a stronger touch screen, lighter device (140 gm and 80 gm), faster battery charging (45 minutes and 30 minutes), the availability of solar power charging, and foldable touch screen. To form the hypothetical smartphones, we applied an orthogonal design in the Choice Experiment technique to match various graphene-based attributes at different levels. The technique requires respondents to choose the most preferred smartphones from a series of smartphones presented to them. We interviewed 657 respondents in Peninsular Malaysia with a face-to-face data collection method. The respondents consist of users and non-users of smartphones and the method of analysis is conditional logit model. In the preliminary data analysis involving the full sample, the estimation results show that most of the selected GBAs are significant. These results imply that it pays for smartphone firms to invest in and commercialize those attributes. When the full sample was divided into users and non-users of smartphones, we found that the results of the user sample mimicked those of the full sample. We took the user sample as our baseline sample and tested whether the preferences over GBAs are different for different consumer segments. We obtained results that are broadly consistent with our hypotheses.

Keywords: Choice Experiment, Conditional Logit Model, Graphene-Based Smartphones, Orthogonal Design, Willingness to Pay

1.0 Introduction

In the past few decades, the world has witnessed numerous advances in information and communication technology (ICT), one of which has come to be known as nanotechnology. As the name implies, nanotechnology refers to technology that is based on nanomaterials; i.e. materials that are extremely small, in the order of the magnitude of at most 100 nanometers, such as carbon nanotubes, fullerenes, and graphene (Batovsky, 2012). By virtue of their size, these nanomaterials offer a lot of opportunities for various existing electronic and non-electronic devices/products to be enhanced. This paper focuses on graphene (Geim & Novoselov, 2007; Novoselov et al., 2012; Kumar et al., 2013).

Graphene is a two-dimensional (2D) crystal of carbon atoms that are arranged in a hexagonal lattice (Novoselov, 2010). In theory, graphene had been discovered as early as the 1930s (Landau, 1937). However, it only appeared as a component of carbon, which is a three-dimensional (3D) material, and it was believed that any attempt to reduce this 3D carbon material into a 2D material will be unsustainable because it is unstable (Landau, 1937). This belief turned out to be wrong when graphene was accidentally synthesized in 2004 by two UK-based Russian scientists, Andre Geim and Konstantin Novoselov; for this important discovery, they were awarded the Nobel Prize in Physics in 2010 (Kumar et al., 2013). The beauty of graphene lies in its many desirable properties: it is mechanically very stiff, strong, and flexible; it is highly electrically and thermally conductive; and it

is highly transparent and impermeable to gases (Novoselov, et al., 2012). All of these properties might prove to be useful in a host of applications such as touch screens, e-papers, organic light-emitting diodes, radio frequency transistors, logic transistors, organic photovoltaic devices, photonics, composite materials, and energy storage (Ferrari et al., 2015; Novoselov et al., 2012).

Consider a specific application in which graphene may find its way into, a touch screen. As the name implies, a touch screen is the screen display of a particular electronic device to which a user communicates by simply touching the screen using an instrument called stylus or his/her finger [Kumar et al., 2013; What is a touch screen? (April 30th, 2020)]. A touch screen is used pervasively in a host of electronic devices today such as in tablets, automatic teller machines (ATMs), point-of-sale (POS) machines, arcade games, e-books, and smartphones. In some of these devices, such as ATMs and POS machines, a simple technology known as resistive technology is used by merely tapping the display area to give certain instructions [What is a touch screen? (April 30th, 2020); How touchscreen works in simple words (July 6th, 2019)]. In other devices, such as e-books and smartphones, a relatively more sophisticated technology known as capacitive technology is used by touching and holding, dragging, swiping and pinching a particular point in the display area [What is a touch screen? (April 30th, 2020); How a touch screen works in simple words (July 6th, 2019)]. At the moment, most touch screens are made using a material known as indium tin oxide (ITO).¹ Although ITO is advantageous in the sense that it is highly electrically conductive and optically transparent, it is disadvantageous in the sense it breaks easily if it is bent or stretched (Ahn & Hong, 2014). With the advent of graphene, scientists have been eyeing at the prospect of designing flexible electronic devices such as flexible touch screen displays (Ahn & Hong, 2014).

Now consider a specific device in which graphene may find its way into, a smartphone. Basically, a smartphone is the advanced version of a mobile phone. Unlike its predecessor (i.e. the fixed line telephone), a mobile phone allows a user to communicate with the other party while he/she is on the move. The mobile phone is also known as the cellular phone (or simply the cell phone) because it operates on a cellular network.² Since its introduction, the mobile phone has evolved very rapidly that today it is getting very sophisticated and functions very much like a mini computer; hence, the term smartphone. A typical smartphone is made up of several components such as touch screen (which is made of ITO), battery (which is made of lithium ion), and system-on-a-chip (SoC) (which is made of silicon). (What is inside your smartphone? Gary explains (Feb. 23rd, 2017). All of these materials suffer from certain shortcomings: ITO in displays cracks easily when bent (Kumar et al., 2013), lithium ion in batteries suffers from low power density (Xu et al., 2013), and silicon in transistors is approaching its technological limits (Yung et al., 2013). If it is technologically feasible to come up with a smartphone which incorporates desirable graphene-based attributes (GBAs), then the world might be looking at a thinner, lighter, and more flexible smartphone than its competitors, plus one that is equipped with a battery that charges faster yet lasts longer. Is this so-called graphene-based smartphone (GBS) a desirable mobile device for consumers? More precisely, is it sufficiently desirable that it pays for a smartphone maker to invest in it and subsequently commercialize it?

Inasmuch as the price of a good is basically a measure of its value, it is imperative that these desirable attributes of a GBS be weighed against its price. By virtue of its attributes, a GBS is likely to be more expensive than a non-GBS (at least initially). Hence, our consideration depends on whether the higher price justifies the desirable attributes. In view of the fact that a GBS with all of these attributes has yet to be introduced to the public at large, the best that we could do is to speculate the consumers' behavior based on their stated preference if they are hypothetically presented with a GBS.

¹ To be more precise, a touch screen is coated with the so-called transparent conductive electrode (TCE), and it is this TCE which is usually made of ITO [How do touchscreens work? (Nov. 7th, 2018)].

² A cellular network is a communication network consisting of cellular towers and optical fiber cables that transmit and receive phone calls [How does your mobile phone work? | ICT #1 (Dec. 30th, 2018); How does the internet work? | ICT #2 (May 30th, 2019)].

Fortunately, a hypothetical scenario which allows us to make an inference on consumers' preference is available via a method known as choice experiment (CE) (more on this shortly). Against this background, the objective of this paper is two-fold: a) to investigate how an individual's stated preference could be used to rank the GBAs to be incorporated into a smartphone, and b) to calculate the market value of such attributes in a GBS.

The rest of this paper is organized as follows. Section 2 briefly explores consumers' preferences over smartphone's attributes and the potential role to be played by the CE technique. This is followed by the design of our study including the selection of the attributes and generation of the choice cards. The fourth section reports the CE's results and consumers' willingness to pay (WTP) for GBAs. The fifth section discusses the CE results with a particular emphasis on the practical implications on smartphone firms. Finally, some conclusions are drawn toward the end of this paper.

2.0 Graphene-Based Smartphones and Choice Experiment Technique

Before we talk about smartphones which incorporate graphene's desirable attributes, it is imperative that we explore what consumers view as desirable attributes of smartphones in the first place. Our literature review indicates that, in choosing to purchase a specific smartphone, consumers consider the following attributes: the durability of its battery once charged, the speed of battery charging, the source of power conductor (electricity or solar energy), the thickness and weight of the device, the strength and sensitivity of its touch screen, the capacity of its data storage, the performance of its camera, the compatibility of the device with numerous applications, and of course the device's price (Osman et al., 2011; Tan et al., 2012; Yew et al., 2013; Lomonaco, 2014; Hong, Teh & Soh, 2014; Lazim & Sasitharan, 2015). Although all of these attributes are desirable, not all of them are GBAs; i.e. attributes that can be contributed and/or enhanced by a GBS. Our investigation concludes that only a handful of these desirable attributes qualify as GBAs: battery performance (both its durability and speed of charging); screen quality (both its strength and sensitivity); device's thickness (it can be as thin as a laminated paper), device's weight (it can be as light as 80 gm as opposed to 200 gm today) and device's foldability (it can be unfolded to increase screen size and folded when not in use). Once we have identified them, then we can ask respondents to make a choice of hypothetical GBAs using the CE technique.

To begin with, CE is an environmental valuation technique to value goods or services that are not traded in the market. The technique is appropriate if the researcher's objective is to value the characteristics of the goods or services rather than the goods itself (Hanley, Mourato, & Wright, 2001). In the case of a smartphone, the market price of the product can be determined directly from their demand and supply interaction in the market. The market however is not able to determine the market value of its characteristics such as stronger touch screen, lighter device, battery charging speed, device weight, power source, etc. Moreover, such characteristics are not embedded yet in the smartphone. Hence, CE is available to estimate the market value of such features.

The CE technique requires respondents to choose the most preferred alternative from a series of alternatives presented to them (Bateman, et al., 2002). Such alternatives consist of attributes of smartphones and their levels. Various attributes of smartphones and their levels need to be identified so that a wide array of alternatives can be formed and presented to respondents. However, including all of the attributes comes with a price. The number of alternatives will be increased exponentially with the increase of attributes and their levels (Bliemer, 2006). This will lead to respondents' cognitive burden problem if they were asked to review all the alternatives before choosing the most preferred one (Hensher, 2006). As a guideline, researchers are suggested to apply four to six attributes in their study that use the CE technique (Bergmann, 2008; Boxall & Adamowicz, 2002; Blamey, Rolfe, Bennett, & Morrison, 2000). In terms of the number of alternatives for each choice card, Rolfe (2008) suggested using two alternatives though some studies (Carson et al., 1994; Smith & Desvousges, 1987) applied four alternatives.

3.0 Study Design

3.1 Selecting Attributes and Their Levels

As mentioned earlier, the potential attributes of a smartphone in this study were determined from a review of relevant previous research on smartphones. The outcome of the review concluded that the attributes that are usually considered on the choice of the smartphone are the durability of its touch screen; the weight of its device; the speed of battery charging, power source, storage capacity, and camera performance. We investigated the suitability of determined attributes by conducting a series of focus group discussion (FGD) on several participants. Three series of FGD were conducted in February 2019 involving a total of 26 students. From these FGDs, we found the following: a) some GBAs such as charging durability, screen sensitivity, and device's thickness seem trivial; b) some non-GBAs such as data storage capacity and camera performance seem essential; and c) consumers' willingness to pay (WTP) for GBSs seems very low (i.e. in the range of RM1,000–RM3,000). We used these findings to modify potential attributes. For example, we dropped some arguably trivial GBAs from the list of attributes. The list of retained GBAs and their levels is presented in Table 1.

Table 1: List of Attributes and Their Levels

Attribute	Description	Levels (Variable Name)
Battery	Speed of battery charging	60 minutes 45 minutes (Chg45) 30 minutes (Chg30)
Source	Source of energy	Electricity Solar Energy (Solar)
Weight	Weight of a smartphone	200 grams 140 grams (Wgt140) 80 grams (Wgt80)
Foldability	Surface of a touch screen	Non-foldable Foldable (Fold)
Strength	Durability of a touch screen	Easily Breakable Unbreakable (Strength)
Price	The maximum price of a smartphone	RM2000 RM2500 RM3000 RM3500 RM4000

Note: The bold word indicates Status Quo

This study applied an orthogonal design where the coefficients of attributes produced in the design are said to be uncorrelated (Bliemer, 2006). The orthogonal design feature in SPSS produced 25 choice cards. Asking respondents to answer all the 25 choice cards is cumbersome and requires higher cognitive burden (Hensher, 2006). Hence this study applied a blocking approach where each respondent was required to answer five choice cards. Each choice card consists of three options including the status quo option (i.e. non-GBS). An example of the choice card is shown in Table 2.

Table 2: An Example of the Choice Card

	GBS A	GBS B	Non-GBS
Battery	45 minutes	60 minutes	60 minutes
Source	Electricity	Solar Energy	Electricity
Weight	200 grams	140 grams	200 grams
Foldability	Foldable	Non-foldable	Non-foldable
Strength	Unbreakable	Easily Breakable	Easily Breakable
Price	MYR4000	MYR 3500	MYR 2000
I prefer to buy (please tick ✓)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

3.2 Constructing Survey Questionnaires

We then proceeded by developing a set of preliminary survey questionnaires which are designed to capture the relevant information from the prospective consumers. The questionnaires consist of several sections. The first section is designed to extract basic information on smartphones from the respondents (e.g. Do you have a smartphone? What is your smartphone's brand and model? What is the price of your smartphone? What are the desirable features that you are looking for in a smartphone?) The second section is the most important one; it is designed to uncover important information from the respondents regarding GBSs. As a matter of fact, here is where the CE analysis comes into picture: the determined GBAs and their levels (as shown in Table 1) were presented and explained to respondents, and each of them was asked to answer five choice cards (an example of which is shown in Table 2). The remaining sections are designed to capture the socio-demographic characteristics of respondents such as age, income, education and occupation.

Next, we conducted the pilot survey on a sample of 60 respondents. It aimed to test the validity of survey questionnaires before the actual survey is carried out. Although the overall findings were satisfactory; there was one unfavorable finding: the price variable is statistically insignificant. Since this result would preclude our analysis on the consumers' WTP for GBSs, we examined how the variable is described. With the benefit of hindsight, we noted that we have used the current smartphone price of individual consumers as the baseline price and asked how much more they are willing to pay if certain GBAs are added. Thus, the price variable is individual-specific. Believing that this could contribute to the poor result, we then followed the common practice of using a common baseline price and increased it by a few levels with the addition of various combinations of GBAs. Using the sample information from the pilot survey, we chose RM2000 as the baseline price and added it by RM500, RM1000, and so on until the price hit RM4000. Hence, price is a discrete variable which ranges from RM2000 to RM4000.

3.3 Developing the Sampling Framework

In order to extract meaningful information, it is imperative that we develop a sampling framework in such a way that our sample is representative of the population. There are two important considerations: sample size and the sampling method.

The population of our survey is essentially all (potential and actual) smartphone users in Malaysia. We consulted a recently conducted nationwide survey on mobile phone users in Malaysia known as the Handphone User Survey 2017 (HPUS2017). This survey was conducted on a sample of 2,401 respondents by the Communication and Multimedia Commission (MCMC) of Malaysia (MCMC, 2017). Given the survey population, a sample size of 600 respondents was deemed sufficient. To be conservative, however, we opted for a larger sample size of 660 respondents.

HPUS2017 provides information on the profile of smartphone users in Malaysia based on a number of dimensions. We picked two of them (residential regions and age brackets/groups of users) as the basis for our survey and used a stratified sampling method. According to the survey, the breakdown of mobile phone users by a) residential regions is as follows: 23.9% (Northern region), 40.7% (Central region), 18.9% (Southern region), and 16.5% (Eastern region); and b) age brackets is as follows: 10.1% (< 20 years old), 45.9% (20-34 years old), 26.4% (35-49 years old), 13.2% (50-64 years old), and 4.5% (> 64 years old). If we cross-tabulate these two dimensions, we obtain the breakdown of mobile phone users as shown in Table 3.

Table 3: Breakdown of Mobile Phone Users by Regions and Age Brackets (%)

	< 20	20-34	35-49	50-64	> 64
Northern	2.3	11.0	6.3	3.2	1.0
Central	4.2	18.7	10.7	5.3	1.8
Southern	2.0	8.7	5.0	2.5	0.8
Eastern	1.7	7.5	4.3	2.2	0.8

Source: Handphone User Survey 2017

This breakdown was used to calculate the number of target respondents in each cell. For a sample of 660 respondents, the number of respondents in each cell is shown in Table 4.

Table 4: Breakdown of Target Respondents by Regions and Age Brackets (persons)

	< 20	20-34	35-49	50-64	> 64	Total
Northern	15	72	42	21	7	157
Central	28	123	70	35	12	268
Southern	13	57	32	17	6	125
Eastern	11	50	29	14	6	110
Total	67	302	173	87	31	660

Given this breakdown, a total of 26 enumerators among university students were employed to administer the survey. These enumerators were chosen in such a way that their residence areas were matched to the residence areas of the respondents. Basically, each enumerator was assigned to approximately 25 respondents. A briefing session was held for them in March 2019 to provide the necessary guidance before they were deployed to administer the survey. The survey was conducted in April and May 2019. Of the 660 respondents interviewed, missing values were found in 3 of the survey questionnaires, leaving us with 657 respondents.

3.4 Model Specification and the Choice Data

The objective of this paper is to examine the extent to which GBSs are accepted by prospective consumers. Based on FGDs and the pilot survey, five GBAs and the price variable are selected and these constitute our independent/explanatory variables as shown in Table 5.

Table 5: List of Explanatory Variables

No.	Variable Name	Variable Notation	Variable Description	Note
1.	Battery Charging Speed	Chg45 (x ₁) Chg30 (x ₂)	1 = 45 minutes; 0 = Otherwise 1 = 30 minutes; 0 = Otherwise	Charging speed of 60 minutes is the reference category (status quo)
2.	Device Weight	Wgt140 (x ₃) Wgt80 (x ₄)	1 = 140 gm; 0 = Otherwise 1 = 80 gm; 0 = Otherwise	Weight of 200 gm is the reference category (status quo)

3.	Power Source	Solar (x ₅)	1 = Solar; 0 = Electricity	Solar is an alternative power source
4.	Foldability	Fold (x ₆)	1 = Foldable; 0 = Unfoldable	
5.	Strength	Str (x ₇)	1 = Unbreakable; 0 = Easily Breakable	
6.	Price	Price (x ₈)	1 = RM2000; 2 = RM2500; 3 = RM3000; 4 = RM3500; 5 = RM4000	

The dependent variable is essentially the choice of a particular GBS made by prospective consumers. Hence, the choice made by respondent i (for $i = 1, 2, \dots, 657$) can be succinctly written as:

$$y_i = \begin{cases} 1 & \text{if individual } i \text{ chooses GBA A} \\ 2 & \text{if individual } i \text{ chooses GBS B} \\ 3 & \text{if individual } i \text{ chooses non GBS} \end{cases} \quad (1)$$

Given the discrete nature of the dependent variable, the empirical model can be specified as the probability of choosing any particular GBS j by individual i conditional on the explanatory variables, $\text{Prob}(y_i = j | \mathbf{x}_{ij})$. This probability can, in turn, be expressed by the conditional logit (CL) model:

$$\text{Prob}(y_i = j | \mathbf{x}_{ij}) = \frac{\exp(\mathbf{x}'_{ij}\boldsymbol{\beta})}{\sum_{j=1}^3 \exp(\mathbf{x}'_{ij}\boldsymbol{\beta})} + \varepsilon_{ij}, \quad (2)$$

where $\mathbf{x}'_{ij}\boldsymbol{\beta}$ is a linear combination of the explanatory variables,

$$\mathbf{x}'_{ij}\boldsymbol{\beta} = \beta_0 + \beta_1 \cdot x_{1ij} + \beta_2 \cdot x_{2ij} + \beta_3 \cdot x_{3ij} + \beta_4 \cdot x_{4ij} + \beta_5 \cdot x_{5ij} + \beta_6 \cdot x_{6ij} + \beta_7 \cdot x_{7ij} + \beta_8 \cdot x_{8ij},$$

where β_0 is a constant and β_h is the coefficient of x_h ($h = 1, 2, \dots, 8$) as specified in Table 5. Given the probability, the WTP of a specific x_h is given by

$$WTP_h = \frac{\beta_h}{\beta_8}, \quad (3)$$

($h = 1, 2, \dots, 7$). The data for the dependent and independent variables were obtained from our interview-based survey of 657 respondents. Of these, 605 (92.1%) of them are the current users of smartphones while the remaining 52 (7.9%) of them are non-users. (We would like to see whether the non-users' preferences over a GBS are different from those of users.) Of 657 respondents, too, 237 (36.1%) of them chose GBS1, 250 (38.1%) of them chose GBS2, and the remaining 170 (25.9%) of them chose non-GBS.

4.0 Findings

The empirical analysis can help us answer a few interesting questions:

- What are the significant determinants of the probability of choosing GBS? How do they rank?
- What is the WTP of each of the significant determinants? How do they rank?
- Is the WTP of each of the above determinants different between smartphone users and non-smartphone users? If this is the case, to what extent?

- Among smartphone users, to what extent does the WTP of each of the above determinants differ between low-income earners and other income earners?
- Among smartphone users, to what extent does the WTP of each of the above determinants differ between youngsters and adults?

In order to answer the first two questions, we estimated the CL model for the full sample, the results of which are shown in Table 6. With regard to the first question, the results show that the estimated coefficient of a) price is negative and significant (permitting us to examine consumers' WTP); b) device's weight and strength are positive and significant; c) solar power is negative and significant; d) battery charging speed is significant only when it is reduced by one-half; and e) device's foldability is negative and insignificant. Given the ranking, priority should be given to the device's strength, followed by device's weight and charging speed. It is surprising that the device's foldability and the availability of solar power as an alternative power source are not valued by consumers. With regard to the second question, the findings indicate that consumers are willing to pay approximately an additional a) RM1,232 for a stronger touch screen; b) RM272 for a lighter smartphone (140 gm); c) RM792 for a much lighter smartphone (80 gm); and d) RM260 for a much faster battery charging (30 minutes).

Table 6: Estimates of the CL Model (Full Sample)

	Coef.	WTP (MYR)
ASC	-1.595*** (0.000)	NA
Chg45	0.077 (0.189)	145.22 (0.190)
Chg30	0.138** (0.049)	259.79* (0.055)
Solar	-0.145*** (0.005)	-270.84*** (0.005)
Wgt140	0.145** (0.020)	271.91** (0.020)
Wgtt80	0.422*** (0.000)	792.18*** (0.000)
Fold	-0.012 (0.809)	-22.44 (0.809)
Strength	0.656*** (0.000)	1231.58*** (0.000)
Price	-0.00053*** (0.000)	NA
LL(β_b)	-3362.491	
LL(β_0)	-3537.191	
Pseudo-R ²	0.049	
Adjusted Pseudo-R ²	0.048	
No. of observations	3285	

Note: The figures in parentheses are p-values; ***, **, and * denote that the corresponding coefficient is significant at the 1%, 5%, and 10% level, respectively. The choice of Non-GBS is the base outcome.

As mentioned earlier, we would like to explore whether the preference of smartphone users is different from that of non-users with regard to GBSs. Hence, we divided the full sample into the respective sub-samples (i.e. 605 and 52 respondents, respectively) and re-estimated the CL model. As shown in Table 7, their preference is indeed different. Specifically, the results for users are similar to those in the full sample with regard to the sign and significance of the estimated coefficients; this is not the case for non-users: apart from price, only the estimated coefficient of device's strength is significant. The discrepancy of the results between users and non-users is hardly surprising (and even

expected) given the fact that some non-users do not have smartphones because they are not interested in them in the first place, let alone GBSs.

Focusing on the sample of smartphone users, we deduce that consumers are willing to pay approximately an additional a) RM1,233 for a stronger touch screen; b) RM293 for a lighter smartphone (140 gm); c) RM832 for a much lighter smartphone (80 gm); d) RM204 for a faster charging time (45 minutes); and e) RM231 for a much faster charging time (30 minutes). If all of these WTP figures are compared to their counterparts for the full sample, we notice that WTP is higher for users in all cases but one. These results suggest that smartphone manufacturers should focus on users when marketing GBSs.

Table 7: Estimates of the CL (Split Samples: Users vs. Non-Users)

	Users		Non-Users	
	Coef.	WTP (MYR)	Coef.	WTP (MYR)
ASC	-1.618*** (0.000)	NA	-1.386*** (0.006)	NA
Chg45	0.110* (0.073)	204.34* (0.075)	-0.267 (0.209)	-563.80 (0.243)
Chg30	0.125* (0.089)	231.04* (0.097)	0.281 (0.265)	593.24 (0.302)
Solar	-0.151*** (0.004)	-281.07*** (0.005)	-0.060 (0.753)	-126.13 (0.754)
Wgt140	0.158** (0.015)	292.69** (0.015)	-0.015 (0.946)	-32.52 (0.946)
Wgt80	0.449*** (0.000)	832.51*** (0.000)	0.153 (0.575)	322.45 (0.576)
Fold	-0.007 (0.899)	-12.22 (0.899)	-0.090 (0.626)	-190.80 (0.631)
Strength	0.664*** (0.000)	1232.83*** (0.000)	0.554*** (0.008)	1169.05** (0.034)
Price	-0.00054*** (0.000)	NA	-0.00047*** (0.002)	NA
LL(β_b)	-3086.986		-269.606	
LL(β_0)	-3255.265		-278.686	
Pseudo-R ²	0.0517		0.033	
Adjusted Pseudo-R ²	0.0503		0.152	
No of observations	3025		260	

Note: The figures in parentheses are p-values. ***, **, and * denote that the corresponding coefficient is significant at the 1%, 5%, and 10% level, respectively. The choice of Non-GBS is the base outcome.

From now onwards, let us restrict our analysis to smartphone users. Our goal is to see whether we can segment smartphone users into different groups. Among them, it is likely that the WTP for GBSs is different based on their income level; in particular, the WTP for luxury-like goods such as GBSs is presumably higher the higher one's income is, *ceteris paribus*. Granted this reasoning, we divided users into two groups: low-income earners and other income earners. For low-income earners, we picked the latest figure for the B40 group, which is RM4,850 (DoSM, 2020). With this cut-off income level, we ended up with 315 users in the low-income group and 290 in the middle- and high-income groups. For ease of reference, let us call them low-income consumers (LICs) and non-LICs, respectively.

Re-estimating the CL model for each sub-sample, we obtained the results as shown in Table 8. In terms of the sign and significance of the estimated coefficients, the results of LICs are similar to those of non-LICs with some exceptions: LICs do not value lighter devices as much as non-LICs do, and

non-LICs do not value faster battery charging as much as LICs do. From these results, it could be deduced the following:

- a) LICs are willing to pay an extra RM1,125 for a stronger touch screen whereas non-LICs are willing to pay an extra RM1,311 (which is consistent with our expectation; i.e. non-LICs are willing to pay more, ceteris paribus);
- b) LICs are willing to pay an extra RM794 for a lighter device (140 gm) whereas non-LICs are willing to pay an extra RM855 (which is also consistent with our expectation);
- c) non-LICs are willing to pay an extra RM382 for a much lighter device (80 gm) whereas LICs are not willing to do so (which is also consistent with our expectation); and
- d) LICs are willing to pay an extra RM403 for a much faster charging time (30 minutes) whereas non-LICs are not (which is inconsistent with our expectation).

Table 8: Estimates of the CL (User Sub-Samples: LICs vs. Non-LICs)

	LICs (< RM4,850)		Non-LICs (≥ RM4,850)	
	Coef.	WTP (MYR)	Coef.	WTP (MYR)
ASC	-1.505*** (0.000)	NA	-1.784*** (0.000)	NA
Chg45	0.113 (0.185)	214.95 (0.188)	0.115 (0.200)	202.57 (0.204)
Chg30	0.211** (0.037)	402.99** (0.047)	0.036 (0.737)	62.88 (0.739)
Solar	-0.150** (0.043)	-286.97** (0.045)	-0.154** (0.046)	-272.67** (0.048)
Wgt140	0.416*** (0.000)	794.02*** (0.000)	0.483*** (0.000)	855.10*** (0.000)
Wgt80	0.104 (0.248)	198.02 (0.247)	0.216** (0.022)	382.16** (0.023)
Fold	-0.078 (0.275)	-149.59 (0.277)	0.062 (0.407)	109.57 (0.410)
Strength	0.590*** (0.000)	1125.27*** (0.000)	0.741*** (0.000)	1311.02*** (0.000)
Price	-0.001*** (0.000)	NA	-0.001*** (0.000)	NA
LL(β_b)	-1636.77413		-1440.817	
LL(β_0)	-1715.4962		-1534.056	
Pseudo-R ²	.0459		0.060	
Adjusted Pseudo-R ²	.0432		0.0578	
No of observations	1575		1450	

Note: The figures in parentheses are p-values. ***, **, and * denote that the corresponding coefficient is significant at the 1%, 5%, and 10% level, respectively. The choice of Non-GBS is the base outcome.

Focusing on smartphone users again, it could be argued that the preferences for smartphones might differ across their age; specifically, the WTP for new gadgets such as GBSs is probably higher the younger a person is, ceteris paribus. Given this line of thinking, we divided users into two groups: those aged less than 35 years old (youngsters) and those aged at least 35 years old (adults). With this cut-off age, we ended up with 362 youngsters and 243 adults.

Re-estimating the CL model for each sub-sample, we obtained the results as shown in Table 9. In terms of the sign and significance of the estimated coefficients, the results of the youth group are similar to those of the adult group with some exceptions: youngsters value lighter devices more than adults, but youngsters do not value faster battery charging as much as adults do. From these results, it could be deduced the following:

- a) youngsters are willing to pay an extra RM1,378 for a stronger touch screen whereas adults are willing to pay an extra RM1,034 (which is consistent with our expectation; i.e. youngsters are willing to pay more, *ceteris paribus*);
- b) youngsters are willing to pay an extra RM846 for a lighter device (140 gm) whereas adults are willing to pay an extra RM809 (which is also consistent with our expectation);
- c) youngsters are willing to pay an extra RM385 for a much lighter device (80 gm) whereas adults are not willing to do so (which is also consistent with our expectation); and
- d) adults are willing to pay an extra RM313 for a faster charging time (45 minutes) whereas youngsters are not willing to do so (which is inconsistent with our expectation).

Table 9: Estimates of the CL (User Sub-Samples: Youngsters vs. Adults)

	Youngsters (< 35 years old)		Adults (≥ 35 years old)	
	Coef.	WTP (MYR)	Coef.	WTP (MYR)
ASC	-1.613*** (0.000)	NA	-1.624*** (0.000)	NA
Chg45	0.068 (0.389)	130.97 (0.390)	0.176* (0.070)	312.50* (0.075)
Chg30	0.108 (0.249)	206.25 (0.260)	0.155 (0.188)	275.15 (0.201)
Solar	-0.101 (0.144)	-193.33 (0.144)	-0.232*** (0.006)	-412.09*** (0.008)
Wgt140	0.442*** (0.000)	846.36*** (0.000)	0.456*** (0.000)	809.25*** (0.001)
Wgt80	0.201** (0.016)	385.40** (0.017)	0.092 (0.373)	163.70 (0.372)
Fold	-0.005 (0.939)	-9.730 (0.939)	-0.007 (0.929)	-13.01 (0.929)
Strength	0.719*** (0.000)	1377.85*** (0.000)	0.582*** (0.000)	1034.15*** (0.000)
Price	-0.001*** (0.000)	NA	-0.001*** (0.000)	NA
LL(β_b)	-1833.715		-1248.092	
LL(β_0)	-1938.479		-1312.046	
Pseudo-R ²	0.054		0.0487	
Adjusted Pseudo-R ²	0.051		0.0452	
No of observations	1810		1215	

Note: The figures in parentheses are p-values. ***, **, and * denote that the corresponding coefficient is significant at the 1%, 5%, and 10% level, respectively. The choice of Non-GBS is the base outcome.

5.0 Discussions

In the above empirical analysis, our goal was to determine which GBAs are statistically significant; once this had been done, we proceeded by measuring consumer's WTP for those GBAs. In the preliminary analysis involving the full sample (which includes users and non-users of smartphones), we found that all of the GBAs are significant except for a faster charging time (45 minutes) and device's foldability. In the subsequent analysis involving the partitioning of the full sample into users and non-users, we found that a) except for foldable touch screen, all of the GBAs are significant for users, and b), except for a stronger touch screen, all of the GBAs are *insignificant* for non-users. Obviously, the preference of smartphone users is very distinct from that of non-users; hence, we decided to focus on users.

Among smartphone users, all of the significant estimated coefficients are positive except for solar power. These results imply that a) it pays for smartphone manufacturers to invest in (and

commercialize) GBSs which feature stronger touch screen, lighter device, and faster battery charging, and b) it does *not* pay to invest in (and commercialize) GBSs which feature device's foldability and the availability of solar power. A few words are in order. First, device's foldability does not matter at all. Therefore, it does *not* pay to invest in this attribute (at least for average consumers) even though it may look sophisticated (it may appeal to a certain segment of consumers, though). Second, the addition of solar power as an alternative power source does matter *but* in a negative way. Thus, it does *not* pay to invest in this attribute as well.

Once the focus had been made on smartphone users, we partitioned them further into different user segments on the account that the preferences over GBAs might be different across segments. One way to segment users is by dividing them into LICs and non-LICs. Here we hypothesized that the preferences over GBAs are greater for non-LICs than LICs because the former can afford the presumably more expensive GBSs. We tested this hypothesis by splitting users into the two corresponding groups and repeating our empirical analysis. In most cases, we obtained results that are consistent with our hypothesis. For both groups, it pays to invest in GBSs which feature a stronger touch screen and a lighter device (140 gm); for LICs, it pays to invest in much faster charging time (30 minutes); and for non-LICs, it pays to invest in a much lighter device (80 gm) as well.

Another way to segment users is by segregating them into youngsters and adults. Here we conjecture that the preferences over GBAs are greater for youngsters than adults because the former is more likely to be fond of newer gadgets. After splitting users into the two corresponding groups and repeating our empirical analysis, we obtained results that are broadly consistent with our hypothesis. For both groups, it pays to invest in GBSs which feature a stronger touch screen and a lighter device (140 gm); for youngsters, it pays to invest in a much lighter device (80 gm) as well; and for adults, it pays to invest in faster charging time (45 minutes).

The issue of whether it pays to invest in (and commercialize) GBSs deserves further scrutiny. To elucidate this matter, consider a specific attribute of a GBS, say, the strength of its touch screen (this attribute has been found to be significant in all cases considered and yields the highest WTP). Our result indicates that consumers are willing to pay at least an extra RM1,000 for a GBS that is fitted with a stronger touch screen (instead of the existing one that needs to be coated with protective glass). If a manufacturer introduces this new model, then it means that the firm can sell it at a higher price than its current model. If the firm's sales volume remains the same (i.e. the quantity demanded of the new model is the same as that of the current model), then RM1,000 is the extra revenue that the firm earns vis-à-vis the current model. Of course, this extra revenue needs to be weighed against the extra cost associated with producing a presumably more expensive model (since graphene is costly). For this reason, it is justifiable for the firm to produce the new model if the extra revenue exceeds the extra cost.³

Another consideration is the R&D investment associated with developing this new model. Unlike the extra cost which is applicable to each unit of smartphones produced, the R&D investment is a one-time (yet probably huge) investment that is needed in order to come up with a new model which is fitted with graphene-based touch screen (instead of the current ITO-based touch screen). With the addition of this fixed cost, the firm needs to assess how long this new model would survive in the market before it is replaced by a newer model. Given this estimate, the firm needs to estimate the net present value of profits to be earned if it innovates in the first place. In competitive environment, this net present value of profits must equal zero to justify the innovation [see Barro & Sala-i-Martin (2004), Chapters 6 and 7].

³ We purposely avoid using the terms "marginal revenue" and "marginal cost" which have already had specific meanings in economics. The terms "extra revenue" and "extra cost" here refer to the difference in the revenue (or cost) of the new model versus the revenue (or cost) of the current model.

6.0 Conclusion

In this paper, we examined the extent to which GBSs are likely to be accepted by consumers. The preliminary analysis was based on an interview-based survey of 657 respondents in various regions in Peninsular Malaysia. The results show that all of the GBAs are significant except for the 45-minute battery charging and device's foldability. These results imply that it pays for smartphone manufacturers to invest in (and commercialize) GBAs which feature a stronger touch screen, lighter device, and faster battery charging. These results also suggest that it does *not* pay to invest in (and commercialize) GBAs which feature device's foldability and the availability of solar power.

We next explored whether these results are also applicable to each user and non-user samples, respectively. We found that the results are robust to the user sample only (i.e. most of the GBAs are significant for the user sample). Accordingly, we took the user sample as our baseline sample (605 respondents) and tested two hypotheses: a) the preferences over GBAs are greater for non-LICs than LICs (on the ground that non-LICs can afford GBAs which are more likely to be costlier), and b) the preferences over GBAs are greater for youngsters than adults (under the assumption that youngsters are more likely to be fond of new gadgets). In each case, we obtained results that are broadly consistent with the hypothesis. Therefore, it is imperative that smartphone manufacturers tailor their GBAs to the needs of different market segments.

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