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José A. Montenegro and José L. Torres

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Consumer preferences and implicit prices of smartphone characteristics

José A. Montenegro
Department of Computer Science. University of Malaga (Spain)

José L. Torres
Department of Economics. University of Malaga (Spain)

Abstract

This paper applies the hedonic pricing approach to study the implicit prices of smartphone characteristics and consumer preferences. Currently, mobile phones are the most widespread technological product worldwide and their performance and technical characteristics have changed dramatically over a short period. The development of smartphones has been a revolution in itself in the mobile telecommunication industry, expanding the capabilities of handsets beyond those of a simple mobile phone. Competition between smartphone producers is fierce and knowledge concerning consumers' preferences regarding smartphone features is vital to survival in this fast-changing market. This paper uses a hedonic pricing model to estimate the implicit prices of smartphone characteristics. A large set of characteristics are analysed including design, communication, connectivity, camera, display, hardware, multimedia, and power. The characteristics most valued by consumers are the screen, followed by memory, battery capacity, and weight. Consumers are willing to pay up to a 95% premium for an Apple smartphone.

Keywords: Smartphones, hedonic pricing approach, characteristics' implicit prices, consumer preferences.

1 Introduction

The mobile phone market has undergone rapid and spectacular change since the time these devices were first introduced. As pointed out by Hausman (1999), the adoption of cell phones has grown at a rate of 25-35 percent per year over the period 1983-1997. Penetration of this device has growth even faster in recent years. As measured by the number of active mobile phone numbers as a percentage of the population today, the mobile phone penetration rate is more than 100 percent in developed countries and close to 100 percent in developing countries. According to ITU (2012), the total number of mobile phone subscriptions had reached almost 6 billion by the end of 2011, corresponding to a global penetration of 86 percent. In fact, 105 countries have more mobile phone subscriptions than inhabitants. Furthermore, the percentage of the worlds' population covered by a mobile signal increased from 61 percent in 2003 to 90 percent in 2010.

On the other hand, mobile phone handsets have undergone dramatic technological changes in their performance and technical characteristics, and are no longer "simple" mobile voice communication devices. Handsets are now lighter and have larger screens with more colors and pixels per inch, enhanced connectivity, and higher resolution cameras among other features. Moreover, current mobile phones include novel performance and technical characteristics, such as touch screens and the ability to run complex software applications, store large amounts of data, and offer enhanced connectivity. The appearance of smartphones has blurred the distinction between Personal Digital Assistants (PDAs), tablets, and computers. Apart from functioning as telephones, they can also function as video recorders, photographic cameras, televisions, videogame consoles, radios, GPS devices, and so on. Such remarkable technological progress implies a fast-changing industry. According to Gartner (2013), smartphones sales finally exceeded those of traditional mobile phones during the second quarter of 2013 (225 million units vs 210 million units, respectively). Competition between smartphone producers is fierce and knowledge concerning consumers' preferences regarding smartphone features is vital to survival in this fast-changing market. The market share of mobile handset manufacturers has changed dramatically from one period to another, as shown by the birth of successful new mobile handset manufacturers like Apple and the demise of others like Nokia. The demand for mobile phone services heavily depends on technological advances in the handset manufacturing industry and, more recently, on developments in mobile application software.

The aim of this paper is to study the implicit prices of smartphone characteristics and consumer preferences. The consumer's marginal willingness to pay for a change in a particular characteristic can be inferred directly from the estimate of the implicit price of such characteristic, using a revealed preferences argument. Increasing our knowledge of consumers' preferences regarding smartphone features is not only of interest to handset manufacturers, but also to the telecommunication industry as a whole. We use a hedonic pricing model to estimate the implicit prices of smartphone characteristics. This method is based on estimating an econometric model that compares the price of a product to the set of its characteristics. Current hedonic approaches are based on the initial work of Lancaster (1966) and Rosen (1974), and assume that the price of a good can be completely described by a vector of characteristics. In the literature, the hedonic pricing approach has been used with two main purposes. First, to estimate the implicit prices of the set of characteristics embodied in a product. Second, to estimate quality-adjusted price indexes for a product in order to disentangle price variations due to changes in characteristics from variations that take place for given characteristics.

Hedonic pricing methods have been applied to a large variety of products, such as automobiles, computers, and houses among others. Dewenter et al. (2007) calculates hedonic prices for mobile phone handsets in Germany using a dataset of 302 handsets covering the period May 1998 to November 2003. It was found that the number of ringtones and the talk-time battery life relative to weight are characteristics that are positively related to price, whereas volume has a negative relationship to final price. They also found that handsets have become cheaper over time, which is characteristic of products that are associated with a high rate of technological progress. Another related study is that by Chewlos et al. (2011), who calculated quality-adjusted price indexes for Personal Digital Assistants (PDAs) for the period 1999-2004. In this paper we focus on smartphones and apply the hedonic approach to a database of 312 different handsets from 34 manufacturers; these handsets were introduced onto the market between January and December 2012 (see Appendix A). A large set of characteristics are analyzed, including design, communication, connectivity, camera, display, hardware, multimedia, and power.

We find that the characteristics most valued by consumers are size and screen resolution. This result is expected given the large number of new smartphone characteristics, which need a large high-resolution screen especially when the smartphone has a touch control system. This finding can explain recent trends in the smartphone manufacturing industry to produce terminals with a larger screen. Other characteristics valued by consumers are memory, the number of CPUs, and battery capacity. Surprisingly, we found that handset weight has a significant positive effect on price, a result that is probably related to screen size, the use of heavy metals in their construction, and battery capacity. In contrast, camera resolution and the inclusion of a second camera are not valued by consumers. Furthermore, advanced technologies such as GPU and NFC are not related to the final price. The operating system and manufacturer are also variables which introduce a price premium across handsets. In particular, we found that consumers are willing to pay up to a 95% premium for an Apple smartphone.

The rest of the paper is structured as follows: Section 2 briefly reviews the hedonic price regression approach; Section 3 describes the dataset; Section 4 presents the results and discusses the estimated hedonic price regressions; and Section 5 offers some conclusions.

2 Implicit prices of characteristics: The hedonic approach

Smartphones are complex high-technology products and have a large number of technical and performance characteristics. This makes them very heterogeneous and thus there is a large number of alternative designs in the market, selling at different prices. Market sales for each model depend on consumer preferences regarding the set of characteristics embodied in them. This raises the issue of how the demand for a particular model depends on the implicit value consumers place on each characteristic. The unobserved implicit price of each characteristic can be measured using the hedonic pricing method.

This method is based on a multiple regression model, where the price of a number of models is determined by their characteristics. The theoretical foundation of this approach is the consumer theory of differentiated product presented by Lancaster (1966). The defining feature of the hedonic approach is that the consumers' utility functions are defined over characteristics instead of goods. The hedonic approach was initially applied by Rosen (1974) based on the hypothesis that goods are valued for their utility-bearing attributes. The idea is that a product can be described as a group of characteristics assumed to be positively valued by consumers. In this context, consumer choice refers to characteristics rather than products. The final price of the product is composed of the sum of the implicit price of each characteristic. Therefore, the price of the product represents the expenditure needed to obtain a given level of attributes.

Hedonic methods use information on the price of the product and a group of characteristics to disentangle the final price of the product from a set of implicit prices each corresponding to a given characteristic. In general, the demand for a product can be modelled as an explicit function of the prices for all products in the market. In a context of differentiated products, the demand for a product is modelled in the characteristics space, in a similar way to the model of competition developed by Hotelling (1929).

The consumer problem consists in choosing a group of characteristics, $x_1, x_2, ..., x_K$, of the good, and a quantity of all other goods, Z, such that utility is maximized subject to the budget constraint. The consumer's utility function can be defined as:

$$U(x_1, x_2, ..., x_K, Z) \tag{1}$$

subject to the budget constraint:

$$P(x_1, x_2, ..., x_K) + Z \leq Y \tag{2}$$

where Z is the aggregate of other goods, where its price in dollars is normalized to one, and Y is income. This problem is similar to the standard neoclassical consumer problem, except for the fact that choice refers to characteristics rather than goods. First-order conditions obtained from the consumer utility maximization problem imply that:

$$\frac{U_{x_k}}{U_{x_j}} = \frac{P_{x_k}}{P_{x_j}} \tag{3}$$

for all pairs of characteristics. This expression indicates that the ratios of the marginal utilities of each pair of characteristics must be equated with the ratios of their marginal prices. The marginal prices indicate the extra amount the consumer has to pay for an additional unit of a given characteristic.

As suggested by Rosen (1974), marginal prices associated with characteristics can be calculated by estimating a regression between prices and characteristics. The hedonic approach states that each product is characterized by the set of its characteristics. For any given product, we can define a vector of characteristics, x, as $x = (x_1, x_2, ..., x_K)$, where x_k, $k = 1, 2, ...K$, denotes each of the characteristics of the product. The key assumption is that for any product there is a functional relationship between the price, p, and its vector of characteristics, x, such that

$$p = f(x) \tag{4}$$

Based on the function above, we can define implicit hedonic prices, which indicate how much the price of a good changes depending on how its characteristics change. In general, the hedonic regression model takes the form:

$$p_{i,t} = f(x_{i,t}, \beta_i) + \varepsilon_{i,t} \tag{5}$$

where $p_{i,t}$ is the vector or prices of the variety i in the period t, $x_{i,t}$ is the vector of characteristics of each variety, β_i is a vector of coefficients, and $\varepsilon_{i,t}$ is an error term. In the empirical analysis, the price of the product is regressed on a function of its characteristics and a time dummy variable. Based on this regression, we can estimate the contribution value of each characteristic (the implicit prices) and the quality-adjusted price (the true price).

The hedonic pricing approach can be empirically applied using several model specifications depending on the final goal. An alternative commonly used in the empirical literature is to estimate a separate regression equation for each observed period. Another standard procedure is to estimate a regression with blocks of data for two adjacent years and include a dummy time variable. Since the dependent variable of these regressions is usually expressed in natural logarithms, the coefficient of the time variable shows the percentage change in price between the two years that are not accounted for by changing specifications. Another widely used procedure is to estimate equation (5) for the full sample period and incorporate a time trend to capture changes in prices not explained by quality changes. This is the method used in this paper. In general, and assuming a semi-log specification for the sake of simplicity, we have:

$$\log p_{i,t} = \alpha + \delta t + \sum_i \beta_i \log x_{i,t} + \varepsilon_{i,t} \tag{6}$$

where t is the time trend.

The model developed by Rosen (1974) has been widely used to estimate the demand function for product characteristics. The reason for this is that this approach can be used not only to estimate the price elasticity of demand for product attributes, but to determine how demand varies between types of consumers. As pointed out by Griliches (1971), hedonic price regressions are simply a reduced form representation of both consumer and producer optimizing behaviour. In this context, it is possible to identify consumer preferences regarding the characteristics of a product.

Hedonic price analysis has been applied to a large variety of goods.[1] Seminal studies include those by Court (1939), Stone (1956), Griliches (1961), and Chow (1967). Griliches (1961; 1964) concluded that almost the entire documented rise in the new automobile component of the Consumer Price Index between 1954 and 1960 could be attributed to improvements in the quality of automobiles. Chow (1967) applied the hedonic approach to computers and found a 20% price reduction per year during the period 1954-1965. Pakes (2003) compared the hedonic approach to matched model indexes for PCs, finding important differences between the methods, since the hedonic approach produced sharp price decreases, whereas matched model indexes are close to zero. Lee (2003) studied the internet market and measured the consumer's willingness to pay for internet connection attributes.

3 Data and variables

Data on mobile phones were automatically collected from a large variety of sources, including several web pages, using a purpose-built computer program. All the mobile phones included in the database were introduced to the market in 2012. We have not consider mobile phones on sale but introduced earlier than 2012. The database contained a total of 312 handsets. The data on their performance and technical characteristics were represented by a set of variables described in Table 1; some of these were dummy variables indicating whether a particular characteristic was present in each handset or not. The table also shows the basic statistics for the variables. In the case of the dummy variables, the average value alone was reported, representing the percentage of handsets in the database which incorporate that characteristic.

The dependent variable was the (retail) price of the mobile handset, measured in current dollars. This price is the free terminal price, that is, the price the consumers had to pay when they purchased the

[1] The first paper to use hedonic price analysis was that of Waugh (1928), who studied the factors that explain the price of asparagus, tomatoes, and cucumbers, followed by the paper by Court (1939) for the automobile industry. More recent studies begin with the paper by Griliches (1961), which also focused on the automobile industry.

Variable		Mean	Std dev.	Min	Max	Description
Price		395.25	231.25	25.2	1137.58	Market price (free terminal price). Current dollars
Weight		128.95	28.54	63	388	Weight (in grams)
Dimension		85843.8	15566.7	55135.56	213.6	Dimension (cubic mm)
Camera		5843318	3339651	0	38391936	Camera resolution (megapixels)
Colours		10.68	7.47	0.051	16	Colours (number)
PPI		230.57	63.72	114	441	Pixels per Inches.
CPUn		1.65	0.84	1	4	Number of CPU
Memory		745.8	459.98	0.8	3000	RAM memory (MB)
Battery		1675.49	455.11	500	4250	Battery (in mAh)
Second		0.666	-	-	-	Second camera. Dummy variable
GPU		0.631	-	-	-	GPU. Dummy variable
NFC		0.301	-	-	-	NFC. Dummy variable
MHL-HDMI-DLNA		0.474	-	-	-	Mobile High-Definition Link, High-Definition Multimedia Interface and Digital Living Network Alliance. Dummy variable
OS	**Android**	0.836	-	-	-	Operating system. Four dummy variables: Android; IOS; Blackberry, Windows
	iOS	0.003	-	-	-	
	Windows	0.061	-	-	-	
	BlackBerry	0.006	-	-	-	
Network	**HSPA**	0.788	-	-	-	Communication standards. Three dummy variables: HSPA, LTE and WLAN
	LTE	0.237	-	-	-	
	WLAN	0.919	-	-	-	

Table 1: Description of the variables and descriptive statistics

mobile phone without signing a contract to purchase prepaid cards. As prices can change rapidly as a consequence of technological change, we also included the month of release as an explanatory variable. The remaining variables refer to the main characteristics of the device, which were divided into the following seven categories: design, cameras, display, communication, performance, operating systems, and connectivity. These are described below.

3.1 Design

The first group of characteristics variables refer to the design of the device. Although product characteristics are usually related to performance and technical capabilities, the design of the product is valued by consumers and can be an important aspect in determining demand for a particular device. To take this into account, we consider two design variables: *Weight* (in grams) and *Dimension* (in cubic mm). Although these two variables are relevant characteristics, they are not clearly related to the performance of the device. Although the form factor (block, qwerty slider, slider, clamshell/fold, and swivel) has been a distinguishing characteristic in previous mobile phone designs, the design of the iPhone has become the most widespread since its introduction by Apple inc., and is the form chosen by the majority of manufacturers.

3.2 Cameras

The trend in mobile phone imaging began with the addition of communication capabilities to cameras. At the end of the 1990s, Sharp and Kyocera introduced the first phones with integrated cameras. Twenty years later, Nokia announced a cellphone with an onboard camera with a resolution of 41 megapixels, whereas the first cameras did not even provide 1 megapixel resolution. Smartphones now offer mobile imaging, high-resolution cameras, and reliable high-speed communication. The number of camera phones worldwide will be nearly 2 billion by 2015, as forecast by InfoTrends (2011). Kindberg et al. (2005) offer an interesting taxonomy of reasons for image capture using a mobile phone. Moreover, new technologies and applications, such as augmented reality and QR Codes, can be run on mobile phones providing they have an onboard camera (Pence, 2010).

At the beginning of the present century, some phone manufacturing companies added a second camera to their devices, the front-facing camera. The main goal of this camera was to enable video calls. The resolution of front-facing cameras has traditionally been lower than rear-facing ones due to communications restrictions. The transmission of the images requires more bandwidth than that required for voice. Nowadays, the resolution of the front-facing camera is steadily increasing due to better communications standards and the blossoming of new applications (Miluzzo et al., 2010).

3.3 Display

Recently, displays have gained importance and are now considered one of the key elements of smartphones. Displays have undergone striking developments between the time of the first mobile phone with an 8-character red LED display and the current devices with 5.5 inch displays. The current role of the display is an indication of how this has evolved. The original function of the display was to show the numbers the user was dialling. Current high-definition display make it possible to watch videos, play games, browse the internet, and so on. Although this improves the user's experience it increases battery consumption and is of serious concern for manufacturers (Carroll and Heiser, 2010; Vallina-Rodriguez et al., 2010; Perrucci et al., 2011).

We considered four variables in this category: *Display size*, *Colors* (number of), *Touch* and *Resolution*. The variable *Pixels per inch (PPI)* is a measurement of both the resolution and the size of the screen. It covers two display variables – display size and resolution – as it is calculated by the following equation:

$$PPI = d_p/d_i,$$

where d_p is the diagonal resolution in pixels and d_i is the diagonal size in inches. Thus, the PPI variable alone has to be included in the model and not display size and resolution. Although we initially considered including the variable touchscreen in the estimated regression, we decided to exclude it as this characteristic is included in the majority of handsets in the dataset.

3.4 Communication

Several variables related to Cellular Network Standards were taken into consideration. Here, we briefly describe the technology and emphasize the data transmission rates of each technology. The European Telecommunication Standard Institute (ETSI) plays a leading role in the deployment of mobile communication technology. ETSI was created in the mid-1980s with the development of the Global System for Mobile (GSM) communication specifications and remains a key player.

The following variables refer to the technology involved in generations 2, 2.5, 3, and 4 (see Table 2). Among their technical characteristics, we have focused on the data transmission rate. These variables have to be taken into account because better data rates mean fast and reliable communication.

HSCSD High-Speed Circuit-Switched Data. This technology provides a 6-fold increase in GSM data transmission velocities (from 9.6 kbps to 57.6 kbps.).

GPRS General packet radio service. This provides a theoretical data transmission rate of 171 kbps.

EDGE Enhanced Data rates for GSM Evolution (also known as Enhanced GPRS (EGPRS)). EDGE can offer a data rate of 384 kbps; it is considered a pre-3G radio technology and part of ITU's definition of 3G. However, it can be viewed as an intermediate solution between 2G and 3G (like 2.5).

UMTS The Universal Mobile Telecommunications System is a 3G mobile cellular technology. It was developed by the Third Generation Partnership Project (3GPP), a new consortium for the establishment of a common system for Europe, Asia, and North America. UMTS offers a data rate of up to 2 Mbps.

HSPA High-Speed Packet Access offers reduced delays and a peak raw data rate of 14 Mbps. Specifications for HSPA are included in Release 5 and 6 of the 3GPP specifications.

HSPA+ Evolved HSPA offers a peak data rate of 42 Mbits within the Release 8 time frame.

LTE Long-Term Evolution is considered part of 4G. LTE allows for peak speeds of 100 Mbits for high-mobility communication and 1 Gbit for low-mobility communication. Specifications for LTE were originally included in Release 8, 9, 10 and 11 of the 3GPP specifications.

Generations of mobile telephony	Network	Data rates transmission
2G	GSM, CSD	9,6 kbps
2G transitional(2.5G, 2.75G)	HSCSD, GPRS, EDGE/EGPRS	57,6 - 384 kbps
3G	UMTS	2 Mbps
3G transitional (3.5G, 3.75G)	HSPA, HSPA+	14 - 42 Mbps.
4G	LTE	1 Gbits

Table 2: Phone network standards

In addition to the aforementioned communication mechanisms offered by Internet service providers, usually at flat rates, the devices can include other mechanisms to provide Internet connection, e.g., the IEEE Technology Family (Dekleva et al., 2007). The IEEE 802.11 network is a specification of the Wireless Local Area Network (WLAN), which has been an efficient alternative to broadband Internet Access or even a complement to cellular networks (Yaipairoj et al., 2008; Chintapalli et al., 2013; Gunasekaran and Harmantzis, 2008) during the last 10 years. The successful increase in WLAN coverage has mainly been due to uptake by public institutions (Tapia and Stone, 2006; Schmidt and Townsend, 2003). Current transmission rates can reach 150 Mbits in version 802.11n.

3.5 Performance

Although users without technical knowledge cannot take this series of characteristics into consideration, these elements have a direct impact on device performance. The *cpu velocity* and the *number of CPUs* are directly related to the execution of the system and the applications running on it.

The *memory size* has a direct impact on phone performance; increased memory capacity means that more applications can be run simultaneously. The Operating System demands a large amount of memory and each application increases this demand. A mismatch between the requirements of the system and the application considerably increases the response time, leading to customer dissatisfaction.

The *GPU* (*Graphics Processing Unit*) is a processor specifically designed to handle graphics. Based on personal computer GPUs, they have been included in smartphones because they are more efficient than CPUs at manipulating computer graphics. Although the main function of GPUs is to improve the performance of mobile games, the research community has adopted this unit to carry out intense computation tasks such as image recognition (Chou et al. ,2014) and, specifically, face recognition (Cheng and Wang, 2011) on mobile platforms.

The functionality of smartphones is severely limited by battery life. Traditionally, the *battery capacity* has been measured in hours (talk and standby time). This measure was appropriate until smartphones were introduced. Although these devices are equipped with a wide variety of components which offer the user a better experience, they also increase energy consumption. In fact, making phone calls is just one "application" which competes with other applications and electronic components for battery life (Pathak et al., 2011b). Thus, we have chosen a technical measurement, milli-Amperes (mA), to measure battery capacity. However, having a large capacity battery does not guarantee long battery life, since this depends on the applications (Pathak et al., 2012) and whether the system is energy bugs free (Pathak et al., 2011a).

3.6 Operating System

In contrast to personal computers, smartphones are designed to run specific software. The operating system (OS) can run on a proprietary or specific platforms, such as iOS and Blackberry OS, or it can be a closed OS, such as Windows Phone that runs on devices from different manufacturers, or an open platform OS, such as Android or its precursor Symbian. Normally, the device manufacturers are the direct consumer of their OSs. Before smartphones dominated the global cell phone market, consumers bought cell phones without knowing which OS was running on the device. However, there is an increasing number of customers who buy a smartphone based on the functionality offered by the software. Therefore, given the current performance capabilities of smartphones, the OS could be a key variable regarding the consumer's choice of phone.

On the other hand, an OS without effective applications is of little use to the consumer. The OS manufacturers need third-party applications or applications created by crowdsourcing developers (Bergvall-Kreborn and Howcroft, 2013). The manufacturers provide the minimum applications to cover the needs of the users and offer the developers the mechanisms and tools necessary to build the applications. Therefore, these tools are key to the successful development of a platform (Holzer and Ondrus, 2011). The number of available applications, especially mobile games (Feijoo et al., 2012), has a direct impact on the number of users and therefore the success of a platform.

Table 3 shows how the market share of smartphones evolved from 2006 to 2012 by operating system. We highlight the fact that in the third quarter of 2012, Android and Apple handsets had 86% of the worldwide market share, whereas in 2009 their market share did not reach the 20%. The high volatility of market shares shows that the OS should be a relevant characteristic in the consumer's choice.

Platform	2006	2007	2008	2009	2010	3Q11	3Q12
Symbian	67	63,5	52,4	46,9	37,6	16,9	2,6
Research In Motion	7	9,6	16,6	19,9	16	11	5,3
iPhone OS	0	2,7	8,2	14,4	15,7	15	13,9
Windows Mobile/Phone	14	12	11,8	8,7	4,2	1,5	2,4
Linux	0	9,6	7,6	4,7	0	0	0
Android	6	0	0,5	3,9	22,7	52,5	72,4
WebOS	5	1,4	0	0,7	0	0	0
Bada	0	0	0	0	0	2,2	3
Other OSs	1	1,2	2,9	0,8	3,8	0,9	0,4

Table 3: Gartner report on Worldwide Sales of Mobile Phones

3.7 Connectivity

In this group, we include different variables which expand the communication capabilities of the handsets:

GPS In the 1970s, when the US Department of Defense (DoD) developed the concept of a satellite-based navigation network, it could not have been predicted how useful the technology would become and how quickly it would spread to a wide variety of fields such as agriculture, aviation, the environment, marine settings, public safety & disaster relief, railways, recreation, roads & highways, space, surveying & mapping, and timing. Originally, the main use of *global positioning systems* (*GPS*) in the civilian market was as navigation systems to assist drivers. Nowadays, the inclusion of GPS chips on smartphones offers position, velocity, and timing information to the applications running on the devices. This information enhances traditional applications by including new functions and makes it possible to create new applications based on geographical information. The number of subscribers of GPS-enabled location-based services (LBS) will increase from 526.3 million in 2011 to 946.7 million in 2015 (iemarketresearch, 2011), with market revenues reaching around US$ 10 billion by 2013 (Researchandmarkets, 2011). Although this characteristic is valued by consumers, it does not form part of the estimation as it is included in almost all of the handsets in the dataset.

NFC *Near Field Communication* (*NFC*) is a technology for contactless communication between devices that evolved out of the Radio Frequency Identification (RFID) technology of the 1990s. NFC extends the capabilities of RFID and has led to increased market interest over the last 3 years. As its name suggests, the operational range of NFC is from touch to a few centimeters, which has had a strong influence applications. Two of the most used applications, payments and tracking objects, were inherited from RFID technology. Card emulation applications have recently increased its popularity. Basically, NFC can be used to replace plastic cards with the smartphone. Recently, Gartner (2013b) has suggested that worldwide mobile payments will reach 235 billion dollars in 2013, although NFC technology is unlikely to have a strong impact on this forecast due to disappointing uptake. However, a recent partnership made between Visa and Samsung at the Mobile World Congress (MWC13) may change this situation (Visa, 2013); if so, NFC will play an important role in mobile payments. The majority of the most popular smartphone OSs provide the developers with the elementary tools to include NFC technology in their applications, with the exception of Apple's iOS.

Bluetooth *Bluetooth* is a wireless technology standard invented by Ericsson in the 1990s for exchanging low bandwidth data over short distances. Depending on which version and operational mode is used, the transmission rate can theoretically range from 1 Mbit to 24 Mbits. The connection distance is limited to 10 m. The main application is to provide mobile devices with connectivity accessories, i.e. hands-free calls. The connection between peers has to pass a security protocol before any information can be exchanged. This protocol is the main security issue concerning Bluetooth, although recommendations on this issue have been published (Padgette et al., 2012). Briefly, Bluetooth has a higher transmission rate and connection distance than NFC, although power consumption is also higher. As in the case of the GPS, Bluetooth has not been included in the estimation as it is a characteristic common to all handsets.

Multimedia Interfaces and Sharing *High-Definition Multimedia Interface* (*HDMI*) is a digital multimedia standard interface for transferring high-definition signals between two devices. It is considered the leading industry technology and de facto standard. The first version of the HDMI specification was released in 2002, followed by four versions up to 2006. Among other technical details, five different size connectors were introduced in each specification, types A to E. Type A is a full-size connector found on high-definition television sets (HDTVs). Type D, the micro, is the connector usually mounted on the smartphones. Over 1200 of the current largest manufacturers of electronic devices, personal computers, and mobile devices have adopted HDMI and over 1 billion HDMI-enabled devices were shipped in 2012. In 2012, the number of mobile phones with HDMI ports was approximately 1 million units (Bloomberg, 2011).

The *Mobile High-Definition Link* (*MHL*) Consortium was established in 2010 by Nokia, Samsung, Silicon Image, Sony, and Toshiba. The main goal of MHL is to establish an industry standard for a mobile audio and video interface that will allow consumers to connect their devices to HDTVs. MHL supports connections using a micro USB connector in the device peer and HDMI type A in the other. One advantage offer by this solution is that the devices are charging at the same time as they are being used and are using the same connection used to visualize multimedia on HDTVs. The same technology can be used to control the phone via the TV remote control.

The *Digital Living Network Alliance* (*DLNA*) was established in 2003 by Sony. The main aim of DLNA is to establish guidelines on interoperability between devices such that digital media can be shared between them. In contrast to HDMI and MHL, DLNA does not introduce any new hardware components. It is based on existing public standards, mainly Universal Plug and Play (UPnP) technology and wired or wireless networks. Approximately 1 billion units of DLNA-certified devices will ship annually by 2014 (In-Stat, 2010).

4 Results and Discussion

Given that mobile phones have a large number of performance and technical characteristics, we have estimated different specifications for a set of them. Table 3 summarizes the results from the estimated hedonic regressions. Six different models were estimated by including alternative sets of dummy variables. The main characteristics are included in all specifications such that the stability of the parameters can be studied across specifications. The estimated regressions explain about 66% of the price variability across phones and the estimated parameter values are fairly similar across the different models. The set of explanatory variables are as follows: month of release, weight, dimensions, camera resolution, second camera, colors, PPI, number of CPUs, GPU, memory, battery, NFC, HML-HDMI-DLNA, HSPA, LTE, WLAN, operating system, and brand dummy variables. Dewenter et al. (2007) use the following characteristics: volume, age, radiation, ring, and the battery life to weight ratio. They also consider a set of dummy variables for WAP, MMS, MP3, and bluetooth characteristics as well as firm dummies. Another related study is that of Chwelos et al. (2008) for PDAs. This study considered a larger set of explanatory variables, including MHz, Ram, Rom, Flash Rom, pixels (display resolution), display size (diagonal inches), colors, weight (ounces), volume (cubic inches), battery life (hours), architecture, operating system, expansion slots, camera, Wifi, type of battery, and ports. As smartphones blur the distinction between mobile phones and PDAs, the set of explanatory characteristics used includes variables from both studies.

The estimated coefficient for the variable month could in principle be either positive or negative. This parameter shows how the price of a phone with a given set of technical characteristics changes by month. That is, this value reflects the quality-adjusted price change. A positive estimated parameter would indicate that the cost of a smartphone with a given set of characteristics increases over time. The difference between this coefficient and the general inflation rate reflects the technological change associated with this device. On the other hand, this parameter could be negative due to very intensive technological progress. The estimated parameter is negative across specifications, as expected of a product undergoing intensive technological change, although the estimated value is not significantly different from zero. This means that no significant change has occurred in quality-adjusted prices during the 12-month sampling

Variable	I	II	III	IV	V	VI
Intercept	-2.519 (-1.235)	-2.924 (-1.414)	-2.223 (-1.103)	-2.478 (-1.217)	-3.797 (-1.827) **	-2.864 (-1.397)
Month	-0.053 (-1.572)	-0.034 (-0.997)	-0.056 (-1.692) **	-0.058 (-1.774) **	-0.040 (-1.204)	-0.046 (-1.364)
Weight	0.276 (2.193) **	0.279 (2.228) **	0.251 (2.009) **	0.292 (2.366) **	0.266 (2.109) **	0.264 (2.137) **
Dimension	-0.025 (-0.138)	0.045 (0.243)	-0.024 (-0.136)	-0.075 (-0.418)	0.103 (0.543)	0.016 (0.090)
Camera	0.023 (0.966)	0.023 (0.981)	0.028 (1.219)	0.011 (0.474)	0.024 (1.051)	0.016 (0.707)
Second camera	-0.140 (-1.867) *	-0.159 (-2.107) **	-0.166 (-2.213) **	-0.125 (-1.692) **	-0.116 (-1.513)	-0.165 (-2.215) **
Colours	0.039 (2.330) **	0.037 (2.191) **	0.043 (2.539) **	0.039 (2.367) **	0.029 (1.695) **	0.040 (2.382) **
PPI	0.762 (5.140) ***	0.715 (4.737) ***	0.751 (5.115) ***	0.727 (4.923) ***	0.815 (5.369) ***	0.695 (4.625) ***
CPU	0.262 (3.223) ***	0.215 (2.573) ***	0.205(2.461) **	0.198 (2.438) **	0.236 (2.886) ***	0.139 (1.635)
GPU	0.018 (0.326)	0.016 (0.295)	0.050 (0.867)	0.05 (0.900)	0.041 (0.723)	0.063 (1.107)
Memory	0.143 (4.798) ***	0.138 (4.644) ***	0.161 (5.036) ***	0.232 (6.181) ***	0.136 (4.644) ***	0.223 (5.848) ***
Battery	0.255 (1.512)	0.230 (1.364)	0.229 (1.370)	0.355 (2.120) **	0.187 (1.085)	0.296 (1.762) *
NFC	-	0.014 (0.235)	-	-	-	-0.031 (-0.485)
MHL-HDMI-DLNA	-	0.141 (2.155) **	-	-	-	0.121 (1.822) *
HSPA	-	-	-0.101 (-1.429)	-	-	-0.045 (-0.628)
LTE	-	-	0.161 (2.429) **	-	-	0.135 (1.957) **
WLAN	-	-	-0.078 (-0.686)	-	-	-0.027 (-0.237)
Android	-	-	-	-0.552 (-3.856) ***	-	-0.452 (-3.202) ***
Blackberry	-	-	-	-0.440 (-1.359)	-	-0.363 (-1.117)
Windows	-	-	-	-0.532 (-3.352) ***	-	-0.445 (-2.661) ***
iOS	-	-	-	0.339 (0.763)	-	0.422 (0.354)
Apple	-	-	-	-	0.953 (2.228) **	-
LG	-	-	-	-	0.144 (1.754) *	-
HTC	-	-	-	-	0.192 (2.059) **	-
Motorola	-	-	-	-	0.161 (1.586)	-
Samsung	-	-	-	-	0.166 (2.400) **	-
Sony	-	-	-	-	-0.052 (-0.518)	-
$\mathbf{R^2}$	0.654	0.661	0.667	0.676	0.673	0.687

t-statistics in parenthesis. ***, ** and * denotes 1%, 5% and 10% of significance, respectively.

Table 4: Hedonic regression results

period. This is expected given that 1 year is a very short period, even in the mobile phone industry. Evidence that mobile phone handsets become cheaper over time was obtained by Dewenter et al. (2007) for a data set covering the period May 1998 to November 2003, a result indicating dramatic technological progress in this product.

The estimated significant positive value for weight suggests a positive relationship between the price of a handset and its weight. The estimated value is around 0.26, which means that a 1% increases in weight results in a rise of around 0.26% in the price of the phone. This does not mean that consumers prefer heavier phones. There may be several explanations for this. First, increases in smartphone weight are mainly due to increases in battery weight which, in turn, is due to the batteries having longer life or extended capabilities. Second, increases in weight may also be related to screen size. Finally, the weight of a phone also depends on the casing and the screen materials. Metals weigh more than plastic, and steel and tempered glass are signs of high quality. The estimated coefficient for dimension is positive but not significant, probably reflecting a trade-off between screen size and total size. People want a smartphone with a large screen but that is still small enough to carry in a pocket. Figure 1 plots the average weight of mobile phone handsets for the period 1995-2013. Terminals became lighter in the period 1995-2002 and the average weight remained almost constant during the period 2002-2008. Nevertheless, from 2008 onwards, handsets began to be heavier.

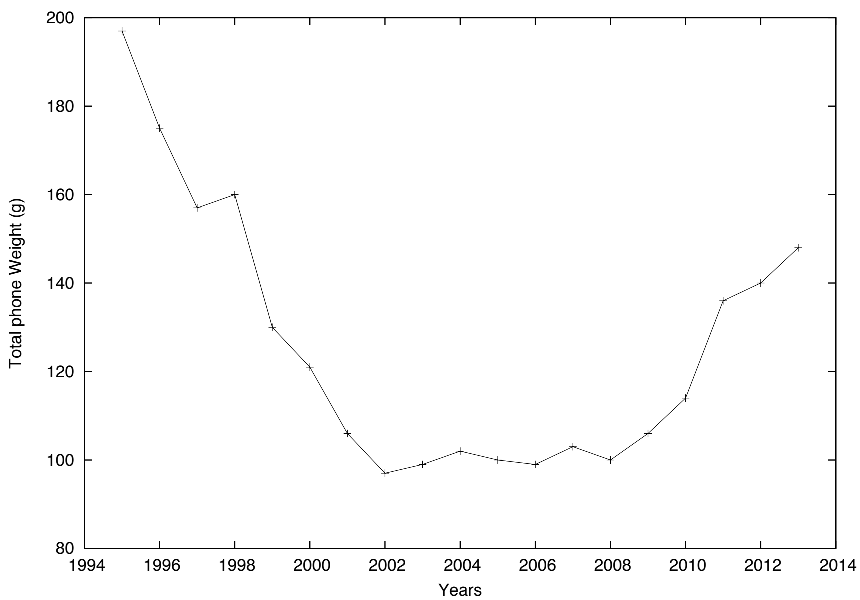

Figure 1: Weight Average 1995-2013

Although the finding of a positive relationship between price and weight cannot be interpreted as consumers preferring heavier phones, weight is positively related to other variables that are positively valued by consumers. Before the beginning of the current golden age of smartphones, which began in 2007 with the release of the first iPhone, over 10% of phone weight was accounted for by the battery, as shown by Rahmati and Zhong (2009). This percentage was considered suitable to guarantee that the user would have a good experience. This percentage is no longer considered sufficient to cover the energy requirements of the components. Current phones need considerable battery capacity. For instance, the Galaxy S3 has a 2100 mAh battery and weighs 38 grams, which is around 30% of the overall weight of

133 grams. Battery weight as a percentage has tripled in just 6 years. Furthermore, at the beginning of this period battery capacity was compared using talk and stand-by time values. However, at present, these values are easy to manipulate since they are usually not tested in realistic settings. The same device under different configurations can yield dissimilar values for this parameter. The phone itself is no longer the most energy-consuming component and therefore the variable that can be used to make a fair comparison is battery capacity in mAh. Customers have grown used to poor battery performance in current smartphones and usually recharge their mobile devices when the remaining capacity is no more than half empty, as reported in Banerjee et al. (2007). This study also reports that battery recharging is driven by location and time of day, i.e., at home every night or at the office during business hours.

The trend in increasing battery weight has been compensated by the introduction of new materials in the building process in order to make the devices lighter. The use of thermoplastic resin (see Lee and Oh, 2010) has recently increased. Nevertheless, the use of light materials is associated with cheap or even low-quality devices. On the other hand, although the use of "heavy" materials adds weight to the final product, the user associates this with high-end designs and style. It also suggests that they are more resistant than lighter materials. Different categories of phones are produced according to the materials used. Apple has recently adopted a new market strategy, based on the users' needs and demands, by offering two iPhone models. The iPhone 5c represents the premium category, using aluminium for its casing, whereas the iPhone 5s uses thermoplastic resin, representing the other category. Apple estimates a price difference of $100 between the two categories. Samsung has been using this market strategy for around 10 years; although Apple offers one product in each category, Samsung has several devices in more than two categories, each device having a wide variety of components.

The result obtained for camera resolution is more surprising. In this case, the estimated coefficient is positive but not significant. In principle, one would expect that camera resolution is of value to consumers. Nevertheless, we found that camera resolution is not a relevant variable in explaining price differentials across handsets. In relation to cameras, another important and consistent result across specifications is that a second camera is not valued by consumers. Furthermore, the estimated coefficient for this dummy variable is negative. In theory, a second camera is intended to be used for video-conferencing, which should be valued by consumers. However, the findings show that this characteristic is in fact negatively related to the price of the phone. The estimated value is around -0.14, which means that a phone with a second camera is on average 14% cheaper than a similar phone without this characteristic.

Two characteristics related to screen quality – the number of colors and the PPI – have a significant positive coefficient. The estimated values are 0.04 and 0.75, respectively, the coefficient estimated for the PPI being the highest for the entire set of characteristics. Strikingly, in the case of the PPI, a 1% increase in its value results in a rise of about 0.75% in the final price of the phone, confirming the fact that screen characteristics have become of fundamental importance to consumer preferences. The performance capabilities of current smartphones requires large high-resolution screens. In fact, almost all mobile phones introduced in 2012 incorporated touchscreen displays, whose functionality heavily depends on the screen's characteristics, and a new term, phablet, has been recently coined to represent this new trend in smartphones. Phablet refers to smartphones with a screen that is more than 5 inches but less than 7 inches, which is close to the size of the tablets screen. This category embraces a new group of smartphones whose popularity has been growing during 2012, see telegraph (2013), despite the fact that they increase the weight and size of the device. According to Engadget (2013) magazine, the primary purposes of smartphones have clearly changed. The factors driving this tendency are the relevance of multimedia contents, browsing, and advanced applications. Figure 2 plots the average screen size of mobile phones for the period 2003-2013. Although screen size remained almost constant during the period 2003-2008, the average size of screens began to increase from 2008 onwards.

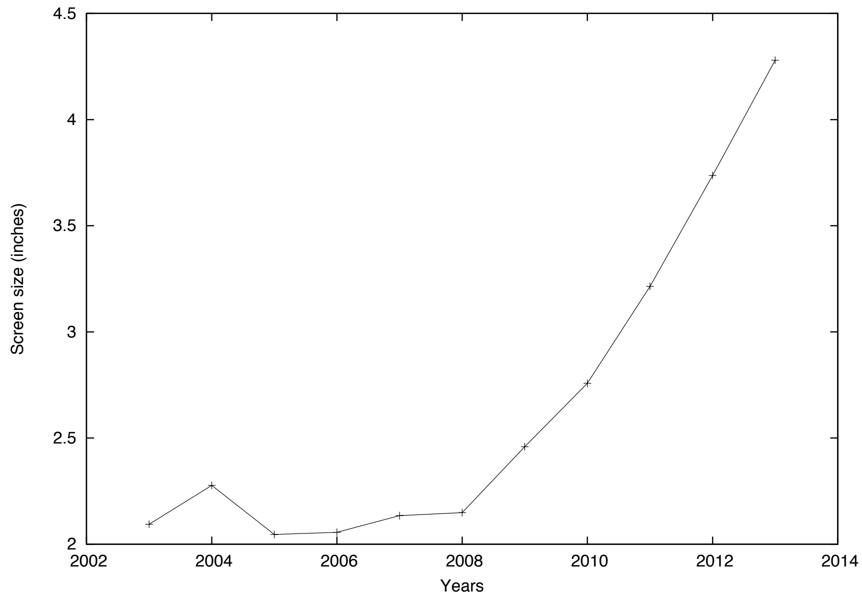

Figure 2: Screen Size Average 2003-2013

The number of CPUs is also another characteristic positively valued by consumers. Nevertheless, the coefficient estimated for the GPU was not significant. The GPU is a powerful tool but largely unknown to typical users. In fact, this technical device is mainly used in mobile phone games and although it is included in some smartphones this characteristic is not valued by consumers. The coefficient estimated for memory was around 0.20, whereas the coefficient estimated for battery capacity was only significant in some specifications.

Regression II introduces two dummy variables, NFC and MHL-HDMI-DLNA, for connectivity characteristics. GPS and Bluetooth are two other connectivity characteristics, but are not included in the estimated equation as almost all phones include these. As expected, the coefficient estimated for NFC was not significant and thus is not valued by consumers, whereas MHL-HDMI-DLNA are positive characteristics valued by consumers. Regression III introduces another alternative group of dummy variables, HPSA (3G+), LTE (4G) and WLAN, for the communication network and data transmission. The coefficient estimated for HPSA was negative, suggesting that this technology has been overtaken by LTE, which has a significant positive coefficient. The coefficient estimated for WLAN was not significant, probably because the great majority of the handsets in the dataset include this characteristic.

These results have several implications for consumers, the industry, and policymakers. The main finding is that smartphones have a set a of characteristics that are not valued by consumers: camera resolution, second camera, GPU, NFC, HSPA, and WLAN. There may be several reasons for this. For example, although smartphones have NFC, it is not widely implemented and thus this characteristic is not valued by consumers. This is an example of the lack of connection between the mobile phone manufacturing industry and other sectors of the economy related to telecommunications. Telecommunications policies should be coordinated with the new technical advances embodied in new phones for these advances to be productive. Given the striking technological changes taking place in the mobile phone industry, future telecommunications policies must pay greater attention to these changes.

Regression IV includes four dummy variables for the OS, focusing on Android, Blackberry, Windows Mobile, and iOS. The coefficients estimated for Android, Blackberry, and Windows were negative and positive but non-significant for iOS. However, in some cases, particularly for Apple and RIM mobile phones, the OS is also brand-specific and hence a potential OS premium cannot be disentangled from a brand premium. In fact, regression V includes dummy variables for firm. We only included firms with the largest number of phone models (Samsung, LG, HTC, Motorola, and Sony) plus Apple. The estimated coefficients were all positive except for Sony. The largest coefficient was for Apple with a estimated value of 0.95. This means that, on average, an Apple phone is around 95% more expensive than a similar phone from another firm. LG, HTC, and Samsung also have a premium, although this is smaller (about 14-19%).

Finally, regression VI introduces three groups of dummy variables: connectivity, communication network and data transmission, and OS.[2] The results do not change significantly from previous estimations, which can be interpreted as proof of the robustness of the estimated coefficients across specifications.

5 Conclusions

This paper has studied implicit prices and preferences for the set of characteristics in smartphones using the hedonic pricing approach. The price of complex products depend on their technical and performance characteristics. The large number of possible combinations of characteristics leads to a very heterogeneous product with different prices, such as mobile phones. In this case, hedonic pricing methods are very useful to estimate the implicit prices of the characteristics of a particular good or equipment.

A revealed preferences approach shows that the characteristics most valued by consumers are screen resolution and size. In fact, the performance of new smartphones is highly dependent on the characteristics of the display. Memory, battery capacity, and weight are also characteristics valued by consumers. The positive relationship between the price of the handset and its weight may be explained by the importance of battery life in new phones, which are intensive energy consumers, and the use of metal and tempered glass in premium category handsets in contrast to plastic non-premium handsets. We also found that some brands have a premium. In particular, consumers are willing to pay up to a 95% premium for an Apple smartphone. Nevertheless, the importance of differences in the OS remains unclear because some OSs coincide with the brand name.

The mobile phone industry is a fast-changing industry. The estimation of the implicit prices of characteristics is important from several points of view. For the industry, it is important to identify consumers' preferences in order to produce handsets with the set of characteristics already valued by consumers and to adjust prices by eliminating or modifying those characteristics of little or no value to consumers. From the point of view of the policymakers, it is important to integrate the new performance capabilities and technical advances in mobile phones into telecommunications policies. In fact, we found that consumers do not value several of the technologies included in smartphones as they are of little use. Perhaps the most representative case is NFC. Despite the fact that it can be used as a mobile-contactless payment system, the results show that this characteristic is not valued by consumers due to its limited

[2] The dummy variables for the OS and for the firm cannot be simultaneously included in the estimation because for some handsets both variables are the same.

implementation. This shortcoming could be solved through better design and the implementation of appropriate telecommunications policies.

An important question that remains pending for future research is the measurement of technological change of this particular product. A measurement of technological change can be also derived using the hedonic pricing approach and the construction of quality-adjusted prices for mobile phones. Evidence that mobile phone handsets become cheaper over time was obtained by Dewenter et al. (2007) for a data set covering the period May 1998 to November 2003, a result indicating dramatic technological progress in this product. Hausman (1999) estimated that price changes in telecommunications services in the U.S. were negative for the period 1988-1997 when quality improvements are taken into account, whereas uncorrected price changes included in the Telecommunication Consumer Price Index were positive, which is additional evidence of technological progress. A quantitative measurement of technical change in this particular industry could be of great interest.

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Appendix A: Number of models by year and firm

Firm	Phones	Headquarters	Founded Year
Acer	5	Taiwan	1976
Alcatel	16	France	1898
Apple	1	USA	1976
Asus	1	Taiwan	1984
BlackBerry	2	Canada	1984
Blu	4	USA	2009
Celkon	4	India	2009
Gigabyte	2	Taiwan	1986
HTC	29	Taiwan	1997
Huawei	23	China	1988
Icemobile	1	Netherlands	2002
Lenovo	8	China	1984
LG	36	South Korea	1947
Meizu	2	China	2003
Micromax	10	India	1991
Motorola	25	USA	1928
NIU	2	-	-
Nokia	18	Finland	1871
Oppo	1	China	2004
Orange	1	France	1994
Panasonic	2	Japan	1918
Pantech	5	South Korea	1991
Philips	1	Netherlands	1891
Plum	3	-	-
Samsung	53	South Korea	1938
Sharp	1	Japan	1912
Sony	23	Japan	1946
Spice	3	Indian	2007
T-Mobile	4	Germany	1990
Verykool	1	USA	1984
Vodafone	1	United Kingdom	1991
Xiaomi	2	China	2010
Yezz	3	USA	-
ZTE	19	China	1985
Total Smartphones processed	**312**		

Table 5: SmartPhone in database by Manufacturer